

Vibrotactile stimulation *vs.* subwoofer : enhancement of car audio frequency response

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INSA-Lyon and LVA ?

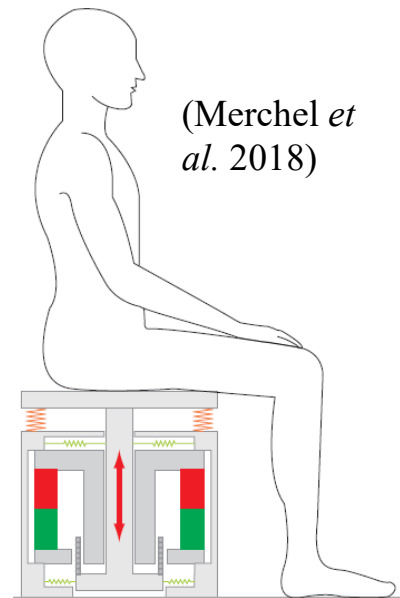
- INSA-Lyon : engineering school, applied sciences.
 - Approx. 5000 undergraduate and master students, plus approx. 550 PhD students.
- Laboratoire Vibrations Acoustique
 - 14 research staff, ~25 to 30 PhD students
 - 4 research topics : vibroacoustics, inverse problems, NDT&SHM, noise and vibration perception
- Lyon Acoustics Center (CeLyA)
 - Network of the acoustics labs in Lyon (aeroacoustics, vibroacoustics, bioacoustics, neurosciences, ultrasound medical applications...).
 - Approx. 95 research staff.

Vibrotactile stimulation

- Vibrotactile stimulation can :
 - (slightly) increase the loudness of sound (Schürmann *et al.* 2004, Merchel *et al.* 2011)
 - Increase the overall quality of music reproduction (Merchel 2018)
 - Increase the emotional response to horror films (Branje *et al.* 2014)



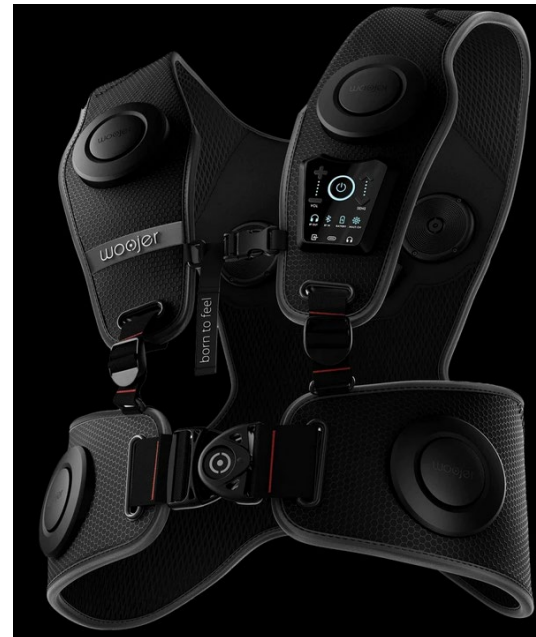
(Schürmann *et al.* 2004)



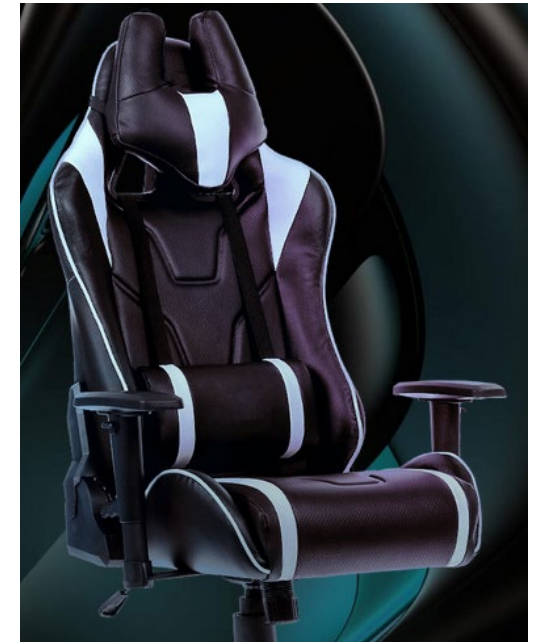
Emotichair
(Branje *et al.* 2014)

Entertainment applications

- Claim to :
 - provide a new high-resolution immersive experience to all media.
 - transfer deep bass frequencies to create an immersive, physical, full-body experience.
- A perfect companion for gaming, movies, VR and music.



Woojer.com



Subpac.com

Application to car audio ?

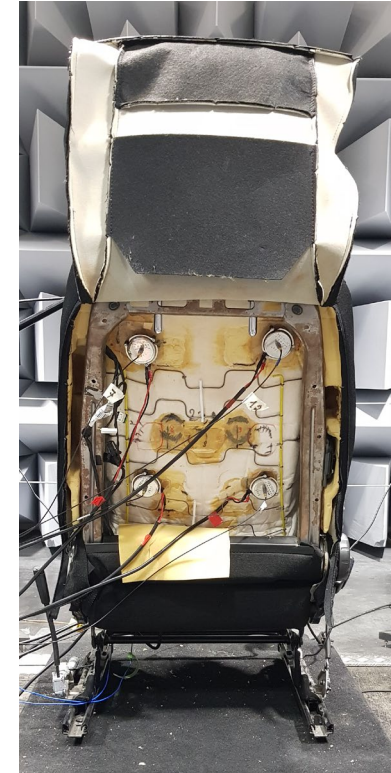
- In the low-frequency range (below 60 Hz), standard car radio loudspeakers have a poor efficiency.
- Additional subwoofers are expensive and take up space in the trunk.
- Question : can vibrotactile stimulation be used instead of subwoofers ?
- This study was funded by Stellantis (PSA, Fiat-Chrysler...)

Overview

- Experimental set-up
- Procedure
- Results

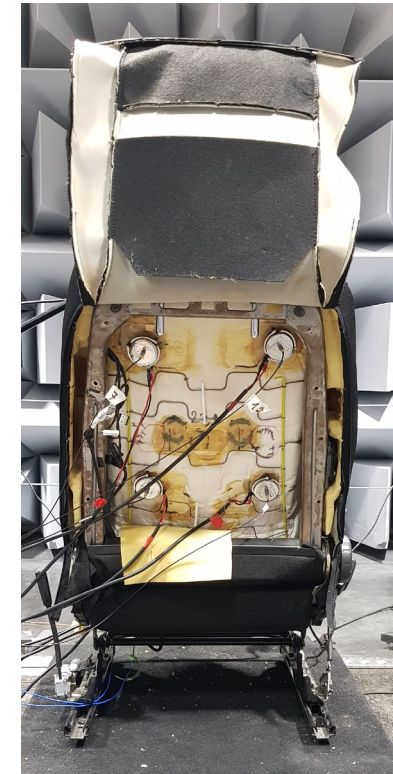
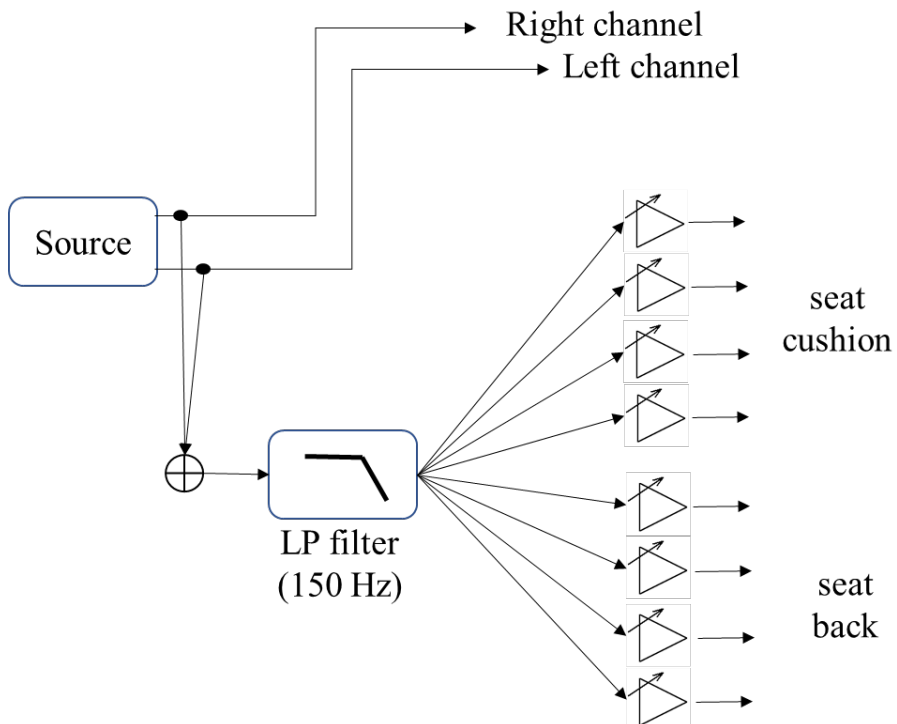
Experimental set-up

- Car seat equipped with 8 vibrators
 - Tectonic TEAX32C30-4/B (130 g, $f_0 \cong 260$ Hz)
 - 4 on the cushion, 4 on the back



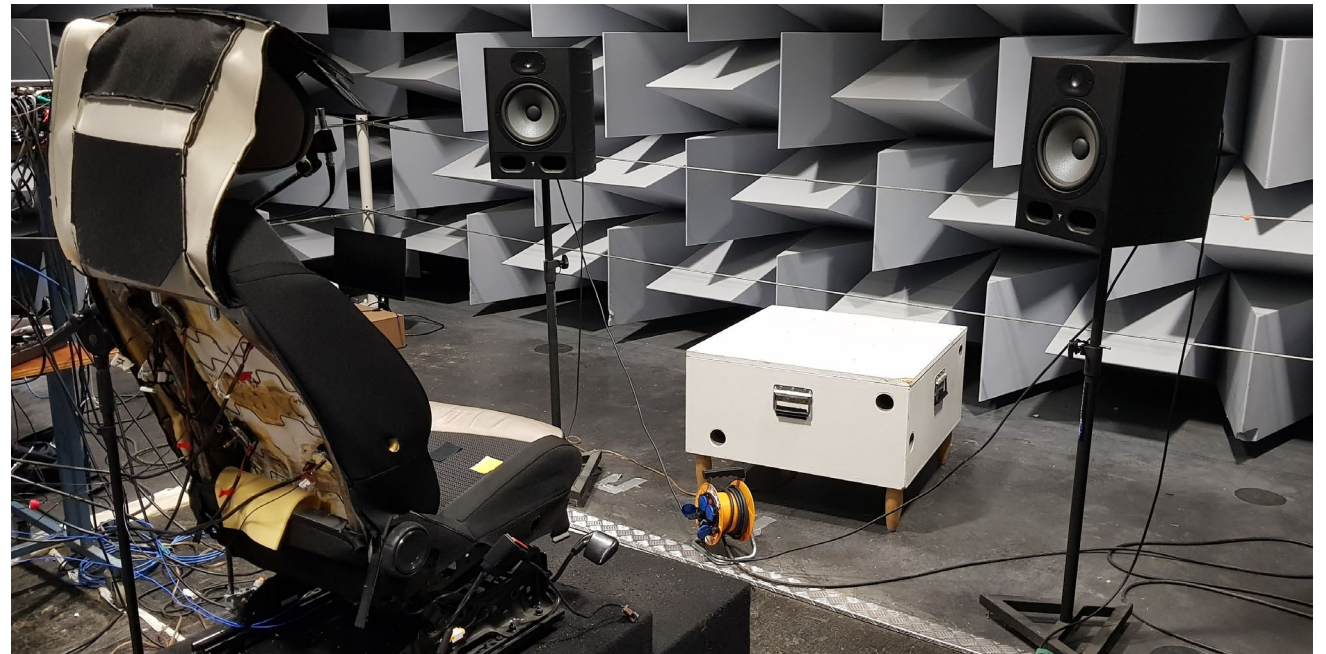
Experimental set-up

- Car seat equipped with 8 vibrators
 - Tectonic TEAX32C30-4/B (130 g , $f_0 \cong 260\text{ Hz}$)
 - 4 on the cushion, 4 on the back
 - Fed with the low-frequency content of audio signal



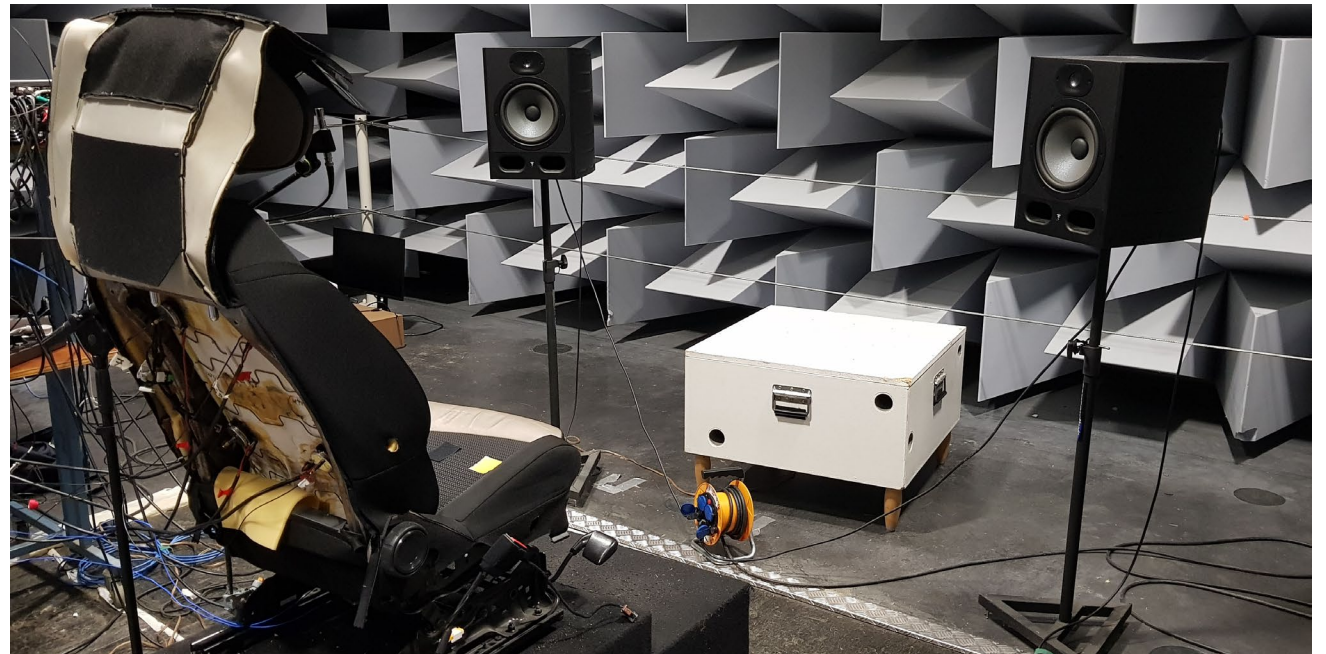
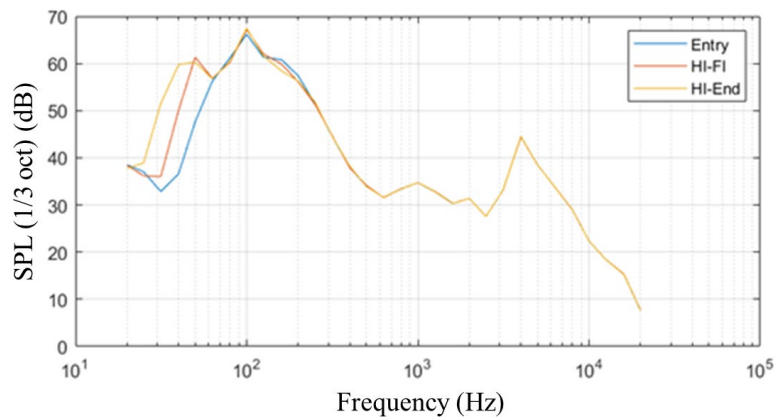
Procedure

- Comparison of 6 audio configurations :
 - 2 HP (basic stereo setup) : reference
 - Low efficiency below 80 Hz







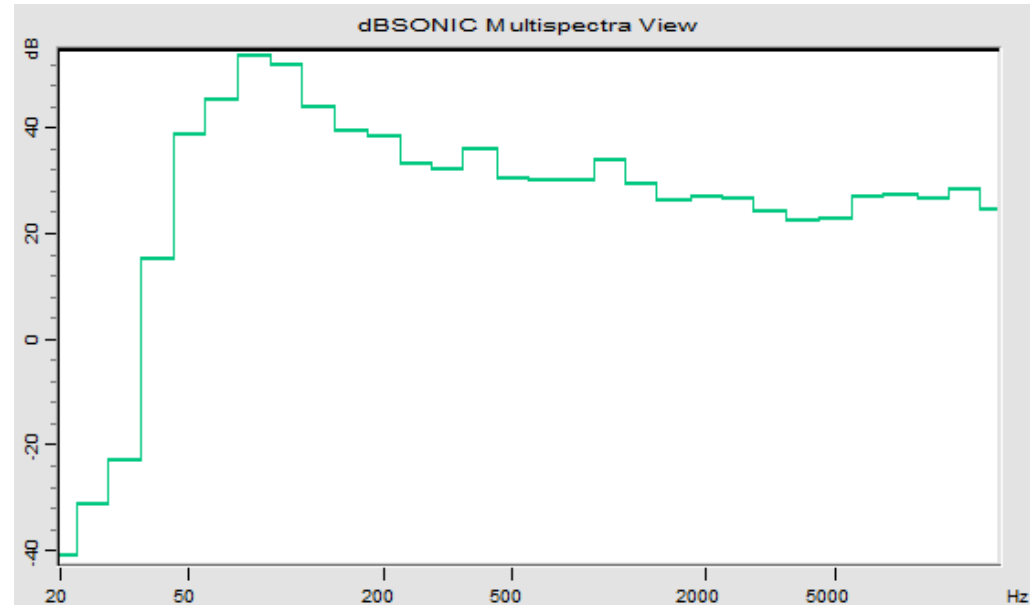
Procedure

- Comparison of 6 audio configurations :
 - 2 HP (basic stereo setup) : reference
 - 2 HP + vibrotactile stimulation (0 dB : level adjustment through informal exp.)
 - - 3 dB
 - 0 dB
 - + 3 dB
 - 2 HP + subwoofer
 - "Hifi" (50 Hz)
 - "Hi-end" (40 Hz)



Procedure

- Comparison of each configuration with the base one (including base vs. base)
- 4 musical excerpts (with low-frequency content, 30 to 48 s.) :
 - Slapping bass 
 - Cello 
 - Drums 
 - Rap 



Procedure

- Comparison of each configuration with the base one (including base vs. base)
- 3 perceptual dimensions :
 - **Bass performance**
 - in which configuration can you hear the low frequencies more clearly ?
 - **Feeling of immersion**
 - in which configuration can you feel most being part of the sound scene ?
 - **Overall evaluation**
 - Which configuration do you prefer ?
- Possible answers :
 - A, B, equal.

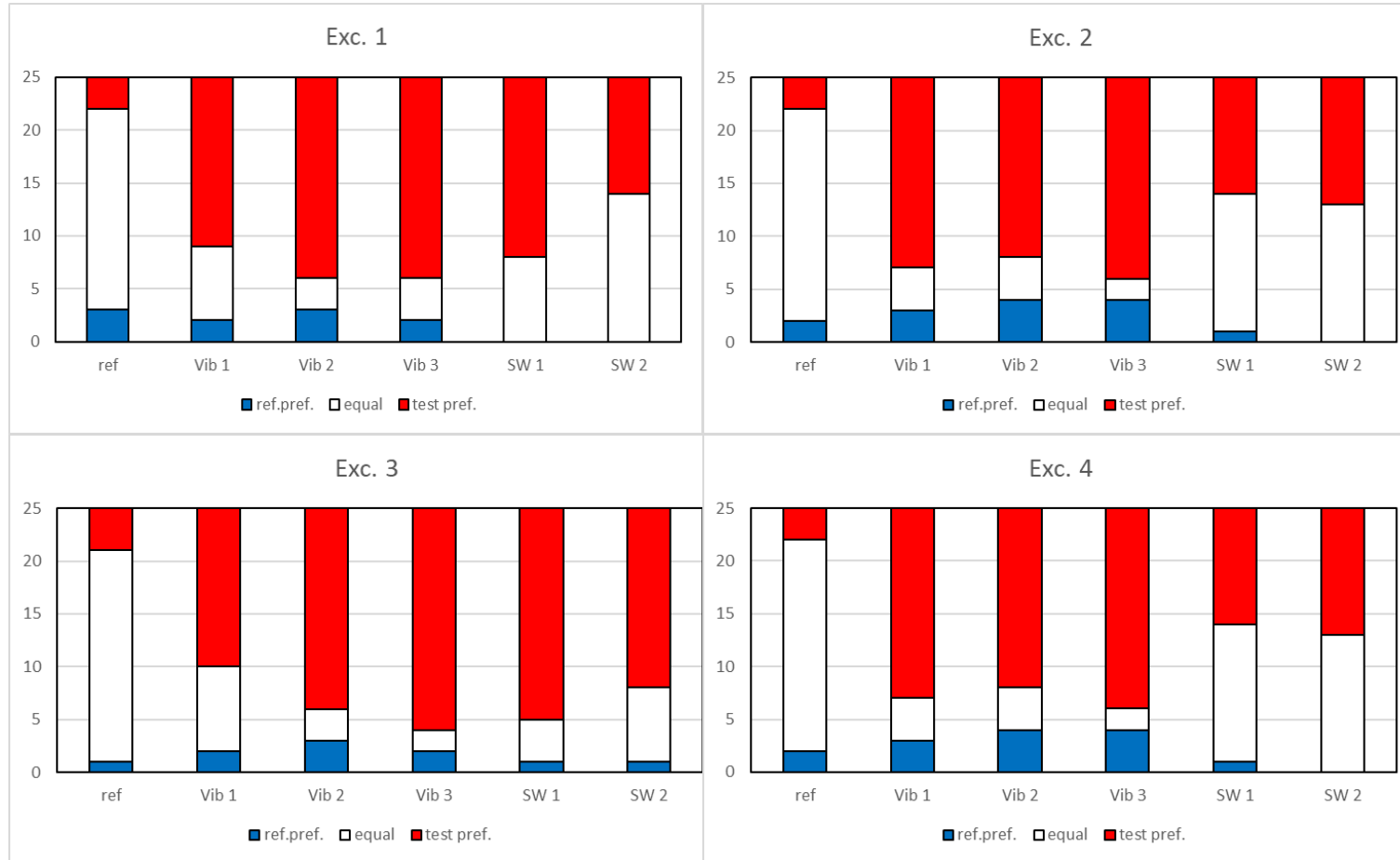
Procedure

- Comparison of each configuration with the base one (including base vs. base)
- Experience conducted with Max/Msp.
 - Synchronised switch between base config. and test config.
 - Random assignement of configurations.
- Participants :
 - 25 young NH people (students, 18 men and 7 women)



Results : Bass performance

Number of answers



- Test configuration is preferred
- No preference
- Ref. configuration (2 loudspeakers) is preferred

- Bass performance is increased by the vibrators (and subwoofers)
- Similar results are obtained for the four musical excerpts

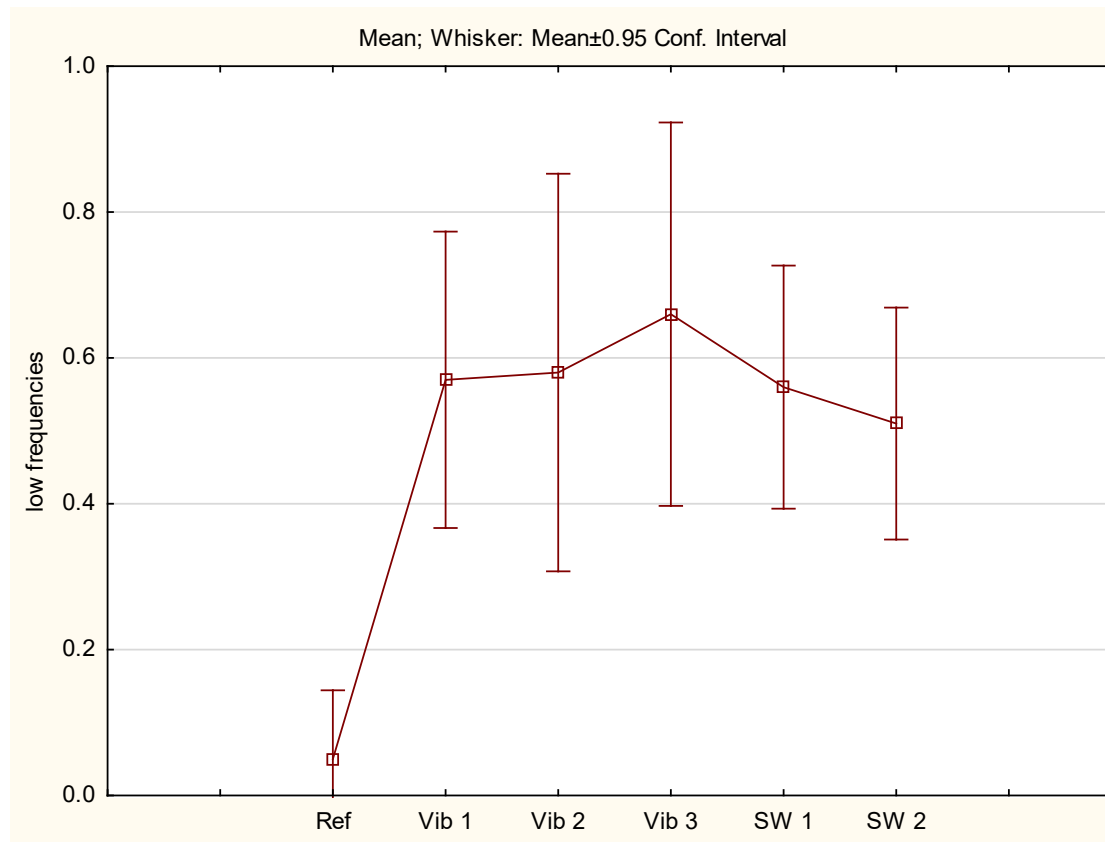
Results

- Individual answers averaged over the four musical excerpts
- RM-Anova,
 - 2 within-subjects factors : **perceptual dimension** (3 levels : bass/immersion/overall quality) and **configuration** (6 levels : ref., Vib 1, Vib 2, Vib 3, SW 1, SW 2).
 - Jasp, Greenhouse sphericity correction

	Sum of squares	df	Mean Square	F	p
Percept. dim.	5.572	1.636	3.405	9.693	< 0.001
<i>Residuals</i>	13.796	39.271	0.351		
Configuration	14.722	2.033	7.241	11.031	< 0.001
<i>Residuals</i>	32.031	48.798	0.656		
Percept. Dim. * Configuration	7.101	3.573	1.987	5.683	< 0.001
<i>Residuals</i>	29.989	85.760	0.350		

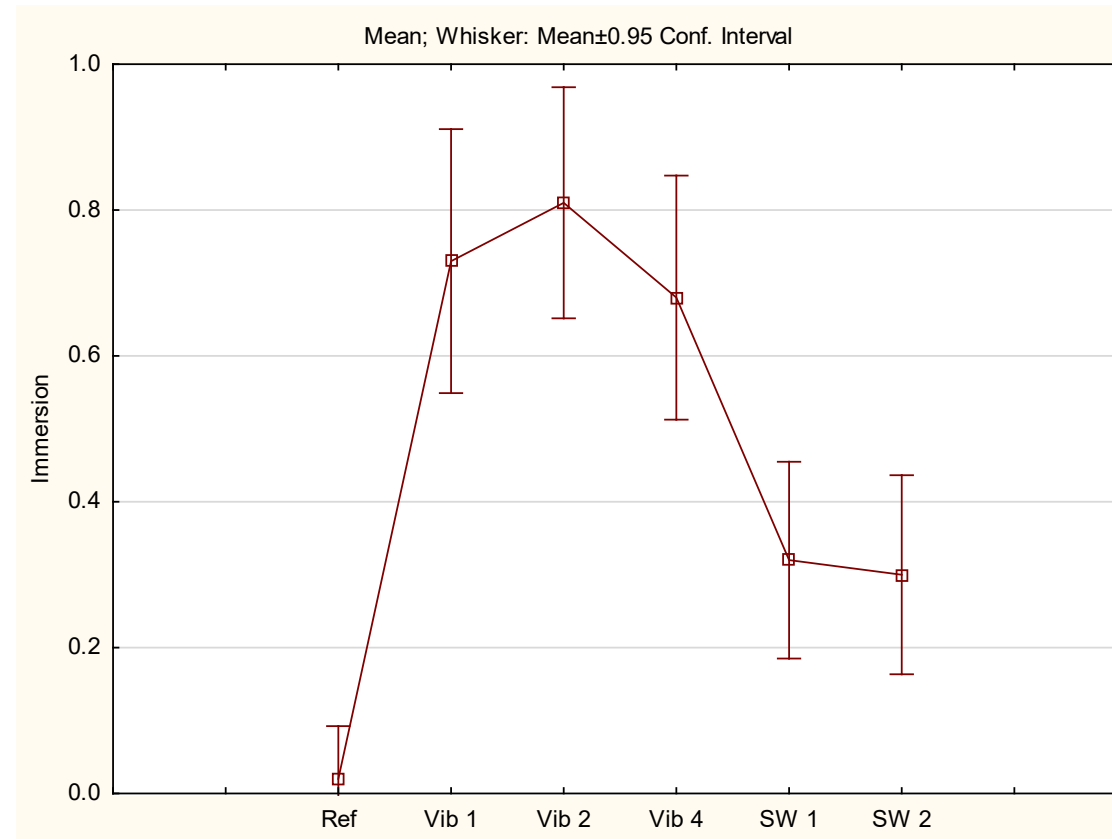
Results overview (1)

- Additional systems (vibrators or subwoofers) significantly improve bass performance



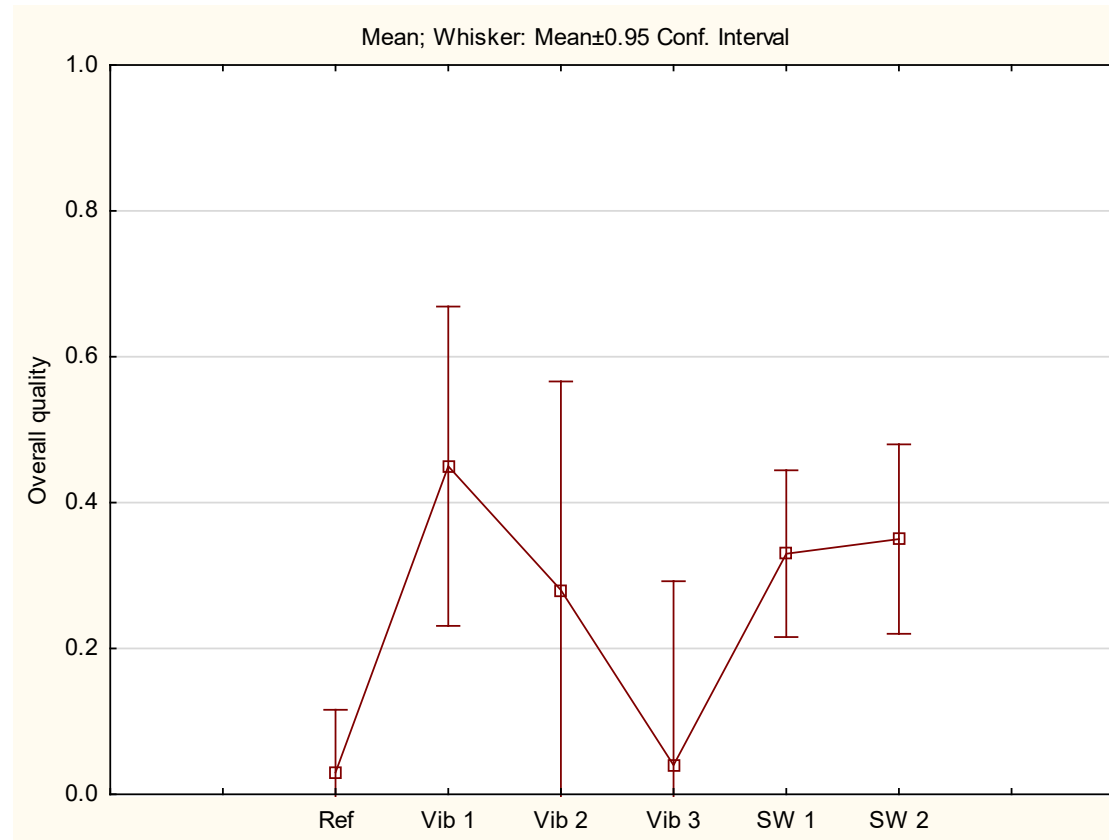
Results overview (2)

- Vibrotactile stimulation enhances feeling of immersion



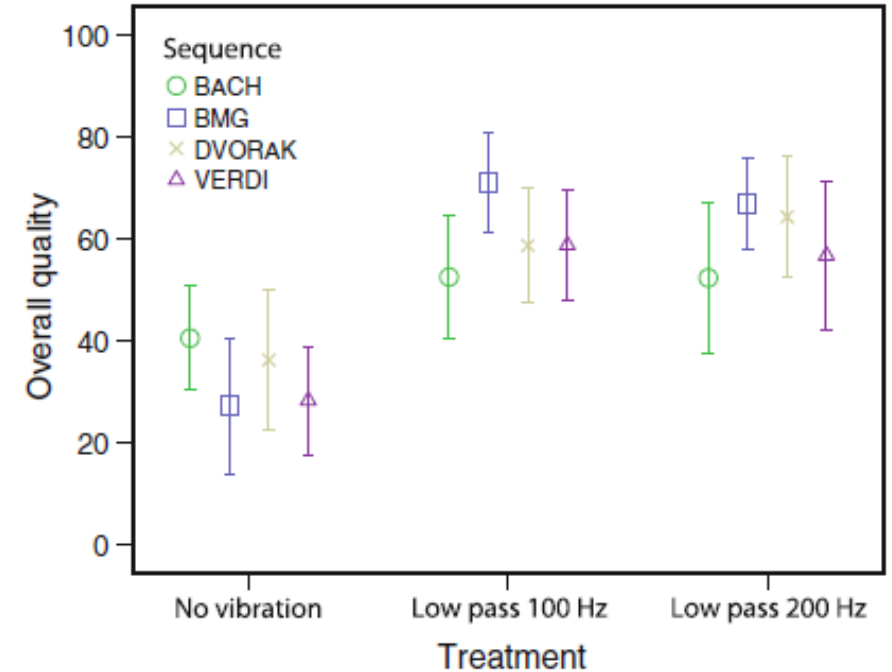
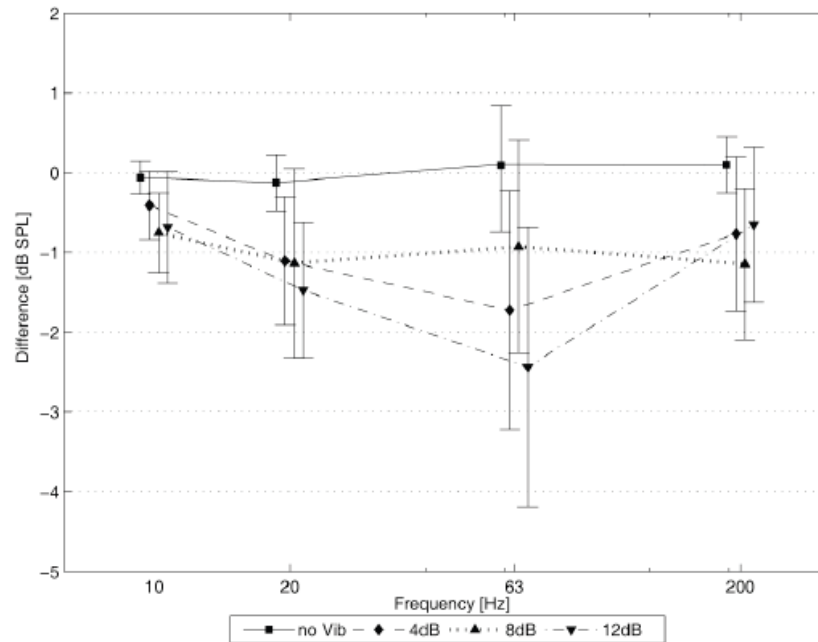
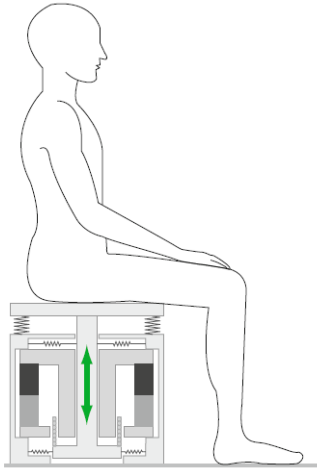
Results overview (3)

- Vibration stimulation (lowest level) increases the overall quality of the system (smaller improvement).



Comparison to Merchel's results (2011 and 2014)

- WBV increase loudness of low-frequency pure tones
- WBV increase overall quality of music reproduction



Conclusion

- Vibrotactile stimulation can enhance the quality of audio reproduction in cars (bass performance, feeling of immersion)
 - Up to a given level !
- This could be a substitute to additional sub-woofers.
- Vibrotactile stimulation could also be used to convey other information (e.g. warning signals, which may be associated to a localization).

Thank you for your attention !

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- S. Merchel, A. Schwendicke, & Altinsoy, M. E. (2011). Feeling the sound: audio-tactile intensity perception. In *Proceedings of 2nd Polish-German Structured Conference on Acoustics, The 58th Open Seminar on Acoustics (Jurata, Poland)*.
- C. Branje, G. Nespoil, F. Russo & D. Fels (2014). The effect of vibrotactile stimulation on the emotional response to horror films. *ACM Computers in Entertainment* 11(1), article 5.
- S. Merchel & E. Altinsoy (2014). The influence of vibrations on musical experience. *J. Audio Eng. Soc.* 62(4), 1-16.
- S. Merchel & E. Altinsoy (2020). Psychophysical comparison of the auditory and tactile perception : a survey. *J. of Multimodal User Interfaces* 14:271-283

- Open PhD position ! Influence of EV interior noise on driver's behaviour
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