Exploring audio and tactile qualities of instrumentality with bowed string simulations

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ABSTRACT
Force-feedback and physical modeling technologies now allow to achieve the same kind of relation with virtual instruments as with acoustic instruments, but the design of such elaborate models needs guidelines based on the study of the human sensory-motor system and behaviour. This article presents a qualitative study of a simulated instrumental interaction in the case of the virtual bowed string, using both waveguide and mass-interaction models. Subjects were invited to explore the possibilities of the simulations and to express themselves verbally at the same time, allowing us to identify key qualities of the proposed systems that determine the construction of an intimate and rich relationship with the users.

Keywords
Instrumental interaction, presence, force-feedback, physical modeling, simulation, haptics, bowed string.

1. INTRODUCTION
Current research in Human-Computer 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 acoustic instruments. In particular, an instrumental interaction can be recreated if the physical variables measured by the interface are of the same nature of controlled variables and if there is 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, but it remains to verify whether these two technologies are sufficient to turn the proposed devices and simulations into playable virtual instruments and under which conditions.

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]). While most studies published so far on the subject focus mainly on technical aspects and on users' success in different tasks, we decided to emphasize user feedback during free manipulation scenarios. Several bowed string simulations were proposed to users for them to explore the possibilities offered. Through observing their experience with the simulation and gathering their impressions, we aimed to perform a qualitative evaluation of the simulations and to identify their characteristics that are the most significant for users, with the goal of reaching a simulated instrumental interaction. We present in this article the results of this study concerning the perception of timbre, haptic stimuli, and their relation.

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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 system) [3] and 2 others were based on waveguide synthesis and a model of the string-bow interaction called DISTPLUCK [7]. All strings were tuned to the same pitch (246,94 Hz). Two models had a 0.5 s decay, similar to that of a real fingered string, and two had a 2.5 s decay, closer to that of a real open string (Table 1). No visual representation of the models was displayed to the users.

The experimental method was inspired by works of Pascal Amphoux [1]. According to the suggestion that, for a qualitative study, subjects can express significant ideas while they are actually doing a task, we decided that a moderator would accompany the experimental sessions in order to stimulate subjects' expression. 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. Towards a quantitative study that is not addressed in this paper, the position and force signals were also recorded.

Table 1. Simulations used for the experiments

Decay time / *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 allowing to control the vertical and transversal positions 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 and February 2011. During the first series, the 7 subjects were given a single goal, which was to explore as much as possible the potential of the 4 simulations, presented 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 haptic interface was equipped with a 3-DOF knob, as shown in Figure 1 (one degree of freedom had no effect on the simulation and was left completely free).

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 of 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. The order of the simulations was randomized, and about 15 minutes were spent on each one, separated by 5-minute pauses. The haptic device was 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.

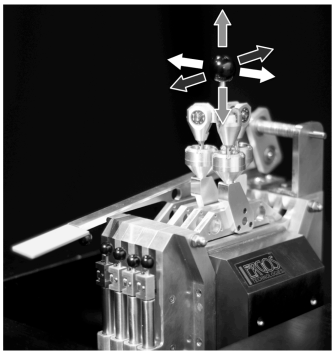

Figure 1. The ERGON_X haptic interface used in the first series of experiments. The longitudinal axis (dark gray arrows) was not connected to the simulation.

Since our goal was to study simulated instrumental interactions in a general way 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, other subjects came from Computer Graphics, Computer Music, or had no background in Computer Arts.

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 CA from DP models from their timbre. They are indeed objectively very different, especially with a predominance of high-order harmonics in DP models (Figure 2).

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 experienced a difficulty to excite the first mode of the DP model, which could easily "get stuck" to the second- or third-order harmonic.

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

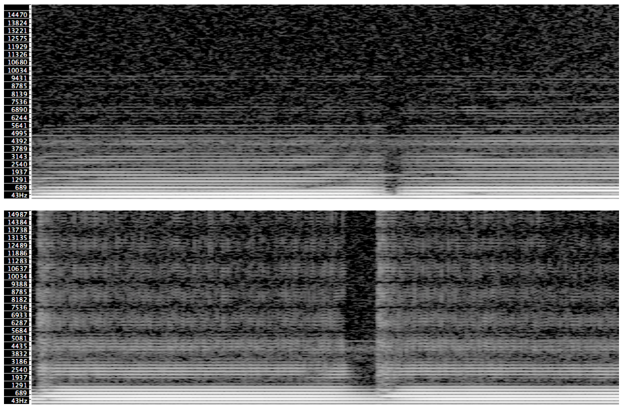

Figure 2. Spectrograms of two consecutive bow strokes. Up: CA model; down: DP model. Total duration: 1.7 s.

Additionally, both types of models differ by the inharmonic content of the sound they produce during attack or playing with hard vertical pressure, 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 the 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 a hyper-reactive flute… It's actually a pan flute! It's true, the attack is flute-like! *"*

Discussions with these subjects tended to show that the perception of a flute sound is induced by the particular attack of DP models, which 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 those two subjects 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, a long decay consequently offers more possibilities than a short one.

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

*"Before [with a 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. [Now] 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, therefore it requires further study.

Lastly, 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 it plays a role in the feeling of presence, although it does not have 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 has some tension in 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 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 acknowledged 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.*

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, where 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 would help him master the simulation. Only when using the third simulation – which was a CA model, following two DP models – did he feel 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, conversely, 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, who was 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 feedback. They have generally emphasized the coherence of this relation:

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

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

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

*"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 vertical pressure and slow movements, which is indeed a known limitation of the model. Secondly, in similar playing conditions, the sounds produced by the DP models were sometimes judged too harsh or somewhat artificial; other subjects actually enjoyed the roughness of these sounds or thought that it was natural.

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 string instrument and the simulations, despite the obvious differences between those situations: different position, use of a single hand, presence of a single string, and the 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 better 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 to develop.

For example, and this is probably one of the most significant points, observing two subjects playing with sound harmonics (including with the DP models, which were particularly suitable for this) it was clearly shown for 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 observers agreed that they were, in fact, improving – and they 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.

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, should 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 may be addressed in future versions of the models.

More importantly, we observed that these kinds of issues have a strong impact on users, who can be confused or even annoyed by behaviours 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 condition offered by the interface, even though these are not all relevant for actual sound production.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] Amphoux, P. L'observation récurrente: une approche reconstructive de l'environnement construit, *in Espaces de vie. Aspects de la relation homme-environnement*, Moser G., Weiss K. (Ed.), Paris : Armand Colin, 2003, p. 227-245.

[2] Cadoz, C. Supra-Instrumental Interactions and Gestures. *Journal of New Music Research*, 38(3):215–230, September 2009.

[3] Florens, J.-L. Expressive Bowing on a Virtual String Instrument, in *Gesture-Based Communication in Human-Computer Interaction*, Camurri A., Gualtiero V. (Ed.), Springer : Berlin / Heidelberg, 2004, p. 447-448.

[4] O'Modhrain, S., Serafin, S., Chafe, C., and Smith III, J. O. Qualitative and Quantitative Assessment of a Virtual Bowed String Instrument. *Proceedings of the 2000 International Computer Music Conference*, ICMA, 2000.

[5] Nichols, C. The vBow: development of a virtual violin bow haptic human-computer interface. In *Proceedings of the Conference on New Interfaces for Musical Expression*, Dublin, Ireland, 2002, p. 29–32.

[6] Pasquinelli, E. Enactive Knowledge, in *Enaction and Enactive Interfaces: A Handbook Of Terms*. Annie Luciani and Claude Cadoz (Ed.), ACROE: Grenoble, 2007, p. 73.

[7] Sinclair, S., Wanderley, M. M., Hayward, V., and Scavone, G. Noise-free haptic interaction with a bowed-string acoustic model. *IEEE World Haptics Conference*, 2011.

[8] Woodhouse, J. Bowed string simulation using a thermal friction model. In *Acta Acustica united with Acustica*, 89:355–368, 2003.