BINAURAL LOUDNESS OF MOVING SOURCES IN FREE FIELD: PERCEPTUAL MEASUREMENTS VERSUS AT-EAR LEVELS

Sabine Meunier, Sophie Savel, Jacques Chatron, and Guy Rabau
Aix Marseille Univ, CNRS, Centrale Marseille, LMA, Marseille, France 4 impasse Nikola Tesla, CS 40006, 13453 Marseille Cedex 13

Abstract

Most investigations on the variations of loudness with the spatial position of a sound source have been made for static sounds. The purpose of this work was to study the loudness of a moving source. By analogy with studies on difference in loudness between sounds increasing or decreasing in intensity (without movement of the source), we studied the global loudness of a moving sound. The analogy with the sounds whose intensity varies is direct because the at-ear level depends on the position of the source, so a moving sound will create levels that vary over time at the entrance of the auditory canal. We measured the overall loudness of a moving source as a function of the starting and ending positions of the stimulus and of its direction of rotation. Overall, we did not find any overall loudness difference according to the direction of variation of the source. Moreover, the results obtained with a static sound seem to confirm, with absolute magnitude estimation, the amount of directional loudness sensitivity measured previously with an adaptive method.

In free field, loudness depends on the position of the sound source (Sivonen and Ellermeier, 2006). In order to quantify the effect of the incidence angle on loudness, the directional loudness sensitivity (DLS) is measured. DSL is defined as the level difference required for equal loudness between a frontal reference sound (azimuth 0°, elevation 0°) and a test sound at a given position. A negative DLS means that the test sound has been perceived softer than the frontal sound and vice versa. In a previous study, we showed a decrease in DLS with an increase in azimuth of an amount of more than 10 dB on average (25 listeners, Meunier et al., 2016). Different studies have also examined the loudness of sounds that increase and sounds that decrease in level. For sounds that only differ in temporal envelop, it has been shown that the global loudness of a sound whose level increases is greater than the global loudness of a sound whose level decreases (Ponsot et al., 2015a, 2015b). This phenomenon has been called asymmetry in loudness.

When a sound source is moving around a listener, the at-ear level of the sound varies. Moreover, if we refer to the studies on directional loudness, its loudness should also vary. The aim of the work presented here was to explore how global loudness of moving sounds is formed and the main point was to determine whether there is an asymmetry between sounds that move in opposite directions as their level and loudness also vary in opposite directions.

Experiment

Ten normal-hearing listeners participated in the experiment.

The loudness of moving sounds was measured in an anechoic room. The Vector Amplitude Base Panning (VBAP) method was used (Pulkki, 1997). It consisted in creating virtual sources from several loudspeakers situated at equidistance from the listener head in varying the gain of each loudspeaker. With this technique it was possible to move the sound around the listener. The speed of the movement was constant. The stimuli used for the experiment were a third-octave noise band centered at 5 kHz and white noise (140-17 000 Hz) of duration 2 s. The levels were 45, 50, 55, and 60 dB SPL. They were measured in the absence of the listener at the theoretical center of the head. The experiment was realized in the horizontal plan (elevation = 0°). The azimuths of the third-octave-band stimulus were either fixed at 75 or 135° (static sources) or varied from 75 to 135° and inversely (moving sources). For the white noise, the static positions were 45, 75, 135 and 150°, and the sound moved from 45 to 150° (and inversely) and from 75 to 135° (and inversely). These positions were chosen in order to produce different at-ear levels and different loudness levels when the stimulus varied in azimuth. For the third-octave-band stimulus, the directional loudness sensitivity decreased by about 8 dB from 75 to 135°; the at-ear level decreased by about 9.5 dB on the right ear (ipsilateral) and varied by less than 2 dB on the left ear (contralateral). For the white noise, the directional loudness sensitivity decreased by about 2.5 dB from 45 to 150° and by about 2 dB from 75 to 135°. The at-ear level decreased by about 6 dB on the right ear from 45 to 150° and by about 4 dB from 75 to 135°. It varied by about 4 dB on the left ear from 45 to 150° and by less than 1 dB from 75 to 135°. The at-ear levels were measured with blocked ear canals for all loudspeaker positions and all listeners. The values given above correspond to the average of the measurements made previously (Meunier et al., 2016) on the 10 listeners of the present work. The loudness was evaluated using an absolute magnitude estimation procedure. One block consisted of all conditions for one stimulus (static and moving sources at the 4 different levels). Each condition was repeated 3 times. A block was repeated once. Thus, for one listener and one condition the loudness was the geometric mean of 6 estimates. A training block was also run for each stimulus.

Results

The geometric means of the 10 listeners are shown in figures 1 and 2. There was no significant effect of the direction of variation on the estimates either for the third-octave-band stimulus [$F(9,1)=0.013$, $p=0.91$] or for the white noise [$F(9,1)=3.33$, $p=0.1$ for 45-150° ; $F(9,1)=0.32$, $p=0.58$ for 75-135°].

For the third-octave-band, a post-hoc LSD showed significant differences between the estimates of the static sounds at 75° and the other conditions ($p<0.001$) and no significant differences between the three other conditions. Whatever the direction of movement, the estimates of the moving sounds corresponded to the estimate of the sound at the position of 135° which was the softest sound.

For the white noise, there were no significant differences between all conditions.

For the static sounds, we found almost the same difference in level between sounds of different positions that were equally loud using an absolute magnitude estimation method (figures 1 and 2, left panels: 6 dB for the third-octave-band, 2 dB for the white noise between 45 and 150° and 1.8 dB for the white noise between 75 and 135°) and using an adaptive method to measure the DLS (figures 1 and 2, right panels : 7 dB for the third-octave-band, 2.5 dB for the white noise between 45 and 150° and 2 dB for the white noise between 75 and 135°).

The exponents of the loudness functions seem to be independent of the sound source position and of the movement (figures 1 and 2, left panels). They were around 0.25 for the third-octave band stimulus and around 0.29 for the white noise.

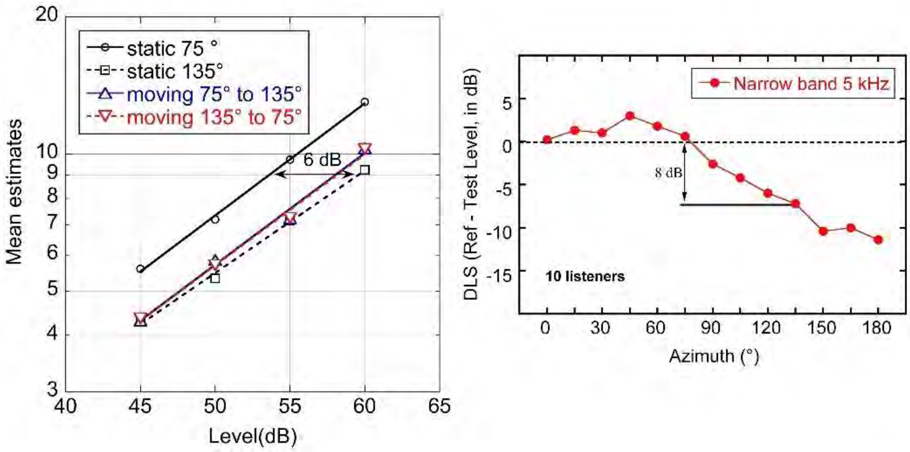

Figure 1. Geometric means (10 listeners) of the loudness estimates for the third-octave band centered on 5 kHz for static and dynamic sounds (left panel) and Directional Loudness Sensitivity as a function of the azimuth: mean of 10 listeners for the third-octave band centered on 5 kHz (right panel)

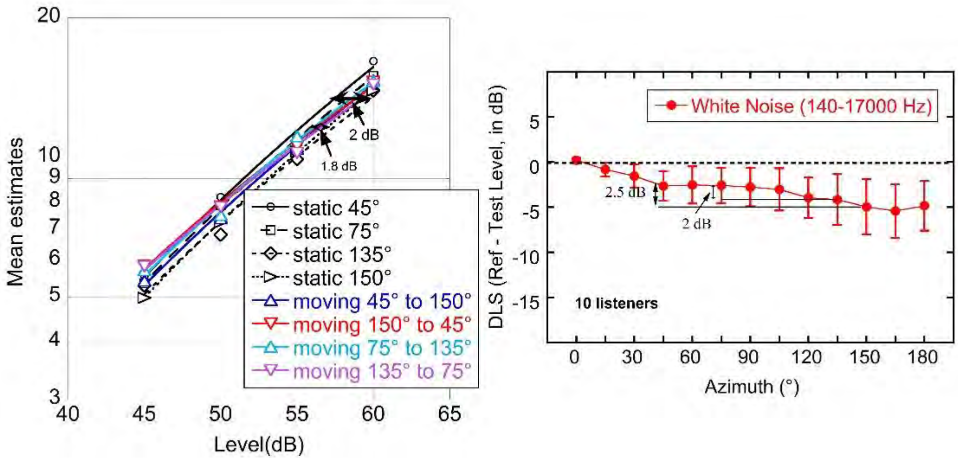

Figure 2. Geometric means (10 listeners) of the loudness estimates for the white noise for static and dynamic sounds (left panel) and Directional Loudness sensitivity as a function of the azimuth: mean of 10 listeners for the white noise (right panel)

Discussion and Conclusion

The direction of the movement does not seem to affect the global loudness while DLS and at-ear levels vary in opposite ways for opposite directions. We did not find any asymmetry in loudness in this case, even if the at-ear level varied. This finding is in disagreement with the results of studies on asymmetry in loudness, in which the global loudness of an increasing sound was found larger than that of a decreasing sound. This may be due to the small amount of at-ear level variation (9.5 dB for the third-octave-band stimulus, 6 dB for the white noise from 45 to 150° and 4 dB from 75 to 135°, in the ipsilateral ear), much smaller than the dynamics of the stimuli used in experiment on loudness asymmetry for static sounds (15 or 30 dB). It may also be due to an influence of the contralateral ear in which the level variations were very small but were present.

For the third-octave band, we found than the loudness of the moving sound corresponded to the loudness of the sound at 135°, whatever the direction of variation. This result is in discrepancy with a prevalence of the louder part of the sound on the global loudness because at 135° the loudness of the third-octave-band stimulus is softer than at 75°. This phenomenon might be due to the fact that at 135° the source is not in the visual field of the listener, which would induce more attention to that part of the space. But for narrow-band noise, the localization is very poor, and around 5 kHz the sound would be localized in front of the listener (Blauert, 1983).

Based on a different procedure, this experiment confirms the amount of directional loudness sensitivity found previously (Meunier et al., 2016). The absolute magnitude estimation is much faster than the adaptive procedure used in Meunier et al. (2016), and would be a promising alternative for measuring directional loudness sensitivity.

The exponents of the loudness functions were the same for the static and dynamic stimuli and did not depend on the position of the sound source. However, the exponents were very small, much smaller than the ones found usually in literature. For example, Canévet et al. (2003) found an exponent of 0.49 for a 4 kHz pure-tone. At 1 kHz the exponent is about 0.6 (Steven, 1957). This may be due to a contextual effect as static and dynamic sounds were presented in the same blocks.

Acknowledgements

This work was supported by the LoudNat project funded by the French National Research Agency ANR-11-BS09-016-01.

References

Blauert J. (1983). Spatial hearing.The psychophysics of human sound localization. MIT Press.

Canévet G., Teghtsoonian M., and Teghtsoonian R. (2003). Assimilation and asymmetry of loudness change in magnitude-estimation measurements. Acta Acustica united with Acustica, 89, 530-539.

Meunier, S., Savel, S., Chatron, J., and Rabau, G. (2016). Interindividual differences in directional loudness. J. Acoust. Soc. Am., 140, 3268–3268.

Ponsot, E., Susini, P., and Meunier, S. (2015). A robust asymmetry in loudness between rising- and falling-intensity tones. Atten. Percept. Psychophys., **77**, 907–920.

Ponsot, E., Susini, P., and Meunier, S. (2015). Erratum to: A robust asymmetry in loudness between rising- and falling-intensity tones. Atten. Percept. Psychophys., **77**, 921–921.

Pulkki, V (1997). Virtual sound source positioning using vector base amplitude panning. J. Audio Eng. Soc., 45(6) :456–466.

Sivonen, V. P., and Ellermeier, W. (2006). Directional loudness in an anechoic sound field, head-related transfer functions, and binaural summation. J. Acoust. Soc. Am., 119, 2965–2980.

Steven S. S. (1957). Concerning the form of the loudness function. J. Acoust. Soc. Am., 29, 603-606.