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# Hands help hearing: Facilitatory audiotactile interaction at low sound-intensity levels

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Auditory and vibrotactile stimuli share similar temporal patterns. A psychophysical experiment was performed to test whether this similarity would lead into an intermodal bias in perception of sound intensity. Nine normal-hearing subjects performed a loudness-matching task of faint tones, adjusting the probe tone to sound equally loud as a reference tone. The task was performed both when the subjects were touching and when they were not touching a tube that vibrated simultaneously with the probe tone. The subjects chose on average 12% lower intensities ( $p < 0.01$ ) for the probe tone when they touched the tube, suggesting facilitatory interaction between auditory and tactile senses in normal-hearing subjects. © 2004 Acoustical Society of America. [DOI: 10.1121/1.1639909]

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Persons with hearing impairment may perceive sounds (including speech) using their sense of touch, either relying on touch alone or on touch combined with aided audition (Gault, 1926; Sherrick, 1984; Weisenberger and Miller, 1987; Lynch *et al.*, 1988; Levänen and Hamdorf, 2001). These findings suggest some shared neural substrates for auditory and tactile perception. Accordingly, a “crosstalk” between auditory and tactile modalities can be demonstrated even in normal-hearing subjects, although such an interaction in everyday life mostly goes unnoticed. For example, tactile exploration of surfaces elicits auditory and tactile input, but the percept is typically dominated by the tactile component (Lederman, 1979). Likewise, when subjects rub their palms together, the tactile input dominates over the concomitant sound. However, as soon as the high frequencies of that sound are accentuated, subjects report a modified tactile percept (the “parchment-skin illusion,” Jousmäki and Hari, 1998).

Here, we quantified audiotactile interaction in normal-hearing subjects whom we asked to adjust the intensity of probe tones to sound equally loud as a low-intensity reference tone. When the subjects touched a tube that vibrated in synchrony with the probe tones, they chose lower tone intensities than without the vibration, suggesting facilitatory audiotactile interaction.

We tested nine subjects (five females, four males; 24–41 years, median 27 years; all but one right-handed, and all normal-hearing by self-report) after informed consent. Pairs of 200-Hz tones (a constant-intensity reference tone of 900 ms and an adjustable probe tone of 500 ms, 100-ms pause in-between; see Fig. 1) were presented binaurally via headphones once every 2 s. The subject was instructed to adjust the probe and reference tones to sound equally loud.

The tones were embedded within a continuous masker (white noise ~60 dB above hearing threshold on one of the authors: constant for all subjects). For each subject, the in-

tensity of the reference tone was adjusted to a level of 10 dB above the individual threshold for detecting the tone within the masking white noise.

The reference–probe pairs were presented in combination with fixed-intensity 200-Hz vibrations, delivered via a vibrating tube simultaneously with the adjustable probe tone. In the “sound & touch” condition, the subject’s left-hand fingers were in contact with the vibrating tube. In the “sound only” condition, the subject did not touch the vibrating tube. Touching the tube resulted in a weak percept of vibration in the fingers. The vibration was equally strong for all subjects: 24–28 dB above tactile threshold, as tested in six subjects separately from the main experiment, with dB values calculated from voltages at tube input.

All subjects were trained to touch the tube in a similar manner (at a marked area, with fingers rather than palm, and without squeezing the tube). In an additional measurement on one of the authors, the perceived vibration varied maximally by 4 dB from gentle to firm touch, a range of grip force much wider than applied in the main experiment. The noise played via the headphones was effective in masking any tube-produced sounds, as was established in pilot experiments on two of the authors.

The subjects first practiced the loudness matching task for 10–20 min and then adjusted the probe during ten sound only and ten sound & touch conditions, presented in an alternating order (sound only, sound & touch, sound only, ..., sound & touch) to minimize adaptation of Pacinian corpuscles to the tactile stimuli. The experimenter measured the adjusted probe amplitude (in rms) as soon as the subject signaled completion of the task. After each trial, the experimenter changed the probe tone to an arbitrary loudness level, either above or below the reference tone. Pauses were given when needed. Depending on the subject, the experiment lasted for 30–90 min.

In the whole group of nine subjects, the adjusted probe tone intensities were weaker in the sound & touch than in the sound only condition (mean difference of the individual median values  $-12 \pm 4\%$ ,  $p = 0.007$ , Wilcoxon’s signed rank

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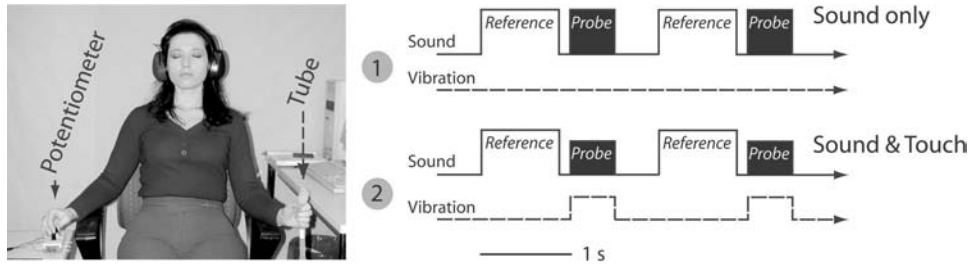


FIG. 1. Left panel: Subject is listening to tones delivered via headphones and simultaneously controlling sound-intensity level with a multiturn potentiometer. Vibratory stimuli are delivered to the subject's left-hand fingers via a blind-ended silicon tube (diameter 16 mm, wall thickness 2 mm) attached to a purpose-built stimulator (loudspeaker in a funnel-shaped housing, not shown, resembling that used by Levänen *et al.*, 1998). Right panel: Pairs of 200-Hz tones (constant-intensity Reference and adjustable Probe), occurring once every 2 s, were embedded within masking white noise and presented via headphones. The 200-Hz vibratory stimuli were driven by the same electrical signals as the probe tones but they were always of constant intensity. The subject touched the tube in the "Sound & Touch" condition but did not touch it in the "Sound only" condition; in both situations the tube, however, vibrated in the same way.

test for paired samples). This difference between the conditions was statistically significant also at individual level in seven out of nine subjects ( $p < 0.05$ , Wilcoxon's rank sum test for independent samples; see Fig. 2). Visual inspection of the data suggested in the adjusted probe tone intensities a weak but statistically nonsignificant tendency to decrease from the first to the last trial (mean decrease 4% as estimated from linear regression; equal trend for sound only and sound & touch conditions).

These data suggest facilitatory audiotactile interaction in normal-hearing subjects when they listen to low-intensity tones embedded within noise. The results agree with tactile input to the auditory cortex, demonstrated with magnetoencephalographic recordings in a deaf human subject (Levänen *et al.*, 1998) and with intracranial recordings in monkeys (Schroeder *et al.*, 2001). More extensive brain-imaging studies are, however, needed to identify the sites of audiotactile interaction in the human brain (Calvert, 2000; Foxe *et al.*, 2002; Lütkenhöner *et al.*, 2002; Gobbelé *et al.*, 2003), and in deciding whether the interaction between sensory modalities

takes place at the perceptual or decision level (Massaro, 1999; Vroomen and de Gelder, 2000)

In everyday life, audiotactile interaction is rarely noticed, but some illusions resulting from modification of the relative saliences of the stimuli may make the interaction evident (e.g., "parchment-skin illusion;" Jousmäki and Hari, 1998; Guest *et al.*, 2002). Additional evidence of audiotactile interaction derives from "tactile capture of audition," in which lateralized sounds can be mislocalized when concomitant tactile stimuli are presented to body midline (Caclin *et al.*, 2002). Moreover, subjects with tactile deficits, e.g., patients using a hand prosthesis after hand amputation, benefit from auditory feedback during tactile exploration (Lundborg and Rosen, 2001). Similarly, in a virtual-reality setup subjects may learn faster to identify texture by touch or may perceive a better quality of match to a test material when complementary auditory information or cues are supplied (Hendrix *et al.*, 1999; Lederman *et al.*, 2003). Thus, auditory input may be important for tactile perception even when it does not reach awareness. In the present study, the low intensities of both auditory and tactile stimuli probably improved our possibilities to detect and quantify the audiotactile interaction in normal-hearing subjects.

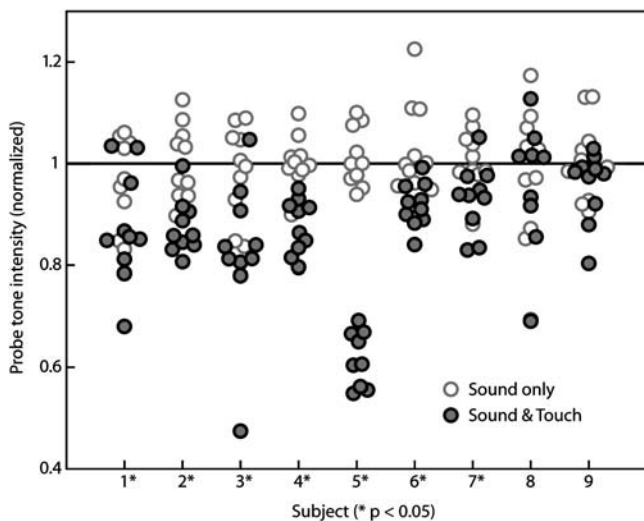


FIG. 2. Probe-rms amplitudes for all nine subjects in all ten "sound only" and ten "sound & touch" trials; the amplitudes were normalized so that each subject's median amplitude in "sound only" trials equals 1.0. The seven subjects in whom the differences between the conditions were statistically significant are marked with asterisks.

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