# Vibrotactile Stimulation Can Affect Auditory Loudness: A Pilot Study

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**Abstract.** Very few cases have been reported where tactile stimulation affects auditory perception. In this pilot study, we asked volunteers to compare the loudness of combinations of vibrotactile and auditory stimuli. A 50-300 Hz band-limited pink noise signal was used as the stimulus in the two modalities, simultaneously heard through headphones and felt in the hands to be compared to when it was heard only. On average, the same auditory stimulus was judged to be about one dB louder when it was simultaneously heard and felt rather than when it was heard only. This condition could be interpreted as having enhanced the perception of loudness by a whole JND.

**Keywords:** Tactile-Audio Interaction, Loudness Perception, Crossmodal Interaction.

## 1 Introduction

There is a large pool of reported interaction effects between touch, audition and vision. They concern perceived stimulus localization, size, orientation, temporal order, roughness, numerosity, and other low-level perceptual dimensions. They also concern, among others, tasks and processes that include attention, attribute discrimination, recognition, or memory. Focusing on interactions between audition and touch, in their greatest majority, these studies reveal an impact of audition on tactile perception, e.g. [1,2,3,4].

Nevertheless, few instances of effects where touch could bias audition have been described. To the best authors' knowledge, reports of such cases are limited to spatial attention effects [5] and to task-irrelevant event counting [6]. There is evidence, however, that touch and audition share common neural machinery in healthy subjects [7,8], which suggests that touch may be similarly able to influence auditory perception, provided that the proper conditions are created.

A basic perceptual attribute of many stimuli is intensity. In audition, there is a specific term, loudness. In touch, no such term exists to refer to the magnitude of a vibration sensation on the skin [9]. Here, for simplicity, we use the term 'loudness' to refer both to the magnitude of vibration sensations and the perceived intensity of sounds.

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We wondered whether we could find a condition where touch affected audition. Using initially a staircase procedure, we performed a series of preliminary experiments to explore various combinations of signals that were felt through a high-quality vibrotactile transducer and heard through high-quality earphones. The combinations of type of signals, continuous, impulsive, ecological, environmental sounds, voices, musical, band-limited, full range, and so-on is immense. We eventually felt that a band-limited (50–300 Hz), $1/f$ pink noise, that is pleasant to feel and to hear, perhaps because it frequently occurs naturally [10], was promising and we used this same signal to stimulate both touch and audition. Here, we compared the perceived loudness of this stimulus when it was heard to when it was heard and felt simultaneously.

## 2 Methods

*Conditions.* We employed a constant stimulus procedure to measure the subjective equivalence of loudness in the auditory-only condition, A-A, versus in the auditory-plus-tactile condition, A-AT. To account for possible order effects, each condition was tested in separate sub-conditions. For A-A testing there was the Ar-Ac sub-condition where the reference stimulus was presented before the comparision and the Ac-Ar sub-condition where the comparison stimulus was presented first. Similarly, there were the sub-conditions ATc-Ar, ATr-Av, Ac-ATr, and Ar-ATc for A-AT testing.

*Apparatus.* The apparatus comprised a generic laptop computer with two audio channels, running the Pure Data freeware (`http://puredata.info/`) to synthesize the stimuli. One audio channel powered the two sides of high-quality headphones (EX-29, DirectSound Headphones LLC, St. Louis, MO, USA) popular with studio musicians, providing 29 dB of passive acoustic isolation. The other channel was connected to an audio amplifier (model PCA1, Pyle Audio, Brooklyn NY, USA) driving a vibrotactile transducer (Haptuator, Tactile Labs, Saint-Bruno, Québec, Canada) concealed in a box, see Fig 1a. This transducer, in contrast with most common types, provided a nearly flat voltage-to-acceleration transfer function in the entire vibrotactile range when applied to an inertial load [11]. The box itself, size 60 × 70 × 22 mm, see Fig 1b, was machined out of solid black polyoxymethylene plastic and weighted about 200 g. Due to its weight, it provided a vivid sensation of vibration activity [12], and its solid construction precluded any modal response. The box had a neutral visual aspect, a smooth tactile finish, and it did not reveal its function in any way.

*Participants.* Four volunteers, 26 to 39 years old, contributed their time. They did not report any known auditory or tactile deficits. They did not know the purpose of the experiment.

*Stimuli.* The pink noise signal was band-pass filtered in the range 50 to 300 Hz with second-order roll-ffs at either ends of the range. The reference signal magnitudes were 50 dB SPL for the auditory stimuli and 2 $m/s^2$ for the box vibration.

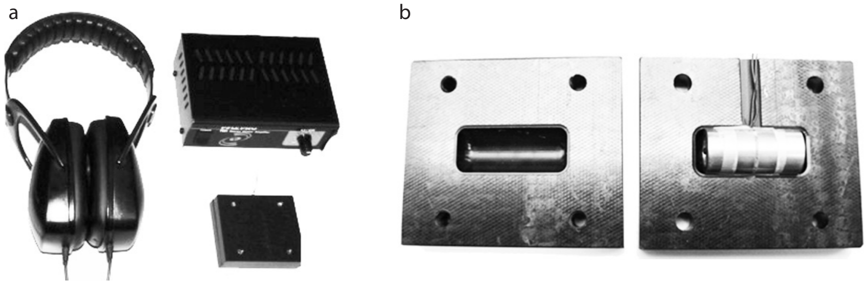


**Fig. 1.** Main components of the apparatus. a) Headphones, amplifier and vibration box. b) The vibration box was made of two halfs with a cavity where the vibrotactile transducer could fit suggly.

The comparison stimuli had the levels -3, -2, -1, 0, 1, 2, 3 dB for audition and touch relatively to the reference. All trials had the following structure. The reference (respectively comparison) stimulus was played for two seconds, followed by a one-second silence, then by a two-second comparison (respectively reference) stimulus.

*Procedure.* The volonteers were introduced to the procedure and instructed to report which of the two stimuli, the first or the second, was the loudest, focusing on comparing the loudness of the stimulus experience alone to the same stimulus experienced in combination. They reported their judgement to the experimenter who entered it in the data base. They sat in a chair, donned the headphone, wore a vision-blocking mask, and held the vibration box, cupping both hands around it.

*Protocol.* A session combining audition and touch to compare with audition only comprised 140 randomized trials, with each of the 7 comparisons presented 10 times first and 10 times last. A session comparing audition to audition and 5 stimulus presentations in one order and 5 in the other order, for a total of 70 trials. Producing an answer took less than 10 seconds, on average.

## 3 Results

The results of the condition Ar-Ac were not significantly different from those of Ac-Ar. Similarly the results of the conditions ATc-Ar, ATr-Av, Ac-ATr, and Ar-ATc were not significantly different from each other. The raw data were merged by main conditions, reducing the results to those of a A-A condition to be compared to a A-AT condition. The data averaged across participants were fitted with cumulative Gaussian functions, $f(s, \sigma, \mu) = 1/\left(\sigma\sqrt{2\pi}\right) \int_{-\infty}^{s} \exp\left[(x-\mu)^2/(2\sigma^2)\right] \mathrm{d}x$, where $s$ is the comparison loudness, $\mu$ is the point of subjective equivalence and $\sigma$ is the 84% discrimination threshold (using Matlab™).

Figure 2 shows the individual results of the four participants for the two conditions A-AT and A-A and with the raw data merged by main condition.

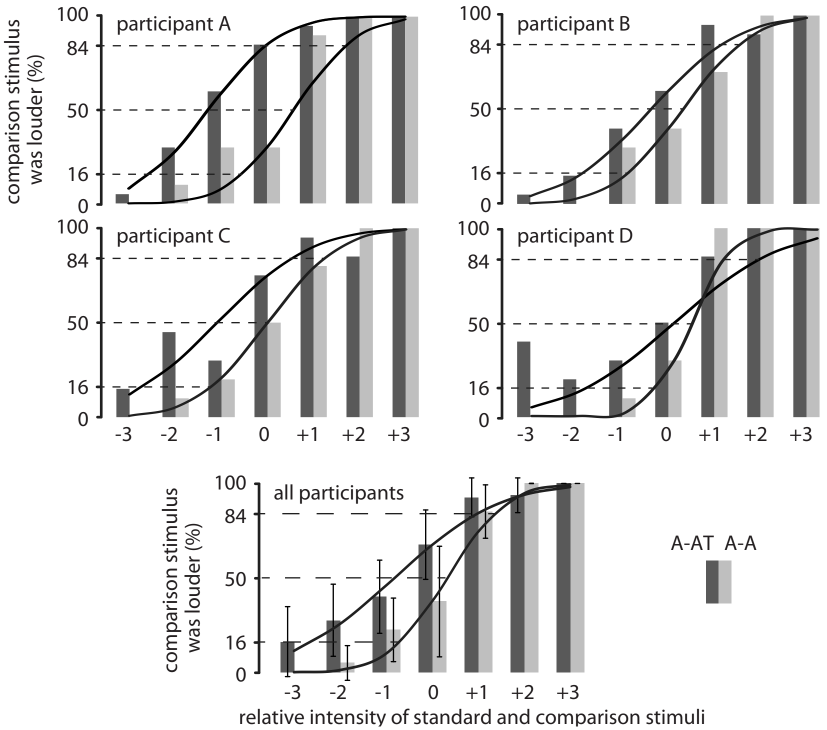


**Fig. 2.** Top panels, individual results of the four participants by main conditions. Bottom panel, merged results of all partcipants by main conditions.

## 4 Discussion

As could be expected, the auditory-auditory condition reproduced the classic result of the human discrimination performance of complex sound loudness of about 1 dB [13]. When the auditory stimulus was compared to the auditory-plus-tactile stimulus, however, there were three visible differences.

The first difference is the point of subjective loudness equivalence that was shifted by about 1 dB, that is, by a whole auditory JND, which is interesting since the participants heard the same auditory stimulus but perceived it to be louder. The second difference is that the JND was increased from 1 dB to a little less than 2 dB. The third difference, which is the combined results of the two previous, is that the two curves do not 'start' at the same relative intensity but 'finish' as the same relative intensity.

From these results we can conclude that we have discovered an instance where tactile stimulation can modify auditory perception, a phenomemon that, we believe, has not been mentioned before. An auditory stimulus was heard to be louder when combined with the same vibratory stimulus felt in the hand. With combined stimulation it harder to discriminate auditory loudness, however.

In everyday life, vibrations are picked up through audition as well as by touch. The shift in perceived intensity can be interpreted in terms of 'cue combination' since the *exact* temporal synchrony of the signals ensured by our apparatus, see [11], informed the brain that the stimuli came from the same source. Accepting such interpretation would imply that humans suffer from a lack of perceptual constancy when judging the intensity of vibrations through different modalities.

Alternatively, it could be equally argued that the laboratory conditions in which we put the participants prevented them to perform efficiently in terms of perceptual constancy. More detailed experiments and finer control of the stimuli are needed to be carried out to decide between these possibilities.

The conditions that we have used to obtain the present results deprived the participants from the sources of information normally at their disposal. One comes from vision and the other from motor behavior, both of which were eliminated here. We anticipate that in future experiments accounting for them, these two sources of information could impact the results significantly. Asking the participants to look at an object, to hold it in the hand, and locating the source of sound in the object itself, would reinforce the prior assumption of a common source of vibration.

We anticipate an even stronger impact tactile inputs on auditory judgement resulting from active motor behavior. Dragging an object against a surface would create new correlates the between sources of information, namely movement speed, mechanical power expenditure, and others, which could be extremely informative to the perceptual system. The reader can easily verify the impact of audition on roughness perception for her or himself under 'active conditions' by performing the procedure described in [14, Section 2.4].

It is difficult to compare our results to other related studies aimed at testing the converse hypothesis, namely that audition can impact tactile perception. One such well-known study is that of Jousmäki and Hari and the follow-up of Suzuki et al. [1,4]. The use of a psychophysical magnitude estimation method, however, makes it difficult to compare the results.

In closing, we would like to point out that the conditions in which we put the participants strongly resemble those in effect during interaction with a mobile device that can be heard and felt, but not seen. As a result, the combination effect that we have described, and related ones, for example during the interpretation of speech, could prove to be quite useful in actual applications in technological devices.

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## References


1. Jousmäki, V., Hari, R.: Parchement-skin illusion: sound-biased touch. Current Biology 8(6), 190–191 (1998)
2. Guest, S., Catmur, C., Lloyd, D., Spence, C.: Audiotactile interactions in roughness perception. Experimental Brain Research 146(2), 161–171 (2002)
3. Bresciani, J.-P., Ernst, M.O., Drewing, K., Bouyer, G., Maury, V., Kheddar, A.: Feeling what you hear: auditory signals can modulate tactile tap perception. Experimental Brain Research 162(2), 172–180 (2005)
4. Suzuki, Y., Gyoba, J., Sakamoto, S.: Selective effects of auditory stimuli on tactile roughness perception. Brain Research 1242, 87–94 (2008)
5. Caclin, A., Soto-Faraco, S., Kingstone, A., Spence, C.: Tactile "capture" of audition. Perception & Psychophysics 64(4), 616–630 (2002)
6. Bresciani, J.P., Ernst, M.O.: Signal reliability modulates auditory-tactile integration for event counting. NeuroReport 18(II), 1157–1161 (2007)
7. Kayser, C., Petkov, C.I., Augath, M., Logothesis, M.K.: Integration of touch and sound in auditory cortex. Neuron 48(2), 373–384 (2005)
8. Zangaladze, A., Epstein, C.M., Grafton, S.T., Sathian, K.: Involvement of visual cortex in tactile discrimination of orientation. Nature 401, 587–590 (1999)
9. von Békésy, G.: Similarities between hearing and skin sensations. The Psychological Review 66(1), 1–22 (1959)
10. Ward, L.M., Greenwood, P.E.: 1/f noise. Scholarpedia 10(1537), 2
11. Yao, H.-Y., Hayward, V.: Design and analysis of a recoil-type vibrotactile transducer. Journal of The Acoustical Society of America 128(2), 619–627 (2010)
12. Yao, H.-Y., Grant, D., Cruz-Hernandez, M.: Perceived vibration strength in mobile devices: the effect of weight and frequency. IEEE Transaction on Haptics 3(1), 56–62 (2010)
13. Moore, B.C.J.: An introduction to the psychology of hearing. Elsevier, London (2004)
14. Hayward, V.: A brief taxonomy of tactile illusions and demonstrations that can be done in a hardware store. Brain Research Bulletin 75(6), 742–752 (2008)