Audiotactile simultaneity perception of musical-produced whole-body vibrations

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Introduction

Everybody has sometimes experienced the vibrations generated by the performance of music. The floor or the seat place can vibrate because of the resonance or the structure-borne sound stimulated by instruments. When these vibrations are correlated with airborne sound, they are additional information for us. The correlation between vibration and airborne sound might be important in implementing, for instance, a virtual reality, to intensify the experience and the quality of it. This study investigates the required synchronism between the auditory and the tactile components. First the terms which are related to the musical-produced whole-body vibrations will be introduced. The next step will be to report on some measurements of musical-produced vibrations. Further, the psychophysical test and the used psychophysical and statistic methods to investigate the time-depending correlations. Finally, the results are presented and discussed.

Terms and Literature-Survey

Two terms need to be explained: 1) "Musical produced" describes an audible or structure-born sound event that is produced by a musical source, like a musical instrument, the voice or even a loudspeaker. The essential characteristic is the musical context of the production-event. These sound events are events in the sense of the "musical consonance", as defined by Zwicker and Fastl [1]. 2) The human responses to vibration can be classified which part of the body is affected. "Whole body vibration" occurs when the vibration transmitted to the whole-body through a supporting surface. For example, when driving a car, the driver is exposed to the whole-body-vibrations which are transmitted by the car seat. The present study considers only the z-axis (i.e., vertical). Until now, most of the investigations into multimodal interaction have concentrated upon the negative and disturbing characteristics of simultaneous vibrations. For instance, Hashimoto and Hatano [2], presented car-inside-noise, vibration and visual information of a car-drive in a "Mockup". In this study, the vibrations increased unpleasantness of the noise, while the visual information increased the quality. Cucuz [3] verified that the random car vibrations are more discomfortable than the harmonic vibrations such as musical-produced whole-body-vibrations. Only very few investigations deal with audiotactile simultaneity perception: Altinsoy, Blauert and Treier [4] have investigated the perceptual aspects of the audiotactile simultaneity in the car-drive context, too. They presented both, original recorded auditory and tactile stimuli of a car, while it passed a bump as well as an impulsive stimulus. They reported perceptual threshold values for auditory-tactile asynchrony. But all these types of sound events are not events in the sense of "musical consonance". Prause [5] has reported another perspective of the whole-body-vibration perception; she published studies from UK and the USA, which are related to the tactile perception of musical events by deaf people. These disabled people are able to distinguish musical events very exactly only by perceiving the vibrations in this context.

Measurements and Experiment

First of all the characteristics of musical-produced vibrations should be investigated. An example for the musical-produced vibrations is the vibrations which are generated by the organ in a concert hall or in a church. Airborne sound of the organ generates also the structure-borne sound; for instance by the resonance of a wooden floor. The details of these measurements: Short sequences of organ-music were played on a pipe-organ in a church. The airborne sound was recorded by an artificial head, and the structure-borne sound by a whole-body seat transducer, lying on a wooden-chair. In the time series it can be seen, that the structure-borne signal is similar to a lowpass filtered air-borne signal. Characteristic resonances of the floor or the chair are recognized as a delayed, increasing signal. The second combination – shown in figure 1 – is the recording of a cello. This instrument is characterized by producing both airborne sound and structure-borne sound, coupled into the floor by its stand. The measurement setup was the same as before; instead of recording in a church the measurement was conducted on a wooden board in an anechoic chamber.

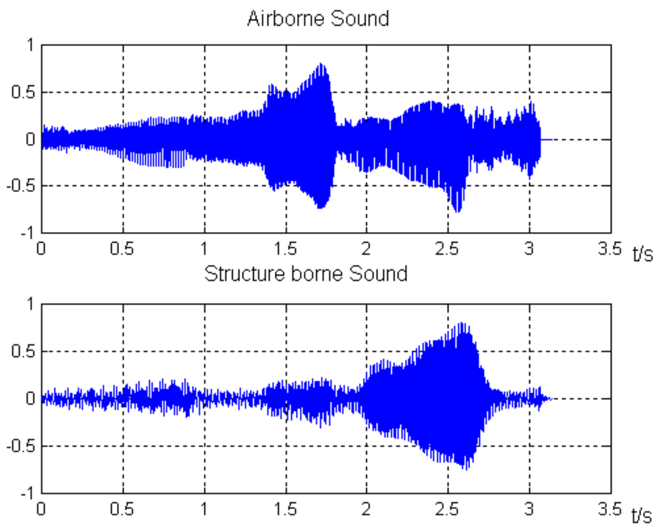

Figure 1: Time series of the cello recording.

In the time series both look quite similar. More high frequencies are visible in the structure-born sound produced by the cello; but the resonances of the wooden-board are very similar to the resonances of the wooden floor in the church. In order to measure the human sensitivity to audiotactile asynchrony, a psychophysical experiment was conducted. The audiotactile stimuli were recorded sound and whole-body vibration of the organ and the cello. The auditory stimulus was presented by headphones, the tactile stimulus was presented via a body-shaker, which was fixed to the underside of a wooden chair. The experiment was controlled by the test person, using a personal computer with an easy graphical user interface. The stimuli were presented in random order with the delays between -360 ms (tactile stimulus first) and 210 ms (audible first) (20 different delay level). The subjects were asked to report on whether the audio signal and the vibration signal were synchronous or asynchronous ("forced choice"). Each condition was presented five times. In the first part of the experiment only organ stimuli and, in the second part of the experiment only cello stimuli were presented. Each experimental session (200 decisions) lasted from 20 to 25 minutes. Altogether 18 persons participated in this experiment, 10 women and 8 men aged between 16 and 55 years. Before the test they were given instructions and, subsequently they had to fill out a questionnaire. The questions of age, sex, being a car- or motorcycle-driver, using vibrating machines, visiting discotheques, being "musical" and playing a musical instrument should inform, if the subjects were familiar with vibrations and/or music. The results should describe nearly a normal-distribution round the Point of Subjective Simultaneity (PSS). To test the significance of the results, the Chi-Square-Test was used.

Results and Explanations

The result of the organ music stimuli is that a trend is visible; at a time-delay of around -135ms most of the subjects judged the stimuli as synchronous. The groups of specialists differ a little bit: the "car-drivers", "instrument-players" and "friends of classic-music" choose a PSS of about -175 ms as the best. The cello stimulus is more plain (see figure 2): The trend is of about -29 ms, the groups "musical", "friends of classic-music" and "men" show PSS of -52 ms, -66 ms and -43 ms respectively.

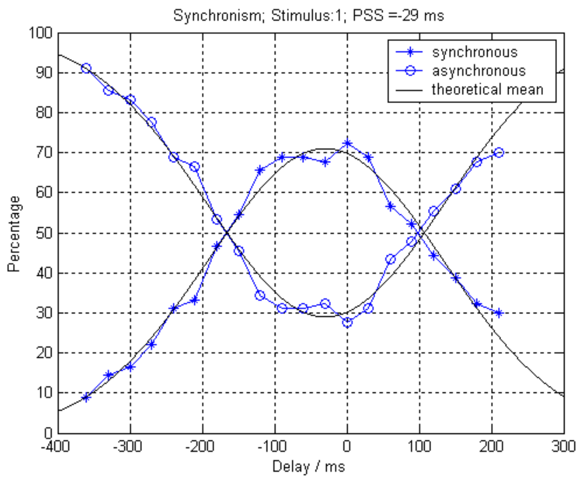

Figure 2: Test-results of the cello-stimulus.

The most important investigation is that the point of subjective simultaneity and the point of objective simultaneity do not coincide. This fact and the result that there are some differences in the PSS of different groups lead up to the question: How does the perception of audio-tactile synchronism work? The time series shows that there must be an influence of detecting the signal's beginning or the peaks of audible and tactile stimuli. Another perspective is given by the mathematics: The cross-correlation function (CCF, Eq.1) describes the similarity of two time-signals; applying this function to these pairs of stimuli yield the following values: The tactile organ-stimulus is most similar to the audible one when delayed about -119 ms, the tactile violoncello-stimulus is most similar to the audible one by delaying about -59 ms. The results of the median-values of the psychophysical tests are very similar to this. The exploration of the specialist-groups shows, that those subjects, who were more familiar with this type of music and stimuli, mainly detected the synchronism by the peaks of the signal, while the "mean-subject" detected it by using a mechanism similar to the cross-correlation-function.

$$R_{s,g}(\tau) = \int_{-\infty}^{+\infty} s(t) \cdot g(t+\tau) dt \qquad (1)$$

Using the cross-correlation-function with the stimuli of Altinsoy, Blauert, and Treier [4] shows that there are some common aspects; but their stimuli had a length of maximum 300 ms; maybe the synchronism detection shows some other aspects there because the stimuli are not in the sense of "musical consonance".

Summary

1) The most important result is that the PSS and point of objective simultaneity do not coincide, neither by organ, nor by cello music. This fact is important for implementing a virtual-reality; no original structure-born sound recording is needed to get a high accordance of audible and tactile stimuli. 2) The perception of audio-tactile-synchronism in a musical-context seems to work similar to the cross-correlation function. 3) Subjects who were familiar with these types of music or stimuli detect the synchronism by the signal's peaks and valleys. 4) There are similarities to the "Gestalt-principle"; prominent characteristics of the underlying structures (peaks and valleys) are determining, as well as the similarity (CCF).

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