Buzzing to Play: Lessons Learned From an In the Wild Study of Real-time Vibrotactile Feedback

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ABSTRACT
Vibrotactile feedback offers much potential for facilitating and accelerating how people learn sensory-motor skills that typically take hundreds of hours to learn, such as learning to play a musical instrument, skiing or swimming. However, there is little evidence of this benefit materializing outside of research lab settings. We describe the findings of an in the wild study that explored how to integrate vibrotactile feedback into a real-world teaching setting. The focus of the study was on exploring how children of different ages, learning to play the violin, can use real-time vibrotactile feedback. Many of the findings were unexpected, showing how students and their teachers appropriated the technology in creative ways. We present some 'lessons learned' that are also applicable to other training settings, emphasizing the need to understand how vibrotactile feedback can switch between being foregrounded and backgrounded depending on the demands of the task, the teacher's role in making it work and when feedback is most relevant and useful. Finally, we discuss how vibrotactile feedback can provide a new language for talking about the skill being learned that may also play an instrumental role in enhancing learning.

Author Keywords
In the Wild Study, Children, Sensory-motor Learning, Vibrotactile Feedback, Violin Teaching, Motion Capture

ACM Classification Keywords
Children, Tactile & Haptic UIs, User Studies

INTRODUCTION
Wearable technologies that are capable of providing real-time feedback on physical movement and posture offer new opportunities for improving people's health and well-being. The ability to measure a person's movements and analyze them from many angles is enabling automated personalized feedback in real-time that potentially can support people to train more effectively. Instead of performing exercises that are, say, videoed and having to wait until after the event to view and reflect upon them using a TV monitor, learners can now receive various kinds of 'body nudges' that can inform in real-time how well a particular part of the body is doing. A small buzz can be provided at what are considered key moments that 'pushes' or 'pulls' a limb, joint or other body part back towards a correct position. It can also be used to lightly 'touch' someone on their arm, leg wrist, etc., rewarding them for a correct limb or bodily movement. It is assumed that the immediacy of both kinds of feedback can be effective at consolidating and correcting body movements, leading to a more noticeable improvement in performance. Moreover, it offers an alternative teaching strategy as the actions of the learners and the feedback they receive are tightly coupled.

While some lab studies have been able to demonstrate how real-time feedback can result in enhanced practice, [21, 22], little is known as to how and whether they are borne out in the real world. The experience of a lesson is very different, often being subject to the vagaries of time, motivation, mood and other external factors. A key question, therefore, is how effective is this promising new technology when used in the wild?

Our research is concerned with how easy it is to integrate haptic technology into realistic teaching practices, and which aspects of teaching and learning they are particularly suited to. In particular, we are interested in how to enhance the practice of violin bowing by using real-time haptic feedback that is delivered to the upper limbs. Typically, learning to play the violin requires many years; a novice player takes around 700 practice hours to master basic bowing skills [13]. Our over-arching goal is to enable students and their teachers to use this new kind of feedback to reduce this practice time and, in so doing, encourage more children to persist with learning.

Our real-time feedback system, MusicJacket, uses a combination of motion capture and vibrotactile feedback in order to provide players with real-time feedback on some of the physical aspects of violin bowing. In this paper, we ask to what extent real users, in a realistic teaching setting, can

CHI 2011, May 7–12, 2011, Vancouver, BC, Canada.

use this system. Are students, often young children, able to attend to vibrotactile feedback while playing music? Do they find it helpful? What challenges do students face when learning the new motor skills required to play the violin? What techniques do teachers use to address the needs of individual students, and how can they use real-time vibrotactile feedback to support their teaching?

We describe an in the wild study using the MusicJacket with two teachers and ten pupils that lasted several months. We discuss the findings in terms of the problems that need to be overcome and the fine-tuning that needs to take place, in order to use such feedback effectively. We discuss the implications of these in the context of the cognitive load that is incurred through attending to vibrotactile feedback. Finally, we present some more general lessons learned for developing vibrotactile systems that can be used to train body movements.

BACKGROUND

Traditional teaching methods for violin playing include giving verbal instructions, physically guiding a pupil's arm through a bowing movement, or getting pupils to observe themselves in a mirror. Each of these methods has limitations. Students find it challenging to translate verbal instructions into complex motor actions; being guided by a teacher requires the students to be passive, rather than making active movements; and it is very difficult for a student to see whether they are bowing at the correct angle. In contrast, real-time vibrotactile feedback can enable players to physically engage in the learning process while still reading music and listening to the notes they are producing.

Haptic Feedback

A few studies have used motion capture technology to analyze violin bowing together with various kinds of augmented feedback to support the teaching of violin playing [15, 19]. For example, Ng *et al.* [15] tracked the precise movements of the bow and provided students with both visual and audio feedback to assist them. The visual feedback was in the form of graphs and an augmented mirror image of the player and their violin, and these gave players detailed information about bow speed, angle and other aspects of their bowing. However, interpreting such visual displays required significant attention by the players who were already busy with reading music notation and concentrating on finger positioning as well as listening to the sound they were producing. Audio feedback was also found to have its drawbacks, as users reported that the alerts that were used interfered with their music making.

Vibrotactile feedback mechanisms have been explored in a number of different contexts, including collision avoidance in virtual reality games [4], navigation systems for pedestrians [16] and rehabilitation exercises for stroke patients [2]. A commonly cited benefit of vibrotactile feedback is that it is useful when other modalities, such as hearing and vision, are under cognitive load [e.g., 7]. Researchers have started to explore whether vibrotactile feedback can be used in music educational contexts, where eyes and ears tend to be very busy. For example, Grosshauser and Hermann [6] gave vibrotactile feedback to violin students on aspects of their playing. The feedback was based on measurements of bowing movements from a variety of sensors attached to the bow and violin. Teaching with this type of feedback can involve the teacher providing 'silent hints' that are physical, rather than verbal. However, there is no systematic evaluation of how such hints are experienced by the pupil or for which type of activity they are most useful.

Haptic guidance, which is closely related to vibrotactile feedback, has also been used in a number of music educational approaches [5, 9, 10]. In the Haptic Drumkit [9] the players 'feel' the beat of a polyphonic rhythm in the form of vibrations on whichever limb is supposed to move and hit the drums. Rather than providing feedback on movements, this approach prompts when a movement should be made, giving the player the opportunity to passively experience the feel of the required rhythms.

Other systems have been designed to provide vibrotactile feedback in response to actual physical movement, with the aim of correcting the current posture or movement. An example is a jacket system developed by Lieberman and Breazeal [14]. To evaluate their system, they instructed participants to mimic the position of an expert's right arm that was shown in a still image or to copy an arm movement that was shown in a short video. A total of eight actuators were placed on each participant's arm, four around the wrist and four around the elbow. The feedback took the form of a 'push' so that if, for example, the wrist was bent too far inward, then the actuator on the inside of the wrist would start to vibrate until the position was corrected, with a magnitude that was proportional to the error detected. Another example of an automated feedback system, is the Tactile Sleeve [4], which helped participants avoid collisions in virtual reality environments. The Tactile Sleeve was embedded with motion capture markers and 24 actuators (8 on the hand and 16 on the arm) that were arranged in bands of four. The part of the arm that was in collision with an obstacle was either marked as red in a display, for visual feedback, or was switched into vibration mode. The vibrotactile system was evaluated using a controlled experiment in a laboratory setting and its efficacy compared with visual feedback by measuring the accuracy and speed at which a set of specified movements could be performed with each of the feedback modalities. Participants were found to be faster when using vibrotactile feedback compared with visual feedback. However, findings from lab experiments do not always carry over to in the wild studies. Furthermore, sometimes quite different findings are demonstrated, questioning the validity of generalizing lab studies to different real world contexts [18].

Figure 1. A six year old participant wearing the MusicJacket

In the Wild Studies

A study by Spelmezan *et al.* [20] tested whether participants were able to identify feedback while they were snowboarding both in the lab and outdoors. They conducted two sessions in the lab, using simulators and Wii boards, and one session on the ski slopes. During each session participants received vibrotactile instructions to which they had to react. Even when the study was conducted outside the laboratory, it still had many characteristics of a controlled experiment. For example, the instructions were randomized and did not relate to moves the snowboarders needed to make on the piste. This randomization prevented such instructions being anticipated by experienced snowboarders, however, it also detracted from the realism of the scenario.

A different in the wild study was for a skiing application where skiers were equipped with cameras and accelerometers in order to record their performance to enhance their skiing experience [11]. The data from the sensors was stored and the skiers were able to playback and analyse their performance on mobile devices after each run. The purpose of this study was to identify the technical challenges involved in using this technology in the real world, and to see how users would appropriate the technology and the services it offered. They found to their surprise that the skiers did not look at their performance data during the day while they were out skiing, but only looked and discussed this with other skiers in the evening, after the day's skiing had finished. They argue that this in the wild approach can be a reliable means of identifying the real usage of a new technology, and in particular, can bring out when users initiate changes of usage that have not been anticipated.

Hoggan and Brewster [8] also stress the importance of in situ studies. They studied mobile devices with multimodal interfaces, and found that certain modalities work better in some environments. They also showed how people develop different habits under different workloads. They argue that different forms of usage cannot be uncovered in short duration laboratory experiments, but instead require a longitudinal approach. There is also evidence [12] that over time the novelty aspect of a new technology wears off and that after longer use people appreciate different aspects of a technology than they do on first encountering it.

RESEARCH AIMS

Findings from in the wild studies show different patterns of usage of new technologies compared with the results arising from lab studies. In so doing, they highlight how a variety of context factors, such as the physical environment, needs to be taken into account when deploying a new technology in situ. In the context of providing haptic feedback for learning a sensory-motor skill, factors that need to be considered are the role of the teacher, the age of the student, their motivation and prior experience. The aim of our study was to determine how such a system could be integrated into an existing music practice set-up. In contrast to most lab-based studies, including our own, the focus was on the effectiveness of vibrotactile feedback for a real use, namely, teaching the violin to children. The objective was to determine how a prototype feedback system would be appropriated by students and their teachers in a realistic setting, namely, where students have music lessons (classroom or home) when learning to play the violin.

THE MUSICJACKET SYSTEM

MusicJacket is a system we have built that uses inertial motion capture sensors to track a violinist's movements and posture during bowing and gives them real-time feedback using vibration motors placed on their arms and torso (Figure 1). It was used to improve the teaching of two basic violin-playing skills: correctly holding the violin and straight bowing. Novices initially find it difficult to hold the violin correctly and tend to let it drop down during playing. Straight bowing involves keeping the bow perpendicular to the strings during bowing and is a complex movement involving the coordination of the wrist, hand, elbow and shoulder.

An IGS-190-M mobile motion capture system was used to track the player's bowing action and violin position (developed by Animazoo [1]). The system operates in real-time, is easy to set up and use, and is portable. This motion capture system consists of inertial sensors containing 3-axis accelerometers, gyroscopes and a magnetometer. The sensors are attached to a Lycra suit and connected to a processing unit. The 3D orientation data from each sensor is computed and transmitted to a wireless receiver attached to a PC. Three dimensional position data are computed from the sensor data using a hierarchical skeleton model.

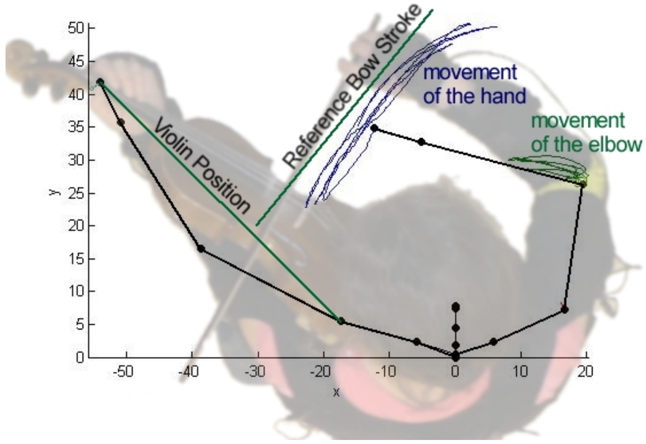

Figure 2: Bow stroke performed by a player, as seen from above, overlaid by reference bow stroke trajectories

The system can be configured to the body size of each user and features can be activated as appropriate. This versatility enables it to be used by participants from a range of ages and abilities. In order to deliver feedback appropriate for each player, we initially define a reference bow stroke or target path (Figure 2). This 'ideal' straight path is individual, depending on a number of factors, such as the build of the player, the way they hold the violin and the particular pedagogy of their teacher. The definition of the individual reference path is obtained by a calibration recording where the teacher guides the bowing movement of the student. By fitting a straight line to the measured bowing path we obtain a target path. Using appropriate tolerance margins, real-time feedback can be given on various aspects of the trajectory.

The feedback component of the system works by delivering a vibration, which feels like a gentle buzz, when the player's bowing moves too far from the target trajectory, whereas feeling no buzz means that they are on the correct path. If the player drops their violin position they also feel a buzz. The vibrotactile feedback is provided by 10mm shaftless DC vibration motors (310-101 Precision Microdrives) [17], similar to those found in mobile phones, which are attached to the motion capture suit. We use five actuators, placed on the arms and torso (Figure 3). On the bowing arm, motor 1 behind the elbow is designed to push the arm forward when it deviates too far from the reference path, and motor 2 on the wrist is designed to push the hand back. The up and downward movement of the violin is governed by motors 3, 4 and 5. Motor 5, behind the left elbow, makes the player aware that this arm needs to move upwards. Motors 3 and 4 are placed on the ribs and stimulate the lifting up of the whole body, including the violin. The precise location for the vibration motors has been gradually refined through user studies and expert advisors [21, 22].

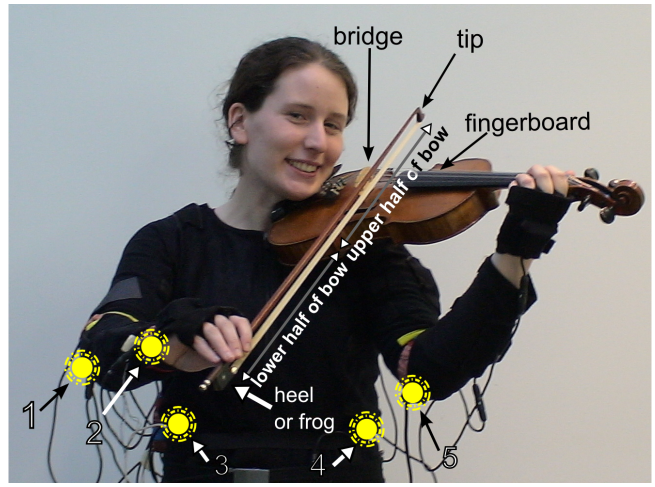

Figure 3: Violin Terminology and placement of motors for vibrotactile feedback

IN THE WILD STUDY

The in the wild study took place over two months with two teachers and ten children. The two teachers selected groups of pupils who they considered appropriate for the study. The teachers also helped to decide where the sessions should take place and how they should be set up so as to make the children to feel comfortable. The lesson materials and instructions were also discussed with the teachers.

The Teachers

Both teachers (teacher A and teacher B) had many years of experience of violin teaching. They were employed by the local Music Service to teach in schools, although they also had a number of private students, both children and adults.

The Pupils

There were two groups of pupils: group A taught by teacher A and group B taught by teacher B. Group A consisted of six girls who had started their violin lessons (with teacher A) only a few months prior to the start of the study. With the exception of one girl, aged nine, they were all just six years old. Their violin lessons took place during school hours in a spacious music room at their school. Teacher A had selected these children as they were absolute beginners and because she felt the children and their parents would be keen to participate. This group of pupils was normally taught as a group for a 20-minute session. A typical lesson when learning how to hold the violin involved singing and dancing, including an elephant song that was intended to help them put their violin on their shoulder and a story about a mouse on their arm to practice how to hold the bow. The aim of these fun exercises was to help pupils get to grips with the basics. The teacher considered an active movement to be very important. By the time our study commenced they had just moved on to learning the early stages of bowing.

Group B consisted of four pupils, also girls, aged between 10 and 13 years. They had all been playing for about three years. These pupils were used to having individual lessons with teacher B – one of them had private lessons outside school hours, but for the others the teaching was organized during school time. The teacher had selected these pupils as each of them had trouble with a particular aspect of bowing and she felt they could all benefit from focused bowing sessions.

The period of the study

We organised five sessions with each teacher over a period of two months, in which they gave individual lessons to each of their pupils using the MusicJacket system. This provided a total of approximately fifty lessons to work with the teachers and pupils. During this period the teachers also continued with their ordinary lessons and pupils practiced at home as usual. Each session took the form of a special bowing lesson, with two researchers present. The activities carried out in these lessons were varied and developed in close collaboration with the teachers. The sessions for group A took place during school time, in the classroom where they normally had their violin lessons (Figure 4), whilst for group B these were carried out in a home setting.

METHODOLOGY

We used a number of data collection methods to assess the suitability and effectiveness of the MusicJacket system for teaching the violin. We began by interviewing the two teachers and observing one of their normal lessons prior to the participants donning the MusicJacket. The MusicJacket sessions that then followed were videoed and field notes were made. During these sessions, observations were made together with informal conversations with the teachers and the pupils about the tasks they were doing and their perception and experience of using the MusicJacket in the context of their lessons. The MusicJacket system also logged each pupil's bowing movements and when they received vibrotactile feedback. Several months after these sessions, we conducted further interviews with the two teachers to reflect on the lessons and to discuss their impact on the children's bowing.

THE MUSICJACKET SESSIONS

There were three main parts to each MusicJacket session: preparation; physically exploring the technology; and playing exercises and pieces, during which different ways of providing feedback were investigated.

(i) Preparation

At the start of each session, the equipment was set up which took about 40 minutes. As each pupil arrived, they were dressed in the MusicJacket. This took about 10 minutes. This was followed by the actual lesson, which ranged from 10 minutes to half an hour. It took only 1 minute to remove the system at the end of a session.

(ii) Physically Exploring the Technology

The pupils were encouraged to physically explore the technology when wearing the MusicJacket to help them understand how it worked. During the first session, we introduced the concept of motion capture and encouraged the pupils to look at themselves using the Animazoo viewer software. This shows a stick figure moving in real-time

Figure 4: The set up during a typical session (the pupil is on right, the teacher in the middle and the researcher on the left)

with the wearer of the suit. Pupils were encouraged to move their arms, rotate their wrists, pretend to bow and make big arm movements. This exercise encouraged pupils to become more aware of their body movements. This was considered particularly useful for very young children who tend to have very little understanding of how their bodies work. In particular young children do not realize that arms can rotate around the elbow or that wrists can bend.

In subsequent weeks, vibrotactile feedback was introduced to the pupils by switching on each actuator in turn. Each pupil experienced how by moving their bowing arm in the right direction they could switch off the vibrotactile feedback and that this indicated that they were now in the correct position. This exercise was repeated for most of the weekly sessions.

(iii) Playing Exercises and Pieces

During the first two sessions, the research team introduced simple bowing exercises where the pupil was required to make long bowing movements on a single string without using fingering. However, these exercises were found to be not appropriate for either group of pupils: they were too difficult for group A and too easy for group B. In consultation with the teachers, we chose to change this approach. For the remaining sessions, the pupils were asked instead to play the exercises and pieces they were studying at that moment. This was thought to be a better strategy because it reinforced their current teaching.

By week 3, we also established that it was not appropriate to teach the technique of straight bowing to the pupils in group A, as their bowing technique was not sufficiently developed. However, the issue of 'holding up the violin' was very relevant for this group. This was the reverse of group B pupils, who had no issues with holding up their violin, but did need to improve their straight bowing.

Finally, a lesson plan was developed in which the early part contained an element of 'deliberately playing badly'. The pupil was encouraged to deliberately play in the wrong way in order to feel the feedback that resulted. This was done using one of their regular exercises – bowing a few strokes in the case of group A, and playing a scale in the case of group B. Later on in the lesson, they played one of their pieces, with the teacher giving verbal feedback on aspects of their playing (e.g., rhythm or intonation) while in the background the MusicJacket was providing real-time vibrotactile feedback on their posture or bowing.

FINDINGS

Both the teachers and the pupils in groups A and B were positive about using the MusicJacket when learning to play the violin. No pupils dropped out from the groups and all were excited at the prospect of having their next lesson using the MusicJacket. Vibrotactile feedback was found to be most successful in improving three aspects of pupils' playing: (i) holding up the violin; (ii) straight bowing, and (iii) using more bow. There was also evidence that as time progressed, both teachers and pupils gained in confidence in using the technology and began to change it for their own objectives. Below we describe in detail the three main improvements followed by the other findings.

(i) Holding up the violin

Holding up the violin was the most successful type of feedback for group A pupils. These pupils were still at a stage where they needed to practice bringing the violin up to their neck and positioning it in the correct place. It was not unusual to see the violin slip back out from underneath a child's chin whilst they were playing, so any teaching approach which encourages holding the violin up was particularly relevant to them at this stage of learning.

Pupils learnt to use the real-time vibrotactile feedback quickly, generally within the space of the first session. This showed both in the way their playing changed and also, for some, by their facial expressions. For one pupil, in particular, it was clear to see when the feedback was on, not only from her good arm movements, but also because she would wrinkle her brow slightly in a thoughtful expression or smile. Some of the other pupils showed when they felt the feedback by smiling or giggling, while others gave very few signals about what they were feeling but would tell us afterwards *"It buzzed about five times."*

Figure 5 shows a graph representing one pupil's playing that is representative for the whole of group A. The data were collected using the motion capture system. In the top part (panel A) of the figure her arm movement is shown without the feedback and in the bottom part (panel B) with the feedback switched on. Panel B shows that the violin is held higher, and in particular, held closer to the target line (at 0) set by the teacher during the calibration for this pupil. The recordings for these two graphs were made shortly after one another. In panel A, the pupil starts at -20cm, that is, the bow is slightly lowered, whereas for the second play through in panel B she starts at a better position, 0 cm.

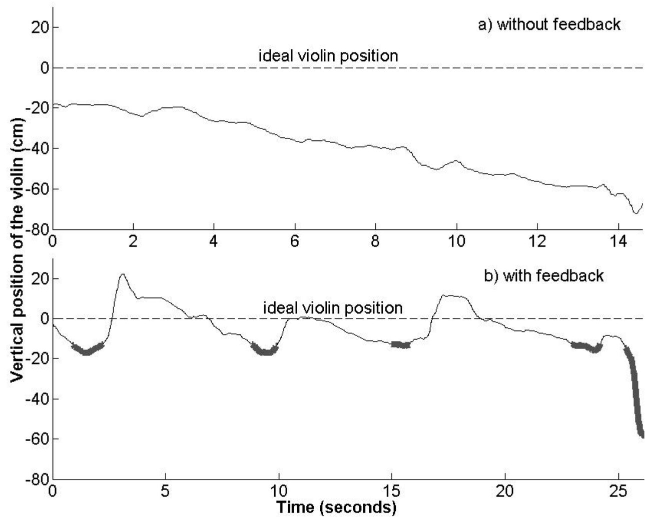

Figure 5: Panel A (no feedback) in top part and panel B (with feedback) in bottom part shows actual violin position relative to ideal position (thicker areas indicate when feedback is on)

This pupil, as well as some of the other pupils, would generally begin a piece holding the violin higher if the feedback was switched on, possibly anticipating what the feedback might tell her. Panel A also shows a general downward trend reflecting how the pupil gradually let the violin drop whilst playing. This was exhibited by many of the other pupils. Often they might deliberately do this at one point to get a better look at the strings and then never return the violin to its proper position. Panel B also shows a section of general downward gradient. However, whenever the feedback comes on there is a sharp upwards slope in the graph, showing that she pushed the violin up in response to the feedback. Overall she maintains a position close to the reference position when playing with feedback. The final trailing off is when she brings her violin down at the end of the piece.

It was also apparent that she took longer to play the piece when the feedback was switched on (25 seconds versus 14 seconds). This is because she played the piece twice in order to make up for an error she had made. We observed that she seemed to make more mistakes when the feedback was switched on, possibly because she was focused on reacting to it.

Analysis of the video and motion capture data showed that all six pupils in group A lowered their violin position at regular intervals in the absence of either vibrotactile feedback or prompting from their teacher. They responded to vibrotactile feedback by adjusting their violin position when playing familiar pieces. However, in situations where they experienced high cognitive load, such as when playing a new piece or when playing along to a CD, they did not respond to the vibrotactile feedback. In these cases they would tell us afterwards that they had not felt it.

Their teacher commented after the study that she thought this type of feedback had been *"useful"*. In one of the lessons she also mentioned how she *"thought the sound really improved when she suddenly held up the violin."* This comment was partly addressed to the researchers but also to her pupil whom she was praising for lifting her violin so well.

(ii) Straight bowing

The feedback on straight bowing was more successful with the group B pupils who were at the stage where they had many demands upon their attentional resources: reading or remembering complicated pieces of music; getting their fingers in the correct place; and bowing. These pupils knew how to bow correctly when this was their main focus but had difficulty doing it while focusing on these other areas. The youngest of the group had particular trouble doing this as she had progressed very quickly to playing more difficult pieces but her bowing had been left behind.

Taking this pupil as an example, the video data shows how the feedback made her glance down at the bow much more whilst she was playing. In her first lesson, without feedback, she only looked down at the bow once during the time she played two pieces. In the following lesson, when she had the vibrotactile feedback, she glanced down at the bow eleven times whilst playing two pieces. The lesson after that, again with the feedback, she looked at the bow fourteen times whilst playing three pieces. These glances are only momentary before she looks back up at the music, but they show that she is much more aware of what her bow is doing. Her teacher was pleased when she noticed this result of the feedback: *"it's quite good to have an eye on your bow and an eye on your music so you're swapping back from your music to your bow, music to your bow… You were doing that a bit more I've noticed today."*

The videos show that the result of this increased awareness was more controlled bowing and she was less likely to bow over the fingerboard, which she did in her initial lesson without feedback. This change was also observed by her teacher: *"you're not drifting as much on to the fingerboard as you have done. That's been a problem in the past."* Similar to many of the pupils in group A, her facial expression changed when she received the feedback. However, the particular change in expression suggests that she had a different kind of experience to the group A pupils. When she played, with or without feedback, she always had a look of concentration on her face. Without the feedback she would often smile with a more self-aware expression when she made a mistake or got to a certain part of a piece, such as the end of a phrase. When playing with feedback, her face moved more frequently but by smaller amounts, alternating between a slight smile and lips pursed together. When the feedback was switched on she seemed to become more tense, and her playing seemed to flow less. This suggests that she found the task more demanding when the feedback was switched on.

A lasting effect of the vibrotactile feedback was to provide the pupils and teachers with new shared terms to express aspects of the lesson that had previously been implicit. Teacher B used the experience of the MusicJacket system as a starting point for working on her pupils' bowing during the months following the study, both of them talking about their movements in terms of vibrotactile feedback. For example:

"We've talked about what we did – how she felt the feedback when she was going too far forward… and how she had to remember to counteract that by bringing her arm back, and she's got to try and do that herself and keep an eye on her bow… rather than just plowing through she's got to make conscious decisions about where she's bowing and how she's bowing."

(iii) Using more bow

One of the pupils in group B had a different problem with bowing, namely, she did not use enough bow. Figure 6a (top part) shows how she regularly used approximately only 10cm of bow (a typical bow is 75cm long). This was a concern for her teacher and she dedicated a large amount of the lesson time to encouraging her pupil to use more bow. The result of this is shown in Figure 6b where she had progressed by the end of the lesson to using 36cm on the longer notes.

When this pupil used the MusicJacket system to improve her straight bowing she did not receive much feedback. This is no surprise as it is easier to bow straight when using very little of the bow. Her teacher pushed her to use more bow by repeatedly reminding her whilst she was playing. However this additional focus upon bow length seemed to prevent her from noticing the feedback on straight bowing. After the session, the pupil reported she did not feel any vibrotactile feedback, even though the system recorded that it had triggered.

In a brainstorming session with the teacher and the pupil during the fourth lesson, we explored the possibility of adapting the MusicJacket system to suit the particular needs of this pupil. The following week we were able to present an adapted version which worked by providing vibrotactile feedback at each end of the bow length, if the student moved far enough along the bow. She was told to *aim* to feel the vibration as opposed to *avoiding* vibration in the usual set-up. Figure 6c is a result from that feedback session, in which she began to regularly use over 50cm of bow. The effect occurred almost as soon as she tried the feedback making it quicker than the lesson shown in Figure 6b. Clearly, this was a breakthrough moment, and both pupil and teacher were very pleased about the new approach. In an interview after the study her teacher noted *"it was very useful and I think that it worked really well"*.

Other findings

As the pupils became more familiar with the MusicJacket system they were more willing to explore its utility to help them learn and by the end of the study some of them had a very good understanding of how it worked. One of the pupils from group B displayed her knowledge when her

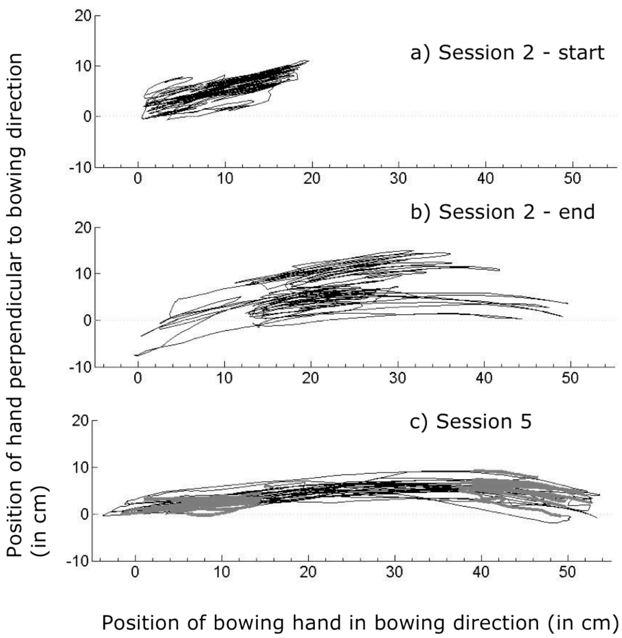

Figure 6: Change in bow length for one pupil over three sessions when provided vibrotactile feedback

ideal bow stroke was not very well calibrated. During her piece she struggled because her bow kept slipping back onto the bridge whilst she was playing and at one point she paused and made a very deliberate correction of her bow position. Afterwards we asked her whether it was the feedback which had made her stop and correct herself, to which she answered clearly: *"it [the feedback] wasn't telling me, it was just the noise of the violin [which told her]"*. She then made some suggestions about how she felt the system should have supported her. This demonstrates how she understood the limitations of the MusicJacket system and the way it inferred the bow stroke from the position of the hand. It took another two attempts to calibrate the system so that the system gave her feedback where she felt she needed it: stricter near the bridge than at the fingerboard.

Each time, she and her teacher were able to quickly evaluate the usefulness of the information it was giving her and decide whether a further calibration was needed. This questioning of the feedback shows a progression from her first feedback session where there was also a problem with the calibration. On that earlier occasion she told us *"it would always buzz when it got to there",* and she did not phrase it confidently as a problem with the system. It was only when her teacher questioned the way she was playing, that we realized that there was a problem with the calibration, rather than her playing.

This example shows how pupil and teacher came to increasingly understand the feedback over the sessions, and consequently were able to articulate clearly what they needed the feedback to do. It also demonstrates how the teacher was important as a voice for questioning the system and backing up what the pupil expressed.

We also found the pupils enjoyed wearing the technology and were quite comfortable with the vibrations of the feedback. For example, one pupil described it as *"a bit bumpy, but I like it".* Another pupil even found the vibrotactile feedback quite ticklish and managed to deliberately play her violin in such a way that the feedback stayed on the whole time. She was intentionally cheeky and playful, but through her action also showed a pretty good understanding of how the system worked. Teacher A also felt the bow hold of her pupils was improved when wearing the jacket simply because the sensor on the glove they wore was stiff, which helped keep their palm more open.

The study also revealed the importance of having teachers help in correcting behavior following the initial onset of vibrotactile feedback. When a vibration is set off, it indicates that a movement has left the desired path (or in the case of the violin hand, the instrument is being held in the wrong position), and there is only a minimal indication of how the student should correct their movement. This can be potentially ambiguous if not guided from the beginning. For example, on feeling a vibration on her elbow, one pupil from group A started to lift her elbow out to the side rather than lifting their whole arm to push the violin up. The teacher noticed and corrected her response by pushing her elbow down underneath the violin and then pushing the whole violin up from underneath. This was less an issue for the group B pupils, who had been playing the violin longer, who interpreted the feedback based upon their knowledge of how they ought to be playing, and with some experience of the vibrotactile feedback learned to flick their eyes briefly to their bow to make necessary corrections in the trajectory when they felt a vibration.

DISCUSSION

Our study has shown how vibrotactile feedback can improve violin playing in a real world context for a number of basic and advanced skills. Specifically, children as young as six can quickly learn how to interpret vibrotactile feedback and use it to improve a number of aspects of their violin playing: holding position; bowing straightness; and length of bow stroke. Older children can use it to help them increase their awareness of how they are playing and when they are making mistakes.

The in the wild study revealed that the effectiveness of the vibrotactile feedback was dependent on two factors. Firstly, it was important to have a teacher initially help the student understand how they should respond to the feedback as otherwise they could move their arm or torso inappropriately, as observed in one the pupils in our study. The feedback cannot tell the student the exact movement to make, only that their current path has strayed from the ideal. As noted by Spelmezan *et al.* [20], vibrations positioned on the body may be interpreted in a variety of ways. The teacher's role is important, therefore, in helping to show their pupils the response to the feedback that would be best for their playing.

Secondly, it is important to consider how other aspects of the playing and setting place demands on a pupil's attention. When there are high attentional demands from these factors, the pupil can pay less attention to the vibrotactile feedback, which means they can ignore or not notice it. For example, our study showed that if pupils are doing a difficult exercise, e.g., trying to play a new piece which requires all of their attention, then they often do not respond to the vibrotactile feedback, sometimes reporting that it had not been on or that they had not noticed it. Similarly, Bhargava *et al.* [3] reported that high cognitive load can reduce the ability to localize vibrotactile stimulation, that is, subjects' responses to vibrotactile feedback is diminished. A high demand on the pupil's attention can result in their responses to vibrotactile stimulation diminishing to the point where the buzzes no longer function as useful feedback to guide movement.

Hence, the effectiveness of vibrotactile feedback is variable, depending on the attentional demands on the player. This finding was uncovered through our in the wild study and was not evident in our previous lab studies. Our in the wild study also uncovered a number of ways the MusicJacket system could be used that we had not anticipated and that were only uncovered by taking the system into a realistic teaching scenario. This included the suitability of the feedback for different ability levels. In particular, we found that feedback on the hold of the violin was only useful for group A, and that group B only benefitted from the feedback for the straight bowing technique. The study also revealed new ways that vibrotactile feedback could be used in violin teaching that we had not considered when designing the MusicJacket system. For example, we discovered that the system could be modified with relative ease to teach long bowing, enabling the teacher to address the needs of a particular pupil. We were simply not aware that the calibration could be used as creatively as was done by the pupil who wanted to feel feedback at a particular point. Another discovery was that in contrast with other in-situ studies of haptic feedback, in which the device or technology under investigation can be handed over to participants with minimal training [e.g., 8, 11], ours required considerable time for the pupils to familiarize themselves with the technology and how to understand the buzzing experience relative to what they were normally used to in the lesson. This suggests the need to include training time with a haptic training system to explore its dimensions and understand what the feedback is meant to map onto.

LESSONS LEARNED

Based on the findings of our study we suggest there are three main areas that need to be considered when taking vibrotactile feedback out of the lab and into real world use. These are: task level; matching to the experience of the user; and how to involve the teachers in training.

Task level

Where learners are following elementary exercises they can attend to the vibrotactile feedback, resulting in them being able to respond to it appropriately and accurately report when it occurs. When learners are doing difficult exercises the vibrotactile feedback can recede into the background and remain unnoticed. The challenge is to find a task of intermediate difficulty where the vibrotactile feedback can play a useful role in guiding the students' playing but not make too many demands on their attention. The teacher can help by selecting appropriate tasks that are tailored to each student's ability.

Relevance of feedback

Vibrotactile feedback is most effective when it gives feedback on an aspect of motor learning that is relevant to a student's goals and level of learning. For example, older pupils found it effective for straight bowing and younger pupils for bow position. Vibrotactile feedback is most likely to be effective when it 'tells' the learners about a mistake they *regularly* make and which their teacher has informed them about.

Dialogue with teachers

Involving the teachers throughout the training process is critical to the effectiveness of using haptic feedback in a teaching context, especially in terms of selecting the appropriate exercises and exploring how the feedback works. This can help the students understand how a system works and also provides new terms that teacher and student can use to gauge their progress.

CONCLUSIONS

Our study has demonstrated the value and importance of in the wild studies when deploying haptic technology out into real world uses. We gained insights into the MusicJacket system that were not evident from our lab-based studies. These included the importance of working closely with teachers who have long experience of teaching and know their individual students very well. We also found that for real-time vibrotactile feedback to be effective at improving training it must be relevant to learning goals and should be used in conjunction with tasks which are the right level of difficulty. If these criteria are not met then the learner may feel overloaded and unable to attend to the feedback. Moreover, it is important to recognize that the addition of feedback can make a task more difficult. Finally, as the study progressed, we observed discussions between teachers and students about movements in terms of the vibrotactile feedback they would elicit. This was most noticeable with the more advanced pupils, where the teacher encouraged them to start evaluating their own performance and diagnosing their own problems. Asking 'whether the feedback came on' became a new line of questioning which was used to initiate a dialogue about movement. Hence, a novel benefit of using vibrotactile feedback for training body movements is that it can provide a common vocabulary for teachers and students to discuss body movements.

ACKNOWLEDGMENTS
We thank the children and teachers who participated in this study, and the reviewers for their thoughtful feedback. This research was supported by the eSense project, funded by the AHRC (AH/F011881/1) and The Open University.

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