Examining the Effects of Embedded Vibrotactile Feedback on the Feel of a Digital Musical Instrument

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ABSTRACT

This paper deals with the effects of integrated vibrotactile feedback on the “feel” of a digital musical instrument (DMI). Building on previous work developing a DMI with integrated vibrotactile feedback actuators, we discuss how to produce instrument-like vibrations, compare these simulated vibrations with those produced by an acoustic instrument and examine how the integration of this feedback effects performer ratings of the instrument. We found that integrated vibrotactile feedback resulted in an increase in performer engagement with the instrument, but resulted in a reduction in the perceived control of the instrument. We discuss these results and their implications for the design of new digital musical instruments.

Keywords

Vibrotactile Feedback, Digital Musical Instruments, Feel, Loudspeakers

1. INTRODUCTION

Most traditional musical instruments inherently convey an element of tactile feedback to the performer in addition to their auditory and visual feedback. Reed instruments produce vibrations which are felt in the performer’s mouth, string instruments vibrations are felt through the fingers on the strings, or through contact between the performer’s body and the resonating body of the instrument [4]. This tactile feedback leads to a tight performer-instrument relationship which is not often found in digital musical instruments.

Studies have shown that while beginners make extensive use of the visual feedback provided by musical instruments, in expert performance it is the tactile and kinaesthetic which is the most important [7]. The majority of digital musical instruments provide only auditory and visual feedback to the performer, which results in a less complete sense of the instrument’s response to the player’s gestures than is available with traditional instruments [4]. It has also been stated that only the physical feedback from an instrument is fast enough to allow a performer to successfully control articulation [11].

In a previous work [9], we presented a digital musical instrument that uses embedded loudspeakers to produce vibrotactile feedback that is directly based on the sound being created by the instrument. In this paper we examine in more detail the ways in which this feedback can be created, compare the vibrations produced with those of an acoustic instrument and examine how the addition of this feedback affects the performer’s perception of the “feel” of the instrument.

2. PRODUCING INSTRUMENT-LIKE VIBRATIONS

One possible use of a vibrotactile feedback system in a digital musical instrument is to produce vibrations that are based on the sound the instrument is producing. In an acoustic instrument the sound production mechanism also produces the vibrations that the performer feels. If we wish to provide vibrations in a DMI that are produced in a similar way to those of an acoustic instrument, these vibrations must then be directly linked to the sound production. Such a link can be achieved by deriving the vibrotactile feedback signal from the sound synthesis output of a DMI.

In order to physically produce these vibrations then, an actuator is needed which meets the following requirements:

1. Capable of producing the full frequency range of human tactile sensation.
2. Offer independent control of frequency, amplitude and waveform.
3. Offer a large range of amplitude control (to allow for instrument dynamics).
4. Be driven by an audio signal, or a signal easily derived from an audio signal.

As discussed in [9], we can see that voice-coil, the tactor and the piezoelectric element each meet these requirements to different extents. Of these, the voicecoil offers the greatest range of frequency and amplitude control. Also of interest is that if we use a voicecoil in the form of a loudspeaker, then the system can also be used as the main sound production method of the instrument. This not only adds sound-related vibrotactile feedback to the instrument but also co-locates the sound production into the instrument itself [5, 1].

2.1 Vibrotactile Feedback from the Sound Synthesis System

By routing the sound output from the sound synthesis system in a DMI to the an amplifier and loudspeakers within the instrument body we can produce instrument-like vibrations within the DMI itself. This was the approach that we

NIME’11, 30 May–1 June 2011, Oslo, Norway.

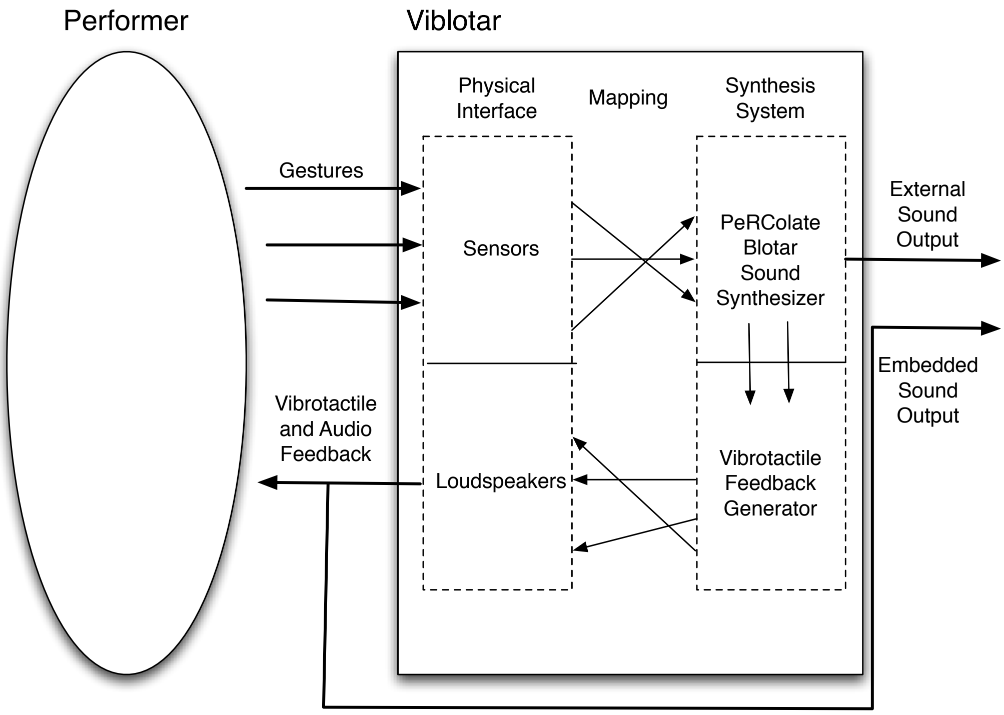

Figure 1: The overall structure of the Viblotar [9], based on the model of a DMI presented in [8].

took in the development of the Viblotar [9]. This section details the components of the Viblotar and the methods by which it generates vibrotactile feedback for the performer.

Figure 1 gives an overview of the components of the Viblotar. The output of the sound synthesis system is used to drive both the *external* sound production and the vibrotactile feedback (and *internal* sound production) components. The internal sound production mechanism consists of the amplifier and loudspeakers embedded in the instrument body. This also acts as the vibrotactile feedback component as the loudspeaker output also creates vibrations in the instrument body. The external sound production would be any amplifiers or external loudspeakers, which could be used to provide amplified sound for performance in a larger space. In many cases the internal and external sound production would be driven using the same signal, so that the external sound is an amplified version of the internal sound. However, the use of separate internal and external sound production mechanisms allows for some interesting effects which will be discussed in more detail in the next section.

In the Viblotar the output from the sound synthesizer is fed to the input of a frequency response modification system. which uses parametric equalizer sections to modify the signal to change the frequency response of the Viblotar output. This modified signal is then sent through a digital to analog converter (DAC), the output of which is a line level audio signal which is fed to the hardware of the Viblotar's vibrotactile feedback component. There it is amplified and output through the embedded loudspeakers.

When the sound synthesis signal is fed directly through the vibrotactile feedback generator, without any modification of the signal, then the vibrotactile feedback provided by the Viblotar is directly related to the sound of the instrument. The sound produced by the embedded loudspeakers is the sound of the instrument itself and this sound causes vibrations in the instrument. However, it is also possible to modify the signal used to drive the vibrotactile feedback component. In this case, the vibrotactile feedback would still be related to the sound produced by the instrument, without being directly caused by it. By using the unmodified signal to drive the external sound production and a modified signal to drive the vibrotactile feedback and internal sound production we can create a number of interesting feedback effects.

2.2 Modifying the Vibration Response

The availability of both internal and external sound production mechanisms in the Viblotar allows 3 main modes of operation:

Internal sound production only: in this mode of operation, all of the instrument's sound is generated within the instrument itself, by the built in loudspeakers. This is closest to how an acoustic instrument such as the acoustic guitar works.

Internal and external sound production: this mode offers two sound sources. The first is the instrument itself, through the embedded loudspeakers. The second source is an external (and possibly amplified) loudspeaker. This mode of operation is based on instruments such as the electric guitar or electric violin.

Modified internal sound production: when using both internal and external sound production it is possible to modify the signal used for internal sound production, creating a difference between the sound created internally by the instrument itself and that produced by the external system.

When using different signals for each sound generating mechanism, we can perform a number of interesting effects, including:

- Compensation for the frequency response of the loudspeakers and/or human skin (as in [3]).

- Simulation of the frequency response of a different instrument.
- Production of only those frequencies for which the skin is sensitive.

Each of these effects can be performed for the internal sound production and vibrotactile feedback portion of the instrument, while still producing the unmodified sound from the sound synthesis system through the external sound production mechanism.

When producing vibrotactile feedback it is interesting to note that neither the actuators used to produce vibrotactile feedback nor the human skin offer a flat response to vibrations across the frequency range. By having separate control over the frequency content of the signal sent to the vibrotactile feedback system we can compensate for these responses. For instance, if the instrument is to generate low frequency sounds it is possible that the loudspeakers used may have a reduced response at these frequencies. By modifying the signal sent to the loudspeakers we could increase the output amplitude for these low frequencies.

Modification of the vibrotactile feedback signal can also be used to modify the vibration response in such a way as to make it more like the response of a different instrument. It is possible to increase or reduce the response at certain frequencies or within certain frequency bands. This could, for instance, be used to produce low frequency vibrations for an instrument with a poor low frequency response. It could also be used, together with measurements of the vibration response of an existing musical instruments, to simulate the resonances of the body of other instruments in the Viblotar.

Finally, by modifying the feedback signal, we can restrict the sound produced by the internal sound production mechanism (and thus the vibrations created) to only those frequencies to which the human skin is sensitive. This results in the internal sound production being used mostly for vibration production, while the actual sound production occurs outside of the instrument itself. In fact, it would even be possible to restrict the internal sound production to frequencies which are too low to be audible, thus using it solely for vibration generation.

It is also possible (and perhaps even advisable) to combine a number of these effects together. For instance, when attempting to simulate the resonances of another instrument it may well be necessary to apply compensation for the actuator so that the target response is produced by the system.

3. MEASURING INSTRUMENT VIBRATIONS

For some of the effects just discussed, and indeed to enable a mechanical evaluation of the vibrotactile feedback system used in the Viblotar, it is necessary to be able to measure the vibrations of a given instrument, whether acoustic or digital. This section describes a method of measuring instrument vibrations and provides examples and comparisons of the vibration of an acoustic guitar and the Viblotar. The measurement method described in this section is based on that used by [2], who measured the vibration response of a number of stringed instruments at different points on the instrument body.

The aim of the measurements made here are to compare the vibrations of an acoustic instrument (an acoustic steel stringed guitar) with a new digital musical instruments (the Viblotar). In particular, we are interested in showing certain common traits between these two different instruments. Questions of particular interest are:

1. Do these instruments produce vibrations above the threshold of human detection?
2. Are there similarities in the spectral content of these vibrations?
3. Are the spectra of the vibrations related to the note being played?

3.1 Methods and Procedure

All vibration measurements were made with the instrument in normal playing position. A PCB Piezotronics ICP accelerometer, model 352C22 was used for all vibration measurements. The output signal from the accelerometer was connected to a PCB Piezotronics ICP Signal Conditioner, model 480E09. Analog to digital conversion of the amplified voltage was performed using a National Instruments PCI-6036E with a 16-bit resolution and a sampling rate of 100 kHz. Finally, control and datalogging was performed using National Instruments LabView 7.1 software. Analysis of the recorded signals was performed with Matlab.

Figure 2: The Viblotar in the playing position.

For each instrument, the accelerometer was attached at the measurement position using adhesive wax. Each instrument was held in the playing position. All measurements were performed using a single pitch, corresponding to the open low E string of the guitar. This gives a frequency of 82 Hz. Multiple measurements were made for each instrument. These measurements were averaged during the analysis stage to reduce the effect of any artefacts from single notes.

For the guitar, the procedure was as follows: the accelerometer was attached to the instrument on the top plate, near the bridge. The instrument was held in the playing position, with the neck resting in the left hand, but no fingers pressed to the fingerboard. The low E string was plucked using a pick at the specified dynamic level and allowed to resonate until no detectable vibrations were present. This was repeated 10 times.

For the Viblotar, the procedure was similar. The instrument was held in the playing position, with the body of the instrument resting on the performer's legs, as shown in Figure 2. The left hand was allowed to rest on the left side of the instrument, near the Force-sensing resistors (FSRs). The right hand was also allowed to rest on the instrument, directly below the linear position sensor. For the purpose of this experiment, the Viblotar mapping was modified so that a touch at any point on the sensor produced the desired note. The linear position sensor is touched using one of the fingers of the right hand. The note is allowed to resonate until no detectable vibrations are present. To ensure no accidental damping or modulation of the note occurs, these functions of the mapping system were also disabled for the duration of the test. As with the guitar, this procedure was repeated 10 times.

3.2 Results

Figure 3 shows the average vibration spectrum measured for the acoustic steel string guitar. Notice the peaks fundamental and each of its harmonics. The spectrum shows especially large peaks at the 2^{nd} and 4^{th} harmonics. Note also how the vibrations in the lower frequencies are above the threshold of human vibrotactile detection.

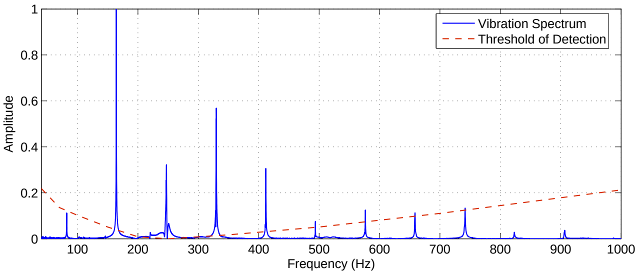

Figure 3: Average vibration spectrum of an acoustic steel string guitar playing open low E (82 Hz), as measured near the bridge.

The average vibration spectrum for the Viblotar is shown in Figure 4. As with the guitar, it shows peaks at the harmonics of the note played. Unlike the guitar, there are also peaks in the spectrum at non-harmonic frequencies. These peaks are due to the flute portion of the hybrid guitar/flute model used in the blotar synthesis. Similar to the guitar, the lower frequencies are above the threshold of detection. Unlike the guitar, a number of higher frequencies are also well above the threshold of detection.

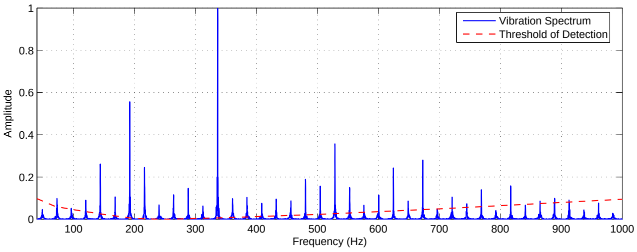

Figure 4: Average vibration spectrum of the Viblotar playing a frequency of 82 Hz, as measured on the top

Examining both spectra, it can be seen that both instruments produce vibrations above the threshold of detection. There are also a number of similarities in the spectra, each producing detectable vibrations at a number of frequencies which are harmonics of the note being played.

Having examined the vibrations produced by these instruments, we can see that both produce vibrations which would be felt by the performer. Also, the vibrations produced by the Viblotar are similar to those produced by an acoustic instrument. This then raises the question of whether these vibrations affect the “feel” of the Viblotar for the performer. The experiment described in the next section attempts to deal with this question.

4. EXPERIMENT: PERFORMER EVALUATION

This section describes an experiment to evaluate the effects of the embedded vibrotactile feedback system on the “feel” of the Viblotar. While the concept of the “feel” of an instrument is one which is often mentioned by performers it is difficult to objectively evaluate. Therefore, for this experiment a measure of the “feel” of the instrument is determined based on a number of different characteristics, which participants are asked to rate:

Ease of use: how easy the instrument is to perform with.

Controllability: how much the performer was in control of the instrument.

Engagement: how much of the performer’s attention was put into playing the instrument.

Entertainment: how entertaining the instrument is.

Potential for further performance: how much potential the instrument offers for further performance.

4.1 Participants

The participants were 5 graduate students from McGill University. All participants were experienced musical performers, having completed at least an undergraduate degree in music performance. Two of the participants had previous experience playing digital musical instruments, while the others did not. None of the participants were familiar with the Viblotar.

4.2 Design and Materials

The aim of this experiment was to examine how the choice of sensors and feedback affected the “feel” of the instrument. To evaluate this we asked performers to play the Viblotar in two different configurations:

1. With external sound production and no vibrotactile feedback.

2. With internal sound and vibrotactile feedback production.

In the external sound production configuration, the synthesized sound is output using a pair of loudspeakers which are placed in front of the performer at a distance of 1 meter. This removes all vibrotactile feedback from the instrument and dissociates the sound from the instrument itself. The result of this is a configuration like existing digital musical instruments.

With the internal sound production, the sound is produced using the two loudspeakers which are in the body of the instrument itself. This results in vibrotactile feedback to the performer and in the sound coming from the instrument in a way most like an acoustic instrument. For both configurations the sound volume was maintained at the same level (90dB peak, A-weighted), measured using a Radio Shack 33-2055 digital SPL meter.

These configurations allow for an examination of the effects of vibrotactile feedback and embedded sound production on performer ratings of the instrument.

Overall, the hypothesis for this experiment is that Vibrotactile feedback should improve the “feel” of the instrument. This means that some performer ratings should be higher for the internal sound production configuration.

4.3 Procedure

Subjects arrived at the lab and were given an Information/Consent form to read over and sign. Subjects were then introduced to the Viblotar and its playing interface. The sensors used on the Viblotar were explained, along with the parameters that they control. They were then given a demonstration of playing the instrument.

Subjects were informed that they would be playing the instrument in two different configurations, although they were not told what the difference between each configuration was. They were told that for each configuration they would be allowed to play the Viblotar for 20 minutes and then asked to rate the instrument on several criteria. They were shown the list of criteria and each item was explained to them. The order of presentation of the configurations was randomized. All ratings were performed on a 5-point Likert scale.

Participants then spent 20 minutes performing with the instrument in the first configuration. Once the time was up, they rated that configuration on each of the criteria being examined. This process was then repeated for the second configuration.

Finally, participants were debriefed verbally after the experiment and asked for any comments they had on the instrument or either configuration. The differences between each configuration was also explained at this point.

4.4 Data Analysis

Results were analyzed in Matlab. As the data was found not to follow a normal distribution the analysis was performed using the Wilcoxon signed rank test.

4.5 Results

There was a marginally significant improvement in engagement for the configuration with vibrotactile feedback [p = .07] (Figure 5). This was the only significant difference found in this experiment. However, there were also two non-significant differences found between configurations.

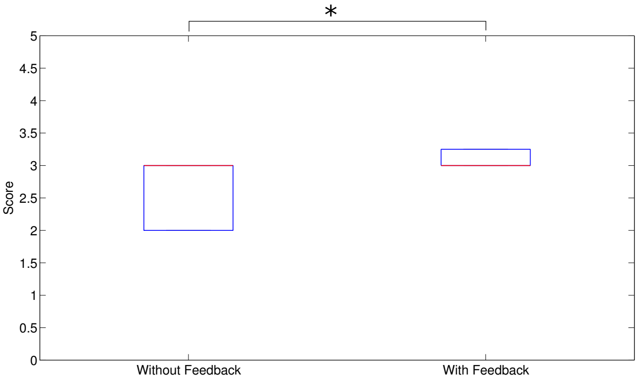

Figure 5: Participant ratings of engagement with the Viblotar, with and without vibrotactile feedback. A * indicates a significant difference. Red lines indicate median values, while blue lines indicate lower and upper quartile values. Whiskers extend to 1.5 times the interquartile range.

Firstly, there was a slight improvement in entertainment ratings for the vibrotactile feedback configuration [$M_{without} = 3.0$, $M_{with} = 3.4$] (see Figure 6). In contrast to this, there was a slight deterioration in ratings of the controllability of the instrument for the vibrotactile feedback configuration [$M_{without} = 3.8$, $M_{with} = 3.4$] (see Figure 7).

There were no significant differences in user ratings of the configurations for ease of use or potential for future performance.

Interestingly, ease of use ratings were high [$M_{ease} = 4.4$] in both configurations. In fact, the ratings were identical for both configurations. This indicates that while the instrument is easy to use, the ease of use is not in any way affected by the addition of vibrotactile feedback. This may be an artefact of the design of the instrument itself, as previous work has shown that vibrotactile feedback can make an instrument easier to use [10].

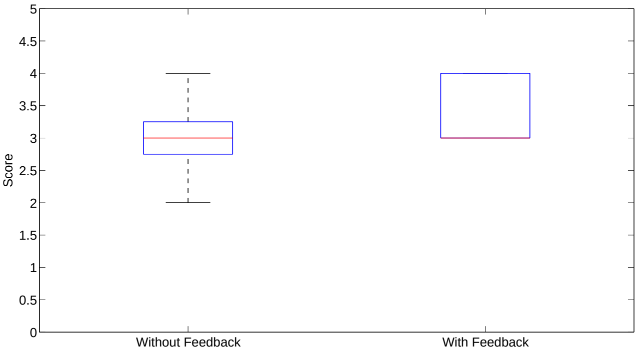

Figure 6: Participant entertainment ratings of the Viblotar, with and without vibrotactile feedback.

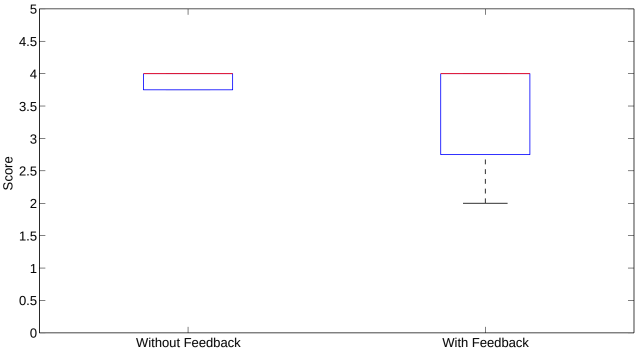

Figure 7: Participant ratings of the controllability of the Viblotar, with and without vibrotactile feedback.

4.6 Discussion

A number of interesting points arise from the results of this experiment. Firstly, the ease of use ratings for both configurations were high. A mean ease of use of 4.4 out of 5 was received by each configuration. This indicates that the sensors chosen provide an easy to use interface. The fact that each participant gave the same ease of use rating for both configurations would also seem to confirm that this result is due to the combination of sensors, gestures and tasks, as it was unaffected by the presence or absence of vibrotactile feedback.

Looking at the effects of vibrotactile feedback, we find a number of criteria which change when this feedback is present. Firstly, there was a marginally significant improvement in engagement when feedback was present [t(4) = 2.45, p = .07]. Participants found themselves more engaged with the instrument when vibrotactile feedback was present. They were more involved in the performance of the instrument, spending more of their attention on the instrument.

Interestingly, participant rating of controllability dropped with the addition of vibrotactile feedback [$M_{without} = 3.8$, $M_{with} = 3.4$]. Participants felt less in control of the instrument when the feedback was present. One participant commented on noticing changes in the sound for the internal sound production configuration that had not been noticed for the other configuration. This could indicate that the vibrotactile feedback channel was providing extra information to the performers that was not present in the other configuration, so that they noticed changes which they would otherwise have missed. Such extra information could be extremely useful for developing expert performance technique. It is also possible to consider that a reduction in controllability might result in an increase in the challenge involved in performing the instrument. This could have an effect on the overall performance potential of the instrument in the longer term.

Finally, there was a small increase in entertainment ratings for the configuration with internal sound and feedback generation [$M_{without} = 3.0$, $M_{with} = 3.4$]. Together with the significant increase in engagement this would seem to indicate that the playability, or indeed the "feel" of the instrument is improved when vibrotactile feedback is present.

5. CONCLUSIONS

The work described in this paper examined the use of embedded vibrotactile feedback in a digital musical instrument and it's effect on the "feel" of the instrument from the performer's perspective. By integrating loudspeakers and amplifiers in to the body of the Viblotar, we produced an instrument that mimics the vibrotactile feedback found in acoustic instruments. That is, the sound production also produces the vibrotactile feedback.

The addition of internal sound generation to the Viblotar produced a number of effects. It localized the sound to the instrument itself and it added vibrotactile feedback to the instrument. Looking at the results of the experiment in Section 4, we can see that this resulted in a marginally significant increase in engagement, along with a small (although not significant) increase in entertainment. This would seem to indicate that there is an improvement in the "feel" of the instrument for the performer when vibrotactile feedback is present.

Interestingly, the additional vibrotactile feedback also resulted in a slight (and again not significant) decrease in performer controllability ratings. In post-experiment debriefing, one of the participants explained that they thought the sound synthesis had changed between configurations. On further examination it was discovered that the participant had noticed changes in the sound under the vibrotactile feedback configuration which had not been noticed under the other configuration. More information was being presented to the performer by the extra feedback channel. It seems that this extra information was causing the performer to feel less in control of the instrument than in the other configuration.

However, this raises some interesting issues. Wessel and Wright state that a musical instrument should offer a "low entry fee" but with "no ceiling on virtuosity" [12]. Instruments which are too easy to use may seem more like toys and less like instruments. Hunt found that users enjoy performing with instruments which offer more of a challenge [6]. For the Viblotar, the addition of vibrotactile feedback resulted in reduced controllability ratings. This might indicate that the instrument becomes more challenging with the feedback present, as it provides more information about the state of the instrument to the performer.

However, a number of issues still remain to be addressed. A longer term evaluation, perhaps with more participants, could lead to much insight into the playability of the Viblotar. Keele states that vibrotactile feedback is used more by expert performers than beginners [7]. As the participants in the experiment in this study were all novice Viblotar players, it is possible that they were not making use of the vibrotactile feedback in the same way as an expert performer would. A longer term experiment examining the changes in user ratings over a longer period of time would allow the participants to increase their skill with the instrument. Such an experiment might also lend insight into the effects of the vibrotactile feedback on the "feel" of the instrument, through changes in participant ratings over time.

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