MUSIC & PRACTICE

PEER-REVIEWED JOURNAL – PERFORMANCE AND PRACTICE STUDIES | ARTISTIC RESEARCH

ISSN: 1893-9562

DOI: 10.32063/0610

THE POTENTIAL OF VIDEOCONFERENCING AND LOW-LATENCY (LOLA) TECHNOLOGY FOR INSTRUMENTAL MUSIC TEACHING

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Abstract: The potential of videoconferencing and low-latency (LoLa) technology for instrumental music teaching

The research presented in this paper seeks to understand the responses of a variety of music teachers and students to using videoconferencing and low-latency (LoLa) audiovisual streaming technology in instrumental music lessons, and to determine the potential and limitations of its use in educational settings.

LoLa technology facilitates remote parties performing together, but there is limited research available on how effective the technology is when used for instrumental music teaching. Pilot studies and interviews with practitioners examine issues surrounding distance learning in instrumental music lessons, and sets the context from which the LoLa trials emerge.

The potential of videoconferencing and low-latency (LoLa) technology for instrumental music teaching

Introduction

This article is drawn from my current doctoral research at the Royal Conservatoire of Scotland into the use of videoconferencing and low-latency (LoLa) audiovisual streaming technology to facilitate instrumental music teaching by distance learning. LoLa is a software package that runs over a specialised network on an expressly specified Windows PC, with dedicated graphics and sound cards.

The literature on distance learning has shown that it offers many benefits to learners, including increased access to tutors and reduced travel time and costs (Davies, 2015). However, a concern voiced by stakeholders, including teachers and students, is that essential aspects of instrumental music pedagogy, including being able to play together, may be missing when teaching via videoconferencing (Riley et al., 2014). As well as removing the physical proximity offered within the traditional teaching studio, videoconferencing introduces into attempts to play synchronously the distracting phenomenon of latency.

Latency refers to the natural delay in sound emanating from a source and reaching an auditor. It is observable in normal acoustic situations where larger spaces are involved, such as when a choir, located behind an orchestra, has to sing very promptly so that its sound does not appear to the audience to lag behind that of the instruments. However, it can become more serious when online transmission across any great distance is attempted.

There is some debate in the literature as to how much latency musicians can adapt to before their ability to synchronise with each other is compromised. Clearly, there is a band of frequencies between the point at which latency first becomes noticeable and that at which it makes synchronised playing essentially impossible. Gurevich et al. (2004) report orchestral musicians being comfortable playing with a latency of up to 35 milliseconds (ms), and Bartlette et al. (2006) report duos being 'strongly affected' by latency beyond 100 ms. The actual threshold where its effects cease to be manageable will likely depend on the genre of music, the acoustic qualities of the performance space and the experience and adaptability of the musicians. The LoLa system was designed and developed to address the problem of latency by offering a high quality audiovisual streaming system with low latency that allows synchronous real-time interaction over large distances (Drioli et al., 2013).

The study described in this article seeks to understand and assess the responses of a variety of music teachers and students to using videoconferencing and LoLa technology in instrumental music lessons. Its aim is to reach an objective view of the opportunities, benefits, and limitations in using these technologies to facilitate instrumental music lessons between institutions.

Questions guiding the research are:

- What changes take place in the quality of experience in lessons between the face-to-face situation, standard videoconferencing systems and a low-latency system such as LoLa?
- Are there elements of instrumental music teaching that can only take place in face-to-face lessons and, if so, which are they?

Current practices and context

Research into conventional face-to-face instrumental music teaching is itself a 'relatively new field of enquiry' (Burwell, 2012, p. 77) but, as Gaunt (2010, p. 178) notes, 'in recent years, there has been a significant growth in research relating to instrumental, [and] vocal … tuition in Higher Education', and a body of scholarly literature now exists in this area. Research into online music teaching is an even more recent development, and according to Koutsoupidou (2014, p. 244), 'relevant studies only appeared after 2000'. Seddon and Biasutti (2009) report that there is little credible scientific evaluation of quality standards in the online music environment.

As to literature concerned specifically with instrumental music teaching via videoconferencing, there is a comparatively limited amount of this and most that is available comprises reports on small-scale interventions and case studies; hence, it is difficult to make generalisations from these studies. However, those studies which do exist suggest that not being able to perform synchronously owing to issues of latency and software was a significant issue for teachers (Dammers, 2009; Koutsoupidou, 2014; Kruse et al., 2013; Prior et al., 2015; Shoemaker and van Stam, 2010). Recent research shows that low-latency systems such as Ultragrid and LoLa do offer the opportunity for musicians to rehearse and perform together (Drioli et al., 2013; Ubik et al., 2016) but, as yet, there is little published research on how effective these tools are when used in educational settings and the available literature suggests a need for more in-depth testing (Riley et al., 2014; Davies, 2015; Iorwerth and Knox, 2019).

The present research attempts to partly address this gap; it also has significance for the way in which instrumental music lessons are delivered in schools, colleges, and higher education institutions. Videoconferencing reduces travel time and costs (not to mention consequent environmental damage) for visiting music teachers; however, as Clements (2018) argues, it is important to critically explore and reflect on whether digital tools that make life 'easier' also make life 'better' for us, both as individuals and as societies. The pilot studies presented in the next section have been designed to investigate instrumental teachers' experiences and attitudes to using technology, specifically videoconferencing.

Initial studies

Survey of instrumental music teacher attitudes

Primary research was undertaken in order a) to collect and interpret original data; b) to elicit information from practitioners to give credibility and authenticity to the studies; and c) not to be unduly influenced by other researchers' interpretations and conclusions (Ruszkiewicz et al., 2006). A mixed methodology using qualitative and quantitative methods was chosen, including semi-structured interviews and observational research. Template analysis was used to interpret the data.

The aim of the first study was to find out how instrumental music teachers working in schools use technology in their lessons, and to evaluate their attitudes to new developments. Six instrumental music teachers working in schools were interviewed; all reported using technology in a variety of innovative ways. These included using apps on smart phones, including 'Speedshifter' (for playing backing tracks at a variety of tempi) and IReal Pro accompaniment software. Audio and video recordings were also being made on smart phones for later review by the student, as well as for giving instant feedback on posture during the lesson.

The use of videoconferencing was seen as a contentious issue by teachers who had little or no experience in teaching via this medium, with concerns being expressed about a possible

social, as well as physical, disconnect from students. This sceptical group also commented that they felt the technology was not yet reliable or capable enough to provide adequate support for remote teaching.

As a complement to the responses from those with limited experience, a further study sought the views of five instrumental music teachers and music lecturers who regularly use videoconferencing in their teaching. The aims of this study were to understand:

- The benefits experienced by those using videoconferencing
- The challenges that teachers experienced using videoconferencing, including technical, pedagogical, social, and interpersonal factors

Results

Nine themes emerged from this second group of interviews:

1. *Greater accessibility for students, and the convenience of a reduction in travel time and costs.* A music lecturer at a university offering a music course by blended learning commented: 'Some of the students get instrumental lessons through Skype… they generally rave about it a lot because, living somewhere remote, if they need to travel to the city, it's a long time on the bus, it's really expensive, it all adds up; so the ones who are doing it… are all sticking to it'. Students are also able to use videoconferencing to maintain contact while their face-to-face teacher is touring.
2. *The challenging nature of the teaching experience using videoconferencing*. All the teachers reported that the experience was more intense and more tiring for them, and they had to work harder. Comments include: 'I need to think a little more about what I'm doing to maybe bridge a little bit of the technology'. Another teacher commented: 'I think it's a lot more work for the teacher; I mean I spend way more hours than I get paid for. There is an expectation that they need a bit of extra support because of the distance'. From a guitar teacher: 'Doing it this way has trained me to hear differently from a teaching perspective. I can't always rely quickly on visual, and if it's a long melody and the student's hand happens to slip down and I can't see it, I don't want to ask them to replay the entire melody; I've just gotten used to hearing what I should be seeing'. From a cello teacher: 'If it is a student that I haven't met face-to-face and worked with, if it looked like there was tension in the upper arm, it could be caused by shoulder tension, back tension, thumb tension all sorts of things… and I think it would be very difficult to diagnose that over the Internet'. From a piano teacher: 'It can work, but perhaps we just have to teach differently and be more responsive to what's in front of us'.
3. *Improved productivity in lessons versus loss of social interaction*. Comments include: 'I find that in Skype lessons, we get so much more done than I would in person. Because in person … they're talking and they're setting up and there's wasted time. I find when it's like this, you sacrifice a bit of the social aspect, but I get much more done in an hour on Skype with a student than I would in person'. Another teacher commented: 'I think a Zoom lesson can be more productive. We seem to get down to work much quicker with most people. I have a student who always likes to talk to me for a good 25 minutes if not longer in an hour's [face-to-face] lesson, but I don't think he would do that if it was on Skype. I think you can be very productive because it feels more like a meeting'. However, a cello teacher commented: 'I thought in a lot of ways, it felt similar as a lesson in person, we spoke about a lot of topics we would have talked about in person. I feel that pretty much we had the same contact as in a face-to-face lesson'.

4. *The technical experience of the hardware and software used in videoconferencing*. This ranged from general satisfaction with the audio and video quality on a standard PC or laptop, through to a preference for using external high-quality microphones and headphones to improve audio quality. One participant commented: 'my biggest concern is really the sound quality. I mean it's good, it's reliable, but it's not nuanced, it's not as nuanced as I would like'. Two teachers noted that, having observed teaching using a bigger screen, it improved the experience; others felt a bigger screen unnecessary and that 'cheap and simple works best'. There were also mixed views on having multiple camera angles. Some teachers considered this important, while others thought that this may be unnecessarily complicated. One teacher wished for a hologram 3D projection so that they could easily observe the student performing from different angles, as though they were walking around the student in a lesson. Some teachers reported wondering what the quality of their sound was like in the remote studio. All teachers stated that they would welcome improvements in the hardware, software, and networks that would allow faster and more reliable connections. There were mixed opinions on using bigger screens or monitors.
5. *The importance of the video element for communicating gestures and seeing facial reactions in checking students had understood concepts*. In situations where network connections were particularly poor, participants would reconnect using audio only, but wherever possible, video was used. A piano teacher reported: 'I realise how valuable a face can be. So, I'll often get a student ask, "Do you want my camera over my keys, or do you want to see me?". I always go for the face, because I can virtually always hear what they're playing, I'd much rather see their reaction. I've realised how important reactions are for my teaching'.
6. *Teachers' inability to physically adjust students' postures or embouchures, or adjust or repair instruments*. Experienced teachers have developed a range of strategies for guiding students in carrying out simple instrumental adjustments or repairs remotely, which include referring students to online YouTube instructional videos. Some teachers use metaphor and imagery to assist students. Schippers (2006, p.211) describes a teacher in a face-to-face setting instructing students lacking subtlety of tone, to play 'as if there is a small bird sitting on your finger, and you don't want it to fly away'. This type of instruction is particularly well-suited to remote lessons.
7. *The problems of not being able to play together*. One teacher commented: 'It's a big frustration. They miss out a little bit on that, definitely. If you're trying to use this to teach in a rural setting, where you're trying to provide a service where there isn't one already, that sort of thing could be much more problematic'. Interestingly, two teachers highly experienced in using videoconferencing felt that LoLa wouldn't offer them any particular advantage over standard videoconferencing. This could be explained by these teachers having already successfully adapted their teaching methods to not being able to perform synchronously with students.
8. *Implications for changes in the instrumental teaching workforce*. Institutions can now potentially hire teachers from anywhere in the world, and private students can hire top professional teachers through online agencies, such as Musical Orbit, without having to study at a conservatoire. One teacher reported that some students have learned entirely via videoconferencing, and never had a face-to-face lesson. However, some teachers sounded a note of caution about the adoption of videoconferencing over face-to-face teaching: 'I've been talking to a conservatoire about this in terms of increasing their distance learning over the summer, and saying I just think they need to be very

careful that it doesn't become something that is any more than enhancing what's already available, that it doesn't become an alternative. I think that could be really difficult for string teachers, or string players'. Concerns were expressed that students learning via videoconferencing should also be exposed to a full range of rehearsal and performing experiences with other musicians.

9. *Additional advantages to delivering lessons via videoconferencing*. These included being able to easily record portions of lessons to be shared later with the student. A jazz piano teacher discussed using MIDI keyboards in lessons, which allow students to easily see which notes are being played: 'We've got all these other tools: the on-screen share, you can see exactly what's happening with my hands. In central London, I've got two grand pianos in the same room, but students don't come over and look, whereas here it's just so visual, and it's easier to record portions of the lesson'.

Summary

A wide range of opinions was expressed, but it was generally agreed that, despite initial uncertainty, teachers found that videoconferencing can successfully be used to deliver instrumental music lessons, albeit with a change of teaching style. Teachers and students reported quickly adapting to the online environment despite it feeling strange at first, as participants cannot trust the intuition that comes from being in the same room.
Teaching via videoconferencing required more planning and preparation, and was a more intense experience for teachers. It was recognised that there was a loss of social interaction when teaching remotely, and that communication styles changed. Thus, teachers adapted their existing teaching styles to suit the medium. The video element was considered important and allowed the use of non-verbal communication, including gesture.

Most respondents reported that improvements in software, hardware, and the network would be welcomed, although some also expressed a preference for simple technology. For students living in more isolated locations, videoconferencing allowed them easier access to teachers, with a saving in travel time and costs. Furthermore, students are potentially able to study with a teacher anywhere in the world, without being restricted to just those teachers in their area. Some teachers were concerned that videoconferencing should not be used as an alternative to face-to-face teaching, but as an additional means to support face-to-face lessons in a 'blended-learning' model. Other teachers, with more experience in the medium, felt that they had been able to overcome any problems they had encountered with remote teaching.

A disadvantage of standard videoconferencing systems is that, because they are optimised for speech and not for high-quality sound, they don't allow teachers and students to play together due to latency and software issues. Experienced videoconferencing teachers compensated for this by using backing tracks and accompaniment software, and two of the respondents stated that they did not feel that playing together was particularly important. However, the vast majority did feel that being able to play together would be a welcome improvement. This led to my next study, to determine how significant the element of playing together was for teachers and students in face-to-face lessons.

An investigation into the frequency with which teacher and pupils perform together in face-to-face instrumental music lessons

The aims of this study were to find out the frequency with which teacher and pupils played together in co-present face-to-face 'traditional' instrumental music lessons, and the implications this would have for a change of teaching styles brought about by instrumental teaching via videoconferencing and LoLa.

Data were collected from 25 instrumental lessons given by teachers of percussion, guitar, brass, and strings. Observation was chosen as the most appropriate method of data collection for this study; the first stage was to define the specific observable behaviours, the second stage was to devise a reliable method for counting those behaviours during the lesson (Yarbrough, 1992, p.90). Face-to-face individual and group lessons were observed in primary and secondary schools, with a range of pupil ages from 10–16 years old and with each lesson lasting between 25 and 35 minutes. Data were also collected from observing four lessons conducted by a brass teacher using videoconferencing; however, only general observations were noted as, owing to the limitations of the technology, the teacher was unable to perform synchronously with the pupils.

Colwell (2011, p.95) describes a model of 'direct instruction', sometimes called 'explicit teaching' or 'systematic instruction' in which instruction is grouped into six teaching functions: daily review, presenting new material, guided student practice, feedback, independent practice and/or homework, and longer term review. The teaching interventions observed in this study related to the first four of these functions.

Four separate types of interventions were logged as events:

- Teacher demonstration—presenting new material
- Teacher and pupil playing the same part simultaneously on the same type of instrument—guided student practice
- Pupil playing with piano accompaniment from the teacher—review and guided student practice
- Pupil playing with a recorded accompaniment—review and guided student practice

An event was counted as an uninterrupted sequence of playing, from just a few bars, up to a full piece. The results were recorded on a handheld whiteboard and were then tallied up at the end of each lesson and collated on a spreadsheet.

Results

The results from the face-to-face lessons showed a range of teaching strategies used in relation to the following factors:

- Number of pupils in the group
- Experience of the pupils
- The type and availability of instruments used, e.g. percussion lessons, where pupils may have to take turns of using larger instruments such as timpani or marimbas
- The stage the pupils were at in the learning cycle with regard to the pieces or studies, from completely new material, to familiar material being reviewed in preparation for a performing exam
- The type of repertoire used

The total results from the 25 lessons were as follows:

Teacher and pupil playing together: (n = 153)

Teacher demonstration: (n = 151)

Pupil playing to teacher accompaniment: (n = 78)

Pupil playing to recorded accompaniment: (n = 66)

The guitar and string teachers in the face-to-face observations spent time at the start of the lessons tuning instruments. During the four brass lessons delivered via videoconferencing, the teacher demonstrated techniques and extracts from pieces and, despite the teacher not being able to perform synchronously with the pupils, the pupils learning in pairs or groups were able to play together with each other in their own studio during the lesson. When playing with backing tracks relayed from the teacher's studio, it was difficult to determine how in-time or out-of-time the pupils were, as they were responding to the backing track with a slight delay due to the latency and this delay was further compounded when the signal carrying the pupil's response was returned to the teaching studio.

Conclusions

Of the four events logged over the 25 face-to-face lessons, the most frequently observed event (after that of the pupil playing on their own) was that of the teacher and pupil playing the same part together at the same time ($n = 153$). This was used as 'scaffolding' during guided student practice— particularly with younger, less experienced pupils— to assist with timing. The teachers also accompanied the pupils during the lessons ($n = 78$).

Owing to issues of latency, instrumental teaching via standard videoconferencing platforms allows only two of the four observed interventions in face-to-face lessons: teacher demonstration, and playing to backing tracks. While these interventions may allow pupils to progress musically, if used exclusively, they do not expose pupils to the full range of playing possibilities that come from playing together with a teacher.

As the observations were limited in scope, it is not possible to generalise about the importance of playing together in face-to-face lessons; a further study with a larger number of teachers and pupils, in a wider range of instrumental disciplines (including voice) and conducted over a longer duration, would be necessary to draw any firm conclusions. However, the study suggests that playing together with a teacher can form a significant element of face-to-face teaching. Since it is not possible to incorporate playing together in standard videoconferencing lessons, LoLa would therefore seem to provide an attractive solution. These findings led to the next stage of pilot studies, investigating the feasibility of using LoLa, before moving onto a larger set of trials.

Pilot studies of LoLa

Introduction

LoLa was conceived at the Conservatorio di Musica Giuseppe Tartini of Trieste in 2005 in response to the demand from musicians for more effective audiovisual streaming systems. It was developed between 2008 and 2010 with the collaboration of GARR, the consortium that runs the ultra-broadband network dedicated to the Italian research and education community. The first public demonstration of LoLa took place in November 2010 as a piano duo performance, with one performer in the Music Conservatory in Trieste, and the other in the institute for Research and Coordination in Acoustics/Music (IRCAM) in Paris, a distance apart of approximately 1,300 kilometres (Drioli et al., 2013). At such a distance, without the considerable bandwidth offered by a dedicated ultra-broadband network, latency would normally become a problem.

LoLa can also be successfully used in other performance contexts such as dance and theatre, as well as wider applications such as medical training (Ubik et al., 2016). However, it requires a fast high-capacity network such as GARR in Italy or the Joint Academic Network (JANET) network in the UK. This may not be a problem for well-established and sizeable academic institutions that are likely already to be connected to such a network, but it represents

a major infrastructural challenge for more isolated communities and individuals. LoLa's success also depends on a variety of additional factors, such as the network bandwidth limitations of the participating institutions, and the availability within those institutions of support from network engineers, sound engineers and technical staff, all of which can place a burden on resources for an institution (Davies, 2015).

An initial trial in 2014 between the Royal Conservatoire of Scotland (RCS) and Edinburgh Napier University, using the original LoLa system, resulted in network problems at RCS, with most of the institution's available 1GB bandwidth being used when LoLa was set to high definition mode. Since that earlier trial, the LoLa software has developed and is now available with a compression mode. The aim of the following trial was to determine the minimum bandwidth required to successfully allow synchronous real-time musical collaboration via the LoLa system in compression mode.

Test of concept: LoLa in compression mode at Edinburgh Napier University

The trial was conducted between different studios in Napier University's music department; this facilitated ease of access to both computers by Dr Paul Ferguson who was overseeing the technical arrangements. The trial participants consisted of myself in the role of the teacher, and an adult student with whom I had previously worked, teaching marimba using the Skype platform. We performed snare drum duets, as the snare drum timbre has a clear 'ictus' or attack, and we wished to assess how successful our rhythmic timing would be when playing complex interlocking rhythmic patterns via LoLa.

The research questions guiding the trial were:

- How can the various permutations of LoLa be adjusted to achieve an acceptable musical experience during a lesson?
- What is the minimum bandwidth required to achieve an acceptable musical experience?
- For sound quality in a lesson, how good is 'good enough'?

Various permutations were tested of frames per second (FPS), camera image size (640 x 480 being one quarter of a full screen), packet size, and compression. Adding compression degrades the synchronisation between audio and video; a lower FPS rate adds more latency between frames. A buffer was added to simulate distance on the network. Download and upload speeds on a network may not be symmetrical, and this needs to be considered when assessing network capacity.

Results

At 30 FPS, 60% compression and picture size of 640/480, the audio and video quality were acceptable for synchronous interaction, and required only 18 Mbps bandwidth, which was well within acceptable limits for an institution with 1GB network capacity. The overall experience was considered superior to lessons via Skype. Despite using compression mode, the audio quality was high, although this could be partly accounted for by using studio quality microphones as opposed to the built-in microphones and speakers on domestic laptops. The video quality was clear, and there were no network issues.

In a duet setting, the musicians should be listening and responding to each other, but whenever latency is an issue, this can quickly lead to a degradation of tempo as players hear each other with a delay, to which they then adjust in a kind of 'feedback loop', thereby compounding the problem. The trials worked better when one player took the lead and maintained a steady pulse without being too unduly influenced by the other player. With low-latency, the duets were found to be natural and easy to perform, although as latency was

artificially increased, there was a greater need for the 'leader' to maintain a steady tempo without being put off by hearing the delayed response from the duet partner.

The adult student commented: 'The technical side was much better, as in the sound and video were so much better, that's obviously the clearest thing. I was really surprised at how easy it was. What I heard while I was playing was us in time together, but... when you increased the delay… you would have heard me delayed. Obviously the fact that your role was as the teacher, that would mean that I would naturally follow you, but I think I was just really surprised by how easy that was from my perspective. And from a teaching perspective, if you're able to do that and ignore the delayed signal, then actually, it's about as good as you'll get in terms of playing with the student'.

The results demonstrated that LoLa could be used with a much smaller bandwidth requirement than the 2014 trial which pushed the RCS network to capacity, and a further trial between RCS and Napier was given institutional approval.

LoLa trial between the Royal Conservatoire of Scotland and Edinburgh Napier University

The aim of this trial was to check the minimum bandwidth required to successfully allow synchronous real-time musical collaboration via LoLa between musicians in remote locations, and to experiment with different permutations to determine how close the synchronisation between audio and video should be.

The trial was conducted with myself playing vibraphone at the Royal Conservatoire of Scotland (RCS) in Glasgow, and a saxophonist at Edinburgh Napier University (approximately 45 miles away). We played a selection of tunes in a jazz style, requiring improvised real-time interaction between the players.

Results

The same four parameters as in the Edinburgh Napier University trial were tested in various configurations, with FPS ranging from 25, 40 and 50; compression ranging between 40, 60, 65, and 80%; packet size from 1000 to 1200; picture size from the smallest at 640/480 RGB24, to low resolution at 1024/768, up to high resolution at 1280/720 RGB24.

With maximum compression (40% quality) problems with lag between the audio and visual were noted, and the picture quality was also noted as being 'jerky'. Audio artefacts (clicks and pops) were noted at packet sizes above 1000 which became distracting to the musicians.

The musician at Napier commented, 'as a super-fast Skype, it is great, but the pops were more apparent and distracting when there's constant playing'. He also commented that the compression mode made him feel 'not quite in the same room', whereas I felt very comfortable. A possible explanation for this lies in experiential differences: the musician at Napier had recently used LoLa in extended recording sessions between Napier and other institutions without compression mode, which would make using LoLa in compression mode feel compromised. I have used Skype, Facetime and Zoom platforms extensively for teaching and learning, and therefore the improvement in latency and audiovisual quality using LoLa resulted in me feeling very comfortable and natural during the session.

Conclusions

The results from both trials demonstrated that LoLa can be successfully used with acceptable audio and video quality for teaching with bandwidth requirements as low as 16 Mbps, making only a modest demand on a 1GB institutional network. The most desirable permutations are to have no compression, a high frame rate, and a large picture size to give the best user experience;

however, a setting of FPS=50, compression at 60%, packet size of 1000, and picture size of 1280/720 RGB24 allowed for successful synchronous real-time musical interaction, with an estimated bandwidth requirement of 33.53 Mbps.

The musical experience in LoLa was superior to that of standard videoconferencing, with better audio and video quality and better network stability; this facilitated performing together. It was agreed that the more the audio and video elements are in synchronisation, the more likely they are to be used for visual cues, and this added to the sense of 'presence'.

However, it is worth noting that both trials required the support of an IT specialist, a network engineer and Dr Paul Ferguson, who has expert knowledge of the LoLa software. The set-up time of the equipment was also far longer than for a standard videoconferencing lesson.

Discussion

The pilot trials of LoLa demonstrate an improvement over standard videoconferencing platforms, with better quality audio, video, and network stability—elements that teachers from my initial surveys reported wishing to see improved. Teachers also reported that being able to play together is an element missing from standard videoconferencing lessons, and my pilot study also showed this was an important and frequently used element in face-to-face lessons. LoLa facilitated playing duets and improvising together, thus allowing for a much richer musical experience.

However, while LoLa allows synchronous interaction between participants in remote locations, other issues found in videoconferencing lessons still remain: these include physical and social separation and not being able to physically adjust posture and instruments. Further research could investigate ways of improving the 'presence' of remote partners, and could explore means of adequately assisting learners to make repairs and adjustments on instruments, together with postural adjustments.

The literature suggests that some instruments are better suited than others to the distance learning environment. Levinsen et al. (2013) discuss vocalists needing to see both close-up facial details and full body posture, while cellos are perhaps better suited to this medium as the participants are seated facing each other, and posture and hand movements are visible in medium-distance and full-body camera views. Nafisi (2013) suggests that voice teachers in face-to-face lessons use gestures in the context of explaining musical concepts, and that this should be a point of pedagogical consideration for online lessons.

Further trials using LoLa are planned in order to gain a fuller understanding of how the characteristics of different instruments, including voice, are affected when teaching via LoLa. For example, the percussion studio may present particular challenges in terms of capturing different frequencies, intensities of sound, and timbral qualities, from low pitched frequencies of timpani, through to high pitched metallic sounds of the vibraphone and glockenspiel. Microphone placement and adjusting camera positions in-session for moving between different percussion instruments may also be problematic.

Iorwerth and Knox (2019) report a need for further studies into the importance of the video element in lessons. Another area of investigation is the use of eye contact in the LoLa lesson, to determine whether musicians really are looking where they think they are, and whether this changes with different screen sizes or screen positioning. From an interview I conducted with a professional jazz pianist, I found it interesting when the subject commented: 'there are probably all these visual cues that I'm not even really fully aware of that I'm responding to'.

The quality of the musical experience is affected by the individual quality of the audio and the video and by the degree of synchronisation between the two, along with the overall sense of co-presence for the participants. The audio is affected by different factors, including the

quality of audio capture, how it is reproduced at each end, and the acoustic properties of each remote location (Ubik et al., 2016; Davies, 2015). Davies also reports problems of responding to live instruments in a studio when mixed with digitally mediated sounds from a remote location. Therefore, the assistance of a sound engineer is helpful to try and achieve the best possible sound (Davies, 2015).

LoLa does not function adequately in conjunction with a network firewall, and it requires network engineers either to circumvent the host institution's network firewall, or to 'punch' through the firewall. There are also problems for institutions with acquiring LoLa equipment as it cannot be bought 'off the shelf' and requires a specialist build with dedicated sound and graphics cards, along with a specialist camera, a separate lens, and high-speed monitors. This, along with the need for IT staff to maintain and assist in operating the equipment, sound engineers, storage facilities for LoLa, studio space, etc. all place additional burdens on staff, resources and infrastructure for a host institution. Brudvik (2018) discusses possible impediments to adopting technology: expense, accessibility, attitudes, and usability; any one of these can stop the process of acquisition and incorporation of educational technology in institutions. However, as Davies (2015, p.78) states: 'there has to be a critical mass of institutions actively using LoLa to allow a range of collaborations to take place'.

Despite these initial setbacks with adopting the technology, LoLa has enormous potential in higher education institutions as it allows new and innovative collaborations to take place. The LoLa team are developing a multi-node LoLa, with the potential to link up three or more sites, thus offering even greater possibilities for masterclasses, rehearsals and performances between institutions. A recent performance at the 2019 Network Performing Arts Production Workshop in Prague linked two organists at different churches in Prague with a studio in which a cimbalom player and dancer performed in front of an audience while another dancer's performance in Barcelona was projected 'holography-style' (NPAPWS, 2019). The SWING project run by the Association Européenne des Conservatoires, Académies de Musique et Musikhochschulen (AEC) is experimenting with LoLa technology to develop international learning opportunities between institutions, helping teachers and students to become skilled in using the new technology (AEC, 2018-2021).

LoLa lessons between institutions allow teachers to see inside other teachers' studios and to exchange teaching methods, styles, techniques, repertoire, etc. This is significant, as instrumental teachers at conservatoires report variations in the levels of ability and experience between students when travelling to study at other institutions, despite the same instrument and nominal level of degree being involved. LoLa lessons offer students the chance to work remotely with a teacher in a different institution before committing to travelling on an exchange to study there, only to find that they are not compatible (and, of course, they offer teachers a reciprocal means of judging compatibility!). There are also opportunities for sound engineers and technicians to train for working alongside musicians and performers in this new environment.

Finally, LoLa also has the potential for younger students who, due to their geographical location, are prevented from attending weekend activities at a junior conservatoire, to receive lessons by connecting to a 'hub' operating from within a higher education institution.

Conclusion

The use of videoconferencing has been shown to successfully facilitate instrumental music lessons between remote locations, with many advantages for teachers and learners, including not having to travel to specialist lessons, saving time, expense and environmental damage. Other advantages include students having access to a wider range of teachers, and vice versa.

However, important elements such as playing together are missing from lessons delivered via conventional videoconferencing platforms.

LoLa technology facilitates being able to play together and also offers superior audio and video quality to videoconferencing, but it needs specialist technical support and it also requires high-capacity networks, such as JANET in the UK. Institutions need to carefully weigh up the costs versus the benefits before purchasing the equipment, but without a critical mass of institutions using the technology, early adopters have fewer possible collaborative partners.

LoLa lessons are not necessarily intended to replace face-to-face lessons, but to offer a greater range of opportunities for students. LoLa also offers the potential for international collaborations, for the development of new interdisciplinary art forms and for the sharing of teaching practices.

Despite LoLa having been available since 2010, take-up of it has been patchy. However, interest in the technology is steadily growing as initial technical issues are resolved. More institutions are adopting LoLa, and the AEC SWING project is exploring and developing opportunities for its use among member institutions. The growing body of available literature and the current level of interest in LoLa suggest that it has a viable role to play in the future of music education. As a next priority, there is a need for further in-depth trials and studies to adequately assess the qualitative aspects of teaching via LoLa across a range of instruments.

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