Exploring audio and tactile qualities of instrumentality with bowed string simulations

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ABSTRACT
Thanks to force-feedback and physical modeling technologies, it seems possible today to reach the same kind of relation with virtual instruments than with acoustic instruments, but the design of such elaborate models needs guidelines based on the study of the human sensory-motor system. This article present a qualitative study of such instrumental interaction in the case of the virtual bowed string, simulated with both waveguide and mass-interaction models. Subjects were invited to explore the possibilities of the simulations and to express themselves at the same time, allowing us to identify key qualities of the proposed systems that determine the construction of an intimate and rich relationship between them and the users.

Keywords
Instrumental interaction, presence, force-feedback devices, physical modeling, computer music, haptics.

1. INTRODUCTION
Current research in Computer Human Interaction and Digital Arts promises to offer interfaces that provide the same degree of richness and intimacy as the relationship with real physical objects and especially with acoustical instruments. The instrumental interaction can be recreated if the physical variables measured by the interface are of the same nature of controlled variables and if there exists an energetic continuum between human gestures and their simulated effect [2].

Such a situation can be obtained today with the combination of force-feedback and physical modeling technologies. It remains to discover the characteristics that turn the proposed interfaces into a virtual instrument, i.e. the objective parameters that give birth to the experience of an instrumental interaction by users.

We study this question with an emblematic instrumental situation: the bowed string, which has already been addressed by different authors (see for example [4], [5], [8]). Different cases of this situation were simulated and proposed to users for them to explore the possibilities offered. Through observing their experience with the simulation and gathering their impressions, we aimed at doing a qualitative evaluation of the simulations and at identifying their characteristics that are the most significant for users in the perspective of reaching a simulated instrumental interaction. The first results of this study, concerning the perception of timbre and of haptic stimuli and the perceived relation between sound and gestures, will be presented in this article.

2. METHOD
We asked a number of users to use 4 different simulations of a bowed string: 2 simulations were based on mass-interaction physical modeling (CORDIS-ANIMA modeling system) [3] and 2 others were based on waveguide synthesis and a model of the string-bow interaction called DISTPLUCK [7]. All simulated strings were tuned to the same pitch (246,94 Hz). Two models had a short decay (0,5 s, which is similar to that of a real fingered string) and two others had a longer decay (2,5 s, which is closer to that of a real open string), as summarized in Table 1. The models had no visual representation, so the subjects had only audio and haptic feedback to their actions.

The experimental method was inspired by works of Pascal Amphoux [1]. According to the suggestion that, for a qualitative study, really significant ideas can be expressed by the subjects while they are actually doing, we decided that the experimental sessions would be accompanied by a moderator who would stimulate expression by his questions. Thus the experiments took the form of a combination of practice of the simulations and nondirective interviews, where the subject was invited to share any impression or thought that would seem interesting to him or her. The experimental setup was completed by note taking, and audio and video recording. In the perspective of a later quantitative analysis – which is not addressed here – the gesture signals (position of the virtual bow and force applied on the string) were also recorded.

Table 1. Simulations used for the experiments

Decay / ***Type of model***	**0.5 s**	**2.5 s**
CORDIS-ANIMA (CA)	CAS	CAL
Waveguide + DISTPLUCK (DP)	DPS	DPL

The force-feedback device used for the experiment was an Ergon_X system from Ergos Technologies, configured as a 2-DOF joystick (Figure 2), which allowed to change the vertical and transversal position of the bow.

The experiments consisted of two separate series with different subjects, the first one in November 2010, and the second one in January/February 2011. During the first series, the 7 subjects were given a single goal, which was to explore as much as possible the possibilities offered by the 4 simulations in randomized order. The time spent on each simulation was not imposed, although the total duration of the experiment was kept to about one hour. The joystick of the haptic interface was equipped with a knob, as shown in Figure 1.

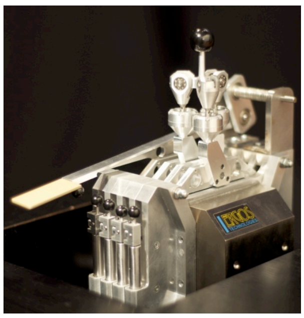

Figure 1. The ERGON_X force-feedback interface equipped with the knob handle.

During the second series, the 16 subjects were asked to perform a specific task, which was to produce as continuous a sound as possible with the simulation, with a specific focus on continuity during bow direction reversals. The success to this task is not in the scope of this article; we will focus on the comments made by the subjects while they were trying to perform it. The experiment consisted of a free exploration on a first simulation, which typically lasted 15 minutes, followed by three sequences of trials, the first one starting with the same simulation used. The order of the simulations was randomized, and about 15 minutes were spent on each one, separated by 5-minute pauses. The haptic device configured differently from the first series: it was equipped with a 10 cm long aluminum stick intended to be held in a similar way as a bow.

Since the goal of our work is to study the virtual instrumental interaction in a general perspective and not to develop a realistic virtual string instrument, the chosen subjects had very different backgrounds and were not all musicians. Besides a cellist and a former violinist – whose comments are obviously much appreciated in this context – other subjects came from Computer Graphics, Computer Music or had no link with the field of Computer Arts at all.

3. RESULTS

Despite the apparent simplicity of the simulation, the comments gathered during the experiments constitute a very rich source of information addressing several topics, including: perception of sound, perception of haptic stimuli and gesture-sound relationship. To date, the audio recordings of the experiments have been transcribed to text and submitted to a qualitative analysis in order to identify the main trends and differences between users. We will discuss here some preliminary results of this analysis.[1]

3.1 Sound Perception

3.1.1 Timbre

The most obvious observation that could be made during the experiments is that all subjects were able to distinguish very quickly the two types of models (CA and DP) from their timbre, which are objectively very different, especially with a predominance of high-order harmonics in DP models (Figure 2).

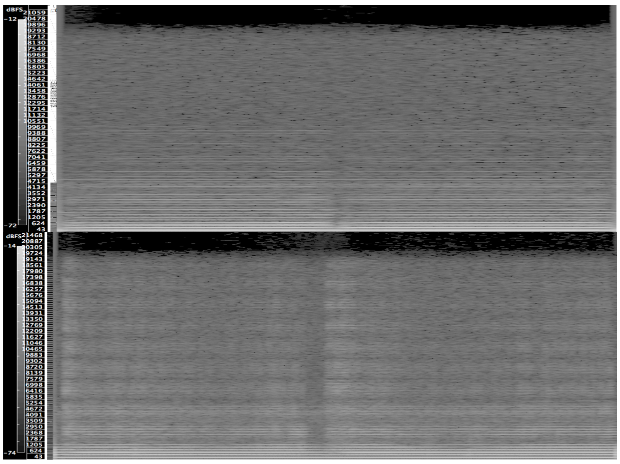

Figure 2. Spectrograms of two consecutive bow strokes with a CA (up) and a DP (down) model.

[1] Quotations marked with a star ("*") were translated from French to English by the authors, while the others are originally in English.

Most subjects remarked that different harmonics were present depending on the simulation and on the playing technique. Since the pitch was fixed, subjects were incited to explore the variability of timbre through variations of pressure and bow velocity. Appreciation of these different timbres diverged between subjects, with some of them preferring the warmer sound of CA models and others the brighter tone of the DP models. Several subjects also experiences a difficulty to get the fundamental mode sounding with the DP model, which can easily "get stuck" to the second- or third-order harmonic.

Besides, both types of models differ by the inharmonic content of the sound they produce, with the DP models producing more noise than the CA models. Ignoring that the simulation technique was not the same for every simulation, several subjects thought that a timbre was a transformation of another heard previously, for example after switching from a DP to a CA model:

"This has a different timbre. It sounds like it's almost low-pass filtered"
*"I feel that sound of the string is a bit filtered *"*

This difference was so important for two subjects that, after switching from a CA to a DP model, they wondered whether they were still interacting with a model of a bowed string:

*"I have the impression… of a wind instrument, I'm blowing into a flute actually *"*
*"It's a flute. It's a flute or… Not a clarinet… Well, it's an hyper-reactive flute… It's actually a pan flute! It's true, the attack is flute-like! *"*

As can be expected, discussions with these subjects tend to show that the perception of a flute sound is induced by the particular attack of DP models than have rich harmonics and a strong noise component. Moreover, music teachers that we questioned about this confirmed that it is quite usual for people to confuse the sound of bowed strings and wind instruments.

Apart from the two subjects that we just quoted and the case of the DP models played in a very specific way (see below), the other subjects did not question the fact that the sounds could be produced by a bowed string. Several users expressed their satisfaction about the sounds obtained:

"*The instrument has an attack timbre very… very close to the violin, which is very specific *"*
"For me it sounds very close to the natural instrument"

This was expected since both physical modeling techniques used are well mastered after several decades of development.

3.1.2 Decay

It is remarkable that nearly all subjects expressed a preference for the models with a longer decay. Several reasons for this have been given. The first one is based on the principle that *he who can do more can do less*: since it is possible to dampen the string at will, simply by holding down the bow on it, the long decay automatically offers more possibilities than the short one.

Moreover, a subject mentioned the fact that a longer decay of string extends the feeling of its presence even though there is no more physical contact with it and no visual representation:

"Before [with the short decay]*, I just had the impression that it was concentrated around my bow and then the instrument would disappear as soon as I stopped interacting with it. It's nice to feel that you interact with an entity that also exists without you *"*

However, this interpretation has not been confirmed nor invalidated by other subjects, so it still had to be studied.

Lastyl, to explain the preference for the long decay, it may also be hypothesized that a weaker dampening of the string tends to smooth out the sound and then brings more tolerance to manipulation errors: the longer resonance makes it less likely that a bad gesture completely stops the oscillation of the string, which can be perceived as an easier, more comfortable playing condition. This is suggested by several quotations, such as:

"I find it [the simulation with a long decay] *more pleasant, easier than the others; compared to the previous one, you can be more confident about whether you'll manage to produce a sound *"*

"I think it's easy to make a sustained note. I think that's because the decay is longer. You can trust in the decay to change the direction of the bow and you can make it steadier"

Despite the quite unanimous subjects' feedback, it is impossible to consider that the preference for the long decay is universal. As one subject told us, this should be "just like a continuous parameter that you have to choose based on your preferences."

3.2 Perception of Haptic Stimuli

Subjects noticed three principal reactions of the force-feedback device: a resistance to lateral motion due to the friction with the string; vibrations of the end effector corresponding to those of the string; and bounces of the bow against the string during vertical movements.

3.2.1 Bouncing Against the String

Most subjects that evoked this behavior used terms that suggest that it plays a role in the feeling of presence, although it has not an important role musically speaking:

"You can pick it [the bow] *up and bounce on it, it feels really nice. Really it feels like you're bouncing on something that same some tension on it"*

*"It's nice to be able to… to see that when I do this [bounces on the string], I can hear the "poom" when the bow leaves the string, we can hear the small impulse, this is nice! *"*

*"What is interesting is the bounce, too, well, this feeling of bouncing *"*

3.2.2 Vibrations and Resistance of the Interface

Vibrations of the interface and resistance to transversal motion have raised contrasted reactions. Some subjects declared that they were feeling no force-feedback at all when trying the first simulation, although it was actually present. The comments made by some of them, who were not familiar with force-feedback interfaces, suggest that they thought that the felt resistance was the normal resistance of the interface for any gesture.[2] By pushing these subjects to focus on the haptic feeling or just by giving them more time to familiarize with the device, they finally acknowledge the resistance of the string. For example:

"Subject: *But now I'm not really sure if there is haptic feedback or not.*
Moderator: *Ok, pay attention to your hand and try to decide.*
Subject: *Yeah. I feel something like subtle vibrations"*

[2] The inner friction force of the ERGON_X is actually at the threshold of perception.

Later during that experiment, we got a clue that audio perception may have a masking effect over haptic perception in some cases:

"Subject: *Yeah, I can feel in the hand now.*
Moderator: *How would you describe it?*
Subject: *I hear it first and then I felt it in the hand.*"

This hypothesis is supported by a remark made by another subject:

*"There's definitely a different sensation in the… in the hand, I don't know exactly if it's a vibration coming from the sound or from… from the instrument itself, I can't identify it *"*

The case of another subject is particularly striking concerning the modulation of haptic perception by other factors. From past experience, this subject was aware of experiments made with multimodal settings such as audio-visual-haptic feedback, were haptic feedback is sometimes deactivated without the subject knowing. At the beginning of the experiment, he declared that he could not feel any friction with the string. Then he made several allusions that he had understood force-feedback was deactivated and that he was waiting for it to be enabled, which help be master the simulation. Only when using a third simulation – which was a CA model, following two DP models – did he felt the friction he was expecting. Here it really seems that the beliefs of the subject were influencing his perception.

From these comments, we may tend to conclude that the vibration's intensity was too small. But, on the opposite, the cellist thought it was exaggerated:

"You can feel the vibration of the string in your fingers, which is quite incredible. You feel it more, I think, than on a real instrument, much more […] On a low-pitched string, this is something that you can imagine. On high-pitched string, thus with higher vibrating frequencies, this is more surprising *"

This opinion was confirmed by another subject, which is not used to playing with a bow:

"I don't think that a bow would vibrate that much."*

3.3 Relation Between Gestures and Sound

Subjects made many comments concerning the relation between their gestures and the sound obtained as a result. Remarkably, these comments outnumber those involving only sound or only haptic perceptions, a fact that we consider as a good indication that an instrumental interaction is approached with these simulations.

After an initial trial period, lasting no more than ten minutes, all subjects were able to manipulate the simulation without any major concern and to discover the influence of their actions on the audio and haptic feedbacks. They have generally emphasized the coherence of this relation:

"That's interesting. I get different timbres by pressing down harder on the string. Ok, it sounds like natural."

*"From the sound, and the reaction, and the touch, it seems realistic. *"*

*"I think it's quite realistic from what I've heard from the violin, the duration of the sound is consistent, and it's also consistent with the effort I put into it. *"*

This last comment and similar ones suggest that an energetic continuum within the system is perceived and enacted, which is one of the requirements of instrumental interactions. It is important to notice also that the concept of realism, which is evoked in the last two quotations, was introduced by the subjects themselves and not by the mediator.

However, subjects reported two main issues with the simulations. Firstly, most subjects were surprised or even bothered that it was impossible with the CA models to put the string into oscillation with a combination of a high pressure and a slow movement, which is indeed a known limitation of the model. Secondly, in similar playing conditions, the sound produced by the DP models were sometimes judged too harsh[3] or somewhat artificial.

While both issues appear in playing conditions that are not likely to be used often during real musical performance – since that level of pressure is probably too uncomfortable to maintain – they should be taken into account for improving the models. Indeed, they can have a real impact on the sensation of presence and believability felt by user. This is most particularly noticeable with the CA models: several users expressed feelings of frustration or confusion due to this behavior, since they had the impression that the string was disappearing precisely when it should be the more present.

Discussions with subjects also show other "clues" of instrumentality. Firstly, the observations suggest that a transfer of skills is possible from the practice of a real bowed stringed instrument and the simulations, despite the obvious differences between those situations: different position, use a single hand, presence of a single string, small size of the playing space. One result – which would require to be confirmed by additional observations – supports this conclusion: during the continuous reversal task, the cellist has performed best than other subjects while he had the most difficult conditions (short decay time for all tested simulations). His performances have even managed to fool the observation team who, not knowing in advance what simulations would be run and in which order, had the habit of trying to guess by watching the subjects performing.

In addition, all the subjects with whom the topic came up said that learning opportunities were real: the complexity of the simulations was sufficient for work-related skills can develop.

For example, and this is probably one of the most significant point, observing subjects playing with sound harmonics (including with DP models, which were particularly suitable for this) has clearly shown for at least both of them the development of enactive knowledge [6], i.e. a knowledge that is difficult or nearly impossible to express with words, but that is nevertheless present in the body. Indeed, since it is possible with the simulations to excite principally a single vibrating mode of the string, these two subjects had decided to try to go from one mode to the other at will. This is a difficult task with no experience of bowed strings – which was the case for both of them – and without the possibility of changing the longitudinal position of the bow. However, their goal has been achieved to some extent and their progress was evident, but they would not acknowledge it. They declared that they were not able to control the harmonics – while the evidence showed the opposite – and were not able to describe their strategies in trying to do so. In other words, they were learning to do something they could not express, a well-known phenomenon in learning acoustic instruments.

[3] However, other subjects actually enjoyed the roughness of these sounds or at least thought that it was natural.

4. CONCLUSION

The experiment described in this article allowed us to gather a great quantity of information thanks to the method that we used to interact with subjects, i.e. the combination of free exploration and nondirective interview. The observations related to psychoperception, such as the masking effect of audio over haptic perception that seemed to happen several times, have obviously to be confirmed through dedicated studies.

Concerning the qualitative evaluation of the proposed simulations, we were able to confirm their general quality in terms of richness and playability and to identify two main issues: the "apparent loss" of the string on CA models played with hard pressure and the quite synthetic timbre of DP models played with high pressure and a low velocity. These issues will be corrected in future versions of the models.

More importantly, we observed that this kind of issues have a strong impact on users, who can be confused or even annoyed by behavior that show a lack of physical consistency of the simulations. From this observation, it seems that designing virtual instruments based on physical models would benefit from focusing on believability in every playing conditions offered by the interface, even though these not all relevant in actual musical applications.

5. ACKNOWLEDGMENTS

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