

COVER PAGE

Document downloaded by @DAEL

Fri Nov 27 05:54:49 2026
For personal use

When automatic English translation is provided, only the original document is authentic.
The EAA cannot be held responsible of any translation error

Bibliographical reference

Are Rising Sounds Always Louder? Influences of Spectral Structure and Intensity-Region on Loudness Sensitivity to Intensity-Change Direction, Emmanuel Ponsot, Sabine Meunier, Abbes Kacem, Jacques Chatron and Patrick Susini, Acta Acustica **vol. 101** (Number 6), 2015, pp. 1083-1093

DOI
https://doi.org/10.3813/AAA.918902

Acta Acustica united with Acustica
Vol. 101 (2015) 1083 – 1093

DOI 10.3813/AAA.918902

Are Rising Sounds Always Louder? Influences of Spectral Structure and Intensity-Region on Loudness Sensitivity to Intensity-Change Direction

Emmanuel Ponsot[1)], Sabine Meunier[2)], Abbes Kacem[2)], Jacques Chatron[2)], Patrick Susini[1)]

[1)] STMS lab, (IRCAM, CNRS, UPMC) 1 place Igor Stravinsky, 75004 Paris, France.
emmanuel.ponsot@ircam.fr; patrick.susini@ircam.fr

[2)] LMA, CNRS, UPR 7051, Aix-Marseille Univ, Centrale Marseille, 13402 Marseille Cedex 20, France.
chatron@lma.cnrs-mrs.fr; abbes.kacem@hotmail.fr; meunier@lma.cnrs-mrs.fr

Summary

In a previous study, a robust asymmetry in global loudness was observed between rising and falling-intensity 1-kHz tones, pointing out the existence of a mechanism specifically sensitive to sound intensity direction [Ponsot et al., Attention, Perception & Psychophysics, 77(3), 907–920 (2015)]. The properties of this "direction-sensitive" mechanism are further explored in the present study, where its dependence on two stimuli characteristics, the spectral content and the intensity-region is examined. In a first experiment, the global loudness of rising and falling-intensity sounds varying over 15-dB ranges was assessed in a magnitude estimation task. The ramps had various spectral contents (pure tones from 250 Hz to 8 kHz and broadband noises) and were presented in different intensity-regions (from 50–65 dB SPL to 70–85 dB SPL). Significant asymmetries were observed across the different frequencies but not for broadband noises. In addition, a significant interaction between the direction of change and the intensity-region was observed for tones and noises. This latter effect was specifically addressed in a second experiment using an adaptive loudness-matching procedure, in which asymmetries were inferred from pairwise comparisons, both for 1-kHz tones and for white noises presented in mid and high intensity-regions. As in Experiment 1, greater asymmetries were observed for tones compared to noises; however significant asymmetries were found for noises as well. Furthermore, for both tones and noises, the size of the asymmetries was significantly decreased with the intensity-region when the sound pairs were composed of a rising followed by a falling stimulus. These results are discussed in the light of recent physiological and neuroscience studies showing that spectrally structured looming sounds are treated specially by the brain.

PACS no. 43.66.Bt, 43.66.Ba, 43.66.Cb, 43.66.Fe, 43.66.Lj

1. Introduction

In the past, a few studies observed that, when listeners are required to evaluate the *global loudness* of time-varying sounds, defined as the overall loudness of a sound over its entire duration, they primarily focus on the loudest portions of the stimuli to construct their judgments (e.g. [1, 2]). In various recent psychophysical experiments on sound source discrimination or identification where psychophysical reverse correlation methods were employed, a somewhat related effect was found: the so-called "level-dominance" effect, reflecting the fact that listeners always tend to assign much greater weights to the loudest elements of the stimuli (e.g., to loudest frequency components in complex stimuli), even though these elements provide less information than others with respect to the required task (e.g. [3, 4, 5]). Using reverse correlation methods to study *global loudness* judgments, we specifically demonstrated that for 2-s, 1-kHz tones with rising- or falling-intensity profiles, the temporal weighting of loudness was also entirely constrained by this "level-dominance" effect [6]. However, although listeners' attention was exclusively focused on the loudest portions of the stimuli similarly for the two profiles, rising-intensity tones were consistently judged louder than falling-intensity tones [6]. The robustness of this asymmetry in "global loudness" was later confirmed using various measurement methods and experimental contexts, but the origins of the effect still remain unknown [7]. Therefore, the present study was conducted to better understand why and how loudness processing of time-varying sounds depends on the direction of intensity-change. In particular, we examined how this "direction-sensitive" mechanism is

Received 20 April 2015,
accepted 22 July 2015.

© S. Hirzel Verlag · EAA

influenced by the spectral characteristics and the intensity-region of the stimuli.

Differences in the perception of looming and receding signals were already reported in various tasks and, interestingly, pure tones and sounds with harmonic spectral structures were found to elicit much larger differences than sounds having random spectral structure, such as white noises. One of the earliest reports of perceptual asymmetries between rising and falling-intensity sounds of a few seconds was made by Neuhoff in the context of *loudness change*, with rising sounds being judged as "changing more in loudness" than falling sounds [8]. This effect was shown to be larger for violin notes, chords or vowels (i.e., with harmonic structures) than for broadband noises[1] [8, 9, 10]. Psychophysical studies investigating duration perception of auditory stimuli with rising or falling intensity profiles also yielded similar observations. Rising-intensity sounds are perceived as significantly longer than falling-intensity sounds (e.g., [11, 12]) and this asymmetry was found to be greater with tones than with broadband noises (e.g., [13]). Recent imaging studies conducted on both human and non-human primates corroborated the aforementioned studies. In particular, it was shown that rising tones but not rising noises recruit specific neural networks and induce different behavioral asymmetries, as compared to their equivalent falling versions ([14, 15, 16, 17, 18]; for further details, see [7]). In addition, several auditory psychophysical tasks revealed that when the stimuli comprise a harmonic spectral structure, humans tend to underestimate time-to-contact [19, 20] and react faster to rising-intensity sounds compared to falling-intensity sounds [18, 21, 22]. For example, reaction times to tone targets measured after the presentation of tonal "looming" sounds (i.e., rising in intensity) were found to be significantly faster than after the presentation of tonal "receding" sounds (i.e., falling in intensity) [21]. This asymmetry was no longer observed for white noises. In a visual orientation discrimination task, a significant decrease in reaction time was observed when spatially congruent tonal auditory stimuli were presented at the same time as visual stimuli [23]. In that study, the orientation of a visual Gabor patch presented on the left (right) part of the screen was detected faster when combined with a rising tonal auditory stimulus presented on the loudspeaker on the same side, i.e. on the left (right), than when combined with a falling tonal auditory stimulus. This facilitation of visual orientation discrimination was no longer observed when rising and falling-intensity stimuli made of white noises were employed. Moreover, concerning perceived duration, Grassi & Pavan [24] showed that the "looming" / "receding" asymmetries in perceived duration might be specific to the auditory modality, since they were significantly reduced using audio-visual stimuli and even totally removed with purely visual stimuli.

All together, these studies indicate important differences in the processing of "looming" and "receding" auditory stimuli, not only regarding loudness. They suggest that a high-level neural mechanism specifically dedicated to "looming" spectrally structured sounds could be responsible for these different outcomes (e.g. [8, 15, 18]). The effect is strong enough to consistently affect various behavioral responses, to facilitate audio-visual integration (e.g. [23, 25, 26, 27, 28, 29] and even to produce crossmodal interactions [30] and remapping [31, 32].

Another important factor that has to be considered when examining the perception of rising- and falling-intensity stimuli concerns their "intensity-region" (i.e., the region of intensity covered between the start and the end of the ramp). Few studies on direct *loudness change* first showed that the asymmetry between the two profiles increased with intensity-region (e.g. [8, 9, 33]). However, it has now been demonstrated that this effect was mediated by an "end-level" recency mechanism biasing participant's loudness change estimates [10, 34]. On the other hand, a previous study on *global loudness* showed smaller asymmetries in highest regions (e.g., culminating at 80–90 dB SPL) compared to other lower regions [7]. As compared to the spectral structure, this factor has been paid less attention so far. The causes for such potential intensity-region dependent effects remained to be addressed more specifically in the context of global loudness asymmetries.

As stated above, the aim of the present study was to examine the influence of two factors (spectral structure and intensity-region) on *global loudness* differences between rising and falling-intensity sounds; global loudness asymmetries have only been reported for 1-kHz tones so far [7]. The main purpose of Experiment 1 was thus to collect quantitative estimates of these differences for other spectral contents in order to test whether the influence of the spectral structure could also be observed in the case of global loudness judgments. Pure tones with different frequencies (between 250 Hz and 8 kHz) were evaluated as well as two broadband noises (pink and white noises) in order to test if the asymmetry was larger for pure tones than for noises, whatever the frequency and the spectral envelop of the noises. We also wanted to investigate whether the magnitude of the asymmetries for tones would be reduced at higher frequencies as, for example the AIM model predicts (e.g., [35]). The use of stimuli having various spectral contents was employed in previous studies examining perceptual asymmetries between short asymmetrical stimuli (<200 ms), both for loudness [36] and perceived duration [13]. The main purpose of Experiment 2 was to explore further the effect of the intensity-region observed in Experiment 1. Based on the afore-

[1] One should note that these results concern *direct* retrospective judgment measurements –i.e., the listeners were asked to produce overall evaluations of *loudness change* at the end of the stimuli – which is the type of judgment investigated in the present study. Opposite findings were found where *indirect* loudness change measurement were used – i.e., when defined as the ratio of separate loudness "snapshots" estimates given by listeners at the start and the end of the stimuli – (e.g., [53, 54, 55]); an effect known as "decruitment" (for a review, see [56]). However, these two types of judgments were shown to reflect different perceptual processes. Since the present study deals with the mechanisms underlying retrospective *global loudness* judgments, this paper will exclusively be focused on the asymmetries observed in various *direct* retrospective judgments.

mentioned studies, greater asymmetries were expected for pure tones compared to broadband noises, as well as smaller asymmetries in highest intensity-regions compared to other lower intensity-regions. The potential origins of these asymmetries are discussed with respect to the results obtained in the two experiments.

2. Experiment 1

In this experiment, an Absolute Magnitude Estimation (AME) procedure was used to measure the global loudness of rising and falling sounds in various conditions. Pure tones covering a wide range of the audible spectrum as well as broadband noises were used. The sounds were presented from mid up to high intensity-regions (50–65 dB SPL to 70–85 dB SPL).

2.1. Materials and method

2.1.1. Participants

Fifteen volunteer participants (5 women and 10 men; age 22-50 years, Mean = 28) took part in the experiment. They were not paid for their participation. All listeners had audiometric thresholds lower than 20 dB HL at octave frequencies of 125–8000 Hz. The participants were all naïve with respect to the hypotheses under test; only two of them (members of the lab) had prior experience in loudness rating experiments.

2.1.2. Stimuli

Stimuli were rising and falling-intensity ramps lasting 2 s, including 20-ms linear (on amplitude) rise and fall times at onset and offset. The main portion of these intensity-ramps lasting 1960-ms (onset and offset excluded) covered a region of 15-dB (i.e., the ramps had a linear variation – up- or downward – of 15 dB). They were presented at five different intensity-regions: 50–65, 55–70, 60–75, 65–80 and 70–85 dB SPL. Different spectral contents were used: pure tones at five frequencies (250Hz, 500Hz, 1kHz, 4kHz and 8kHz) and two broadband noises (white noise, pink noise).

2.1.3. Apparatus

The stimuli were generated at a sampling rate of 44.1 kHz with 16-bit resolution using Max/MSP Software. Sounds were converted using a Focusrite Saffire PRO24 soundcard and were presented diotically through headphones (Sennheiser HDA 200). The levels were calibrated using a Brüel & Kjær artificial ear (type 4153) coupled with the mounting plate provided for circumaural headphones with no free-field equalization. Each participant was tested in a double-walled sound-insulated booth at LMA, Marseille.

2.1.4. Procedure

The Absolute Magnitude Estimation (AME) procedure was employed, based on the instructions of Hellman [37]. No standard was given to the participants, whose task was to give a number proportional to the global loudness of each sound regardless of the numbers assigned to previous stimuli [6, 7, 34]. The ramps were presented in 14 different blocks (2 directions × 7 spectral contents), depending on their direction of intensity (rising/falling) and spectral content. The order of presentation of these blocks was randomized. Each was made of 30 trials (5 intensity-regions × 6 repetitions) presented in random order, i.e., in a given block the stimuli simply differed with respect to their intensity-region (for example, a block was made of 500-Hz falling ramps presented 6 times at each of the five intensity-regions). The whole experiment lasted approximately 90 minutes for each participant, including several pauses.

2.2. Results

Mean global loudness estimates, taken as the geometric means of all individual estimates, are presented in Figure 1. Statistical analyses were conducted using R [38]. We performed repeated-measures ANOVAs (rmANOVAs) with univariate approaches for the main analyses, using Bonferonni corrections where appropriate. Unless otherwise specified, all the tests were two-tailed and used a probability level of .05 to test for significance. Effect sizes are reported using partial eta-squared η_p^2. For this experiment, an overall 2 × 5 × 7 (Direction, Intensity-Region, Spectral Content) rmANOVA was conducted, as well as planned contrasts to examine the expected tones/noise differences regarding the effect of the direction. These analyses were performed on linearized data, computed by taking the logarithm of the raw estimates (see [7]).

The main significant effect revealed by the analysis was, as expected, the intensity-region [$F(4, 56) = 117.72$, $p < .001$, $\eta_p^2 = .894$], meaning that the participants primarily considered the energy of the stimuli in their estimates. As it can be observed on Figure 1 in most of the conditions, greater estimates were observed for rising tones compared to falling tones; this was supported by a significant effect of the Direction [$F(1, 14) = 25.350$, $p < .001$, $\eta_p^2 = .644$]. However, the size of these asymmetries was found to depend on the type of stimuli (Spectral content), as shown by a significant Direction × Spectral Content interaction [$F(6, 84) = 4.901$, $p < .001$, $\eta_p^2 = .259$]. Planned comparison showed that the magnitude of the asymmetries was significantly greater for tones (all frequencies combined) compared to noises (pink and white noises combined) [$F(1, 14) = 23.217$, $p < .001$]. Although a look at Figure 1 suggests that the overall size of these asymmetries was marginally greater for 1-kHz and 8-kHz tones compared to other frequencies, a later post-hoc rmANOVA conducted on the estimates given to pure tones only showed no significant differences across tone frequencies ($p > .05$). Similarly, no significant differences between white and pink noises were found ($p > .05$). Finally, a significant Direction × Intensity-Region interaction was found [$F(4, 56) = 6.202$, $p < .001$, $\eta_p^2 = .307$].

2.3. Discussion

Overall, greater global loudness estimates were obtained for rising tones as compared to falling tones when pure tones were used but not when broadband noises stimuli were used (significant Direction × Spectral Content interaction). The differences between rising and falling tones

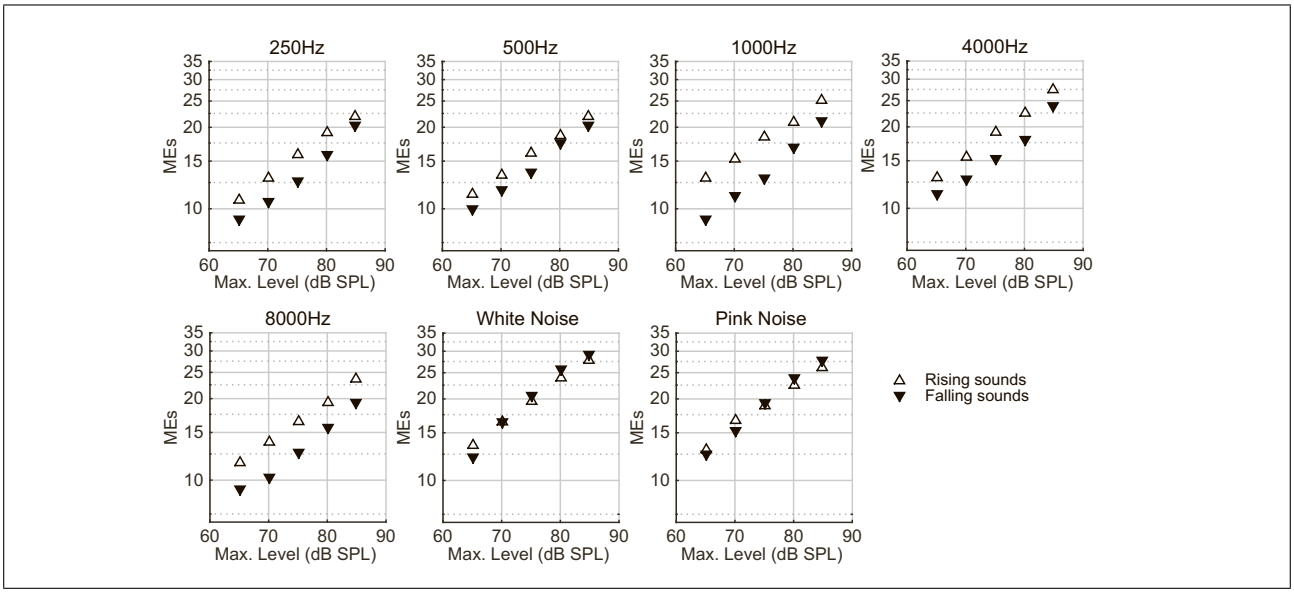

Figure 1. Geometric mean global loudness ratings for each frequency-spectrum (pure tones from 250 Hz to 8 kHz; white noise; pink noise), plotted as a function of the upper bound of the intensity-region at which the ramps were presented (i.e., these regions ranged from 50–65 dB SPL to 70–85 dB SPL but are referred to using their maximum only). Upward (unfilled) triangles correspond to loudness estimates attributed to rising-intensity sounds; downward (filled) triangles correspond to loudness estimates attributed to falling-intensity sounds.

estimates were significant and similar across frequencies, and no significant differences were found for white noises and pink noises. These results support the hypothesis proposed in the introduction that the type of sound does play a role in the formation of these asymmetries, as it has previously been shown for *loudness change* judgments (e.g. [8]).

A significant Direction × Intensity-Region interaction was also found. As mentioned in the introduction, this interaction was already obtained in a previous study with 1-kHz tones: using either loudness matching or magnitude estimation procedures, loudness asymmetries for 1-kHz tones were significantly smaller in the highest regions examined, in 65–80 dB SPL and 75–90 dB SPL regions respectively (see [7]). In the case of broadband noises, the estimates given to rising tones appeared to be slightly greater than the estimates given to falling tones in lowest intensity-regions, whereas the opposite was observed in highest intensity-regions (however, post-hoc analyses between these specific conditions did not reveal any significant effect). The overall significant Direction × Intensity-Region interaction observed in the main rmANOVA of the present experiment reflects a common deviation in loudness judgments, where the effect of intensity direction (rising/falling) is mediated by the intensity-region in which the stimulus is presented. Since this intensity-dependent effect was also observed for 1-kHz tones in a loudness matching experiment [7], it can reasonably be assumed that it was not induced by a contextual effect related to the magnitude estimation procedure presently employed.

Two conclusions can be drawn from the present results. First, the presence of loudness asymmetries between rising and falling ramps depends on the tonal characteristic of the sounds. Second, the Direction × Intensity-Region interaction observed with pure tones at different frequencies and with broadband noises suggests that a specific intensity-dependent mechanism could be involved in the global loudness evaluation process of rising and falling sounds, regardless of their spectral content. This interaction was further explored in a second experiment with 1-kHz tones and white noises in particular. To assess the significance (or non-significance) of the asymmetries in specific intensity-regions, a loudness-matching procedure was employed where the asymmetries were directly measured in each region. Since 1-kHz tones and white noises presented at the same SPL are not perceived with the same loudness, these asymmetries were measured in different intensity-regions that allowed a control of their intrinsic loudness differences (the intensity-regions of the noises were translated with respect to a loudness equalization of their maximum intensities; for details, see below). From this design, the respective influences of spectral content and intensity-region on the results could be accurately distinguished [39].

3. Experiment 2

In this experiment, loudness asymmetries were measured for 1-kHz tones and white noises using an adaptive loudness matching procedure. The ramps were presented in the lowest and highest intensity-regions used in Experiment 1 (i.e., 50–65 dB SPL and 70–85 dB SPL, respectively). The noises were presented in these two regions and in two additional regions judged as having the same loudness as the two regions at which the tones were presented. Thus, asymmetries were measured in both *non-equalized*

Table I. Individual level differences between the 1-kHz tone and the white noise obtained in the preliminary loudness matching experiment; a positive value of x dB indicates that the noise was matched x dB lower than the tone to produce equal-loudness. These level differences (in dB) are specified for each participant (from P_1 to P_{18}) and for each level of the 1-kHz test tone, i.e. 65 dB SPL (D_{65}, first row) or 85 dB SPL (D_{85}, second row).

Participant	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9
D_{65} (dB)	9.1	5.8	5.6	14.0	9.9	8.4	3.9	2.0	8.2
D_{85} (dB)	9.2	8.7	11.2	9.3	6.8	5.1	3.2	3.2	10.4
Participant	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}	P_{16}	P_{17}	P_{18}
D_{65} (dB)	-3.3	7.6	0.3	0.5	3.5	7.7	8.3	12.0	2.0
D_{65} (dB)	-3.6	7.6	4.7	7.2	7.7	5.0	1.8	3.6	7.8

and *equalized* regions (in loudness) to control the potential influence of loudness on the results.

3.1. Materials and method

3.1.1. Participants

Eighteen new volunteer participants (12 women and 6 men; age 19-31 years, Mean = 24) took part in this experiment. The participants gave their informed written consent prior to the experiment and were paid for their participation. All were naïve with respect to the hypotheses under test and had no prior experience with loudness rating experiments.

3.1.2. Stimuli

The stimuli were constructed in a similar fashion as in Experiment 1, using intensity-ramps varying positively (rising) or negatively (falling) over 15-dB during 1960 ms. Only 1-kHz pure tones and white noises were used. Since the aim was to examine more specifically the Direction × Intensity-Region interaction while controlling the potential influence of their intrinsic loudness differences, the tones were presented in the two most distant intensity-regions of the first experiment (i.e., 50–65 dB SPL and 70–85 dB SPL), whereas the white noises were presented in four intensity-regions: the same two intensity-regions as for the 1-kHz tones (i.e., 50–65 dB SPL and 70–85 dB SPL) and two additional regions producing the same maximum loudness as the tones presented in these regions (50–65 equal* and 70–85 equal*; an asterisk is used to indicate that it was specifically determined for each participant). These latter equal-loudness regions were obtained individually in a preliminary experiment (see section 3.1.4 below).

3.1.3. Apparatus

The stimuli were generated at a sampling rate of 44.1 kHz with 16-bit resolution using Matlab. Sounds were converted using a RME Fireface 800 soundcard and presented diotically through headphones (Sennheiser HD 250 Linear II). The level calibration process was similar to Experiment 1. There was no free-field equalization and the frequency characteristics of the headphones were not compensated. Participants were tested in a double-walled IAC sound-insulated booth at Ircam, Paris.

3.1.4. Preliminary experiment: Individual tone/noise loudness equalization

As stated above, the aim of this second experiment was to evaluate the influence of the intensity-region and the spectral content of the sounds on their asymmetries while controlling the potential influence of intrinsic loudness differences between tones and noises. To determine intensity-regions for noises that induced the same loudness as those for tones, preliminary measurements were conducted to evaluate for each participant the exact levels of white noise producing the same loudness levels as 65 and 85-dB SPL 1-kHz tones, that is, only obtained from the maximum intensity of each region. These individualized "equal-loudness" regions (also covering a 15-dB variation) were inferred from a tone/noise loudness-matching task conducted with each participant before the main experiment. The method employed was similar to the main experiment (see section 3.1.5 below). An adaptive 2I, 2AFC procedure with four interleaved tracks was used, comprising the two orders of presentation (tone-noise / noise-tone) and two repeated tracks for each order. Each participant matched in loudness 500-ms constant-intensity white noises with 500-ms constant-intensity 1-kHz tones. Tones were presented either at 65 dB SPL or at 85 dB SPL in distinct blocks. The levels of white noises producing the same loudness as 65 and 85-dB SPL 1-kHz tones (averaged across the four tracks) were saved and used individually in the main experiment to produce intensity-regions of equal-loudness.

The averaged level differences between noises and tones that yielded equal-loudness judgments for each participant are presented in Table I, as a function of the reference tone level (65 or 85 dB SPL). There was no significant difference between the results at 65 and 85 dB SPL [$t(17) = 0.184$, $p = 0.572$]. Large interindividual differences were found however, either when the tone was presented at 65 dB SPL (Mean = 5.8, SD = 4.5) or at 85 dB SPL (Mean = 6.1, SD = 3.6), covering a large range of almost 18 dB between the most extreme participants, as reported in studies on spectral loudness summation (e.g. [40]). This comforted our view that it was better to conduct this preliminary experiment in order to equalize tone/noise intensity-regions in an individual basis rather than referring to the mean difference inferred from any loudness model. It should be noted that participants were particularly consistent in their judgments, since the

mean intraindividual differences between the four conditions (2 repetitions × 2 presentation orders) was remarkably small (Mean SD = 1.4 dB at 65 dB SPL; Mean SD =1.7 dB at 85 dB SPL), consistently with previous studies measuring equal-loudness points between noises of different bandwidths [41] and tones compared to noises with subcritical bandwidths [42]. One may note that one participant (P10) surprisingly matched the noise in loudness around 3dB lower than the tone. A closer look at his/her results revealed a strong pair-order effect: the noise was matched clearly lower when it was the second sound of the pair (the mean loudness matching level averaged over the two intensities for this order was 0 dB, SD = 0.8 dB) than when the noise was the first sound of the pair (where it was −7.5 dB, SD = 1.6 dB). This pair-order effect was not observed with other participants. However, since his/her results were very similar between the two tracks with the same presentation order, this participant could not be considered as an outlier and was thus kept in subsequent analyses.

The individual loudness equalizations measured in this preliminary experiment were used to create two intensity-regions at which the noises were perceived as equally loud as the 1-kHz tones by each participant, i.e., the 50–65 equal* and 70–85 equal* regions.

3.1.5. Procedure

A loudness-matching task was employed to determine the loudness asymmetries between rising and falling ramps in the different conditions, as simply inferred from the difference between the measured point of subjective equal-loudness for rising and falling sounds, respectively. This procedure was already employed in a previous study (see [7]). The stimuli were presented in a 2I, 2AFC paradigm based on an interleaved adaptive procedure [43, 44] comprising four interleaved tracks with the two orders of presentation (rising-falling / falling-rising) and two types of varying sounds (rising varying / falling varying). The Inter-Stimulus Interval (ISI) was 500 ms.

Listener's task was to indicate which sound of the pair was louder. The level of the variable tone, was adjusted according to a one-up, one-down rule [45]. An initial step size of 6 dB was chosen. The starting value was randomly selected either 5 dB higher or lower than the test stimulus. The step size was reduced by a ratio of 2 after every two reversals; after six reversals, it was then held constant. This procedure ended when 8 reversals were achieved for each track. The loudness matches were then defined as the average of the maximum level of the variable tone in the last two reversals of each track, thus tracking the 50% point (i.e., equal-loudness) on each underlying psychometric function [45].

The experiment was divided into 6 blocks; one block was used for each spectrum and for each intensity-region. A block was thus composed of the four interleaved tracks (2 orders and 2 types of stimuli varying). The blocks were presented in a random manner between participants. Since the order of the ramps could affect the subsequent loudness asymmetries, the loudness matches were derived for each spectral content, intensity-region and pair order, simply by averaging the loudness matches obtained in the two repetition tracks. In each condition, the asymmetry was calculated as the difference between the maximum level of the falling sound and the maximum level of the rising sound derived from the loudness matches [7]. An experimental session (comprising the tone/noise preliminary loudness matching experiment) lasted approximately 1 hour for each participant.

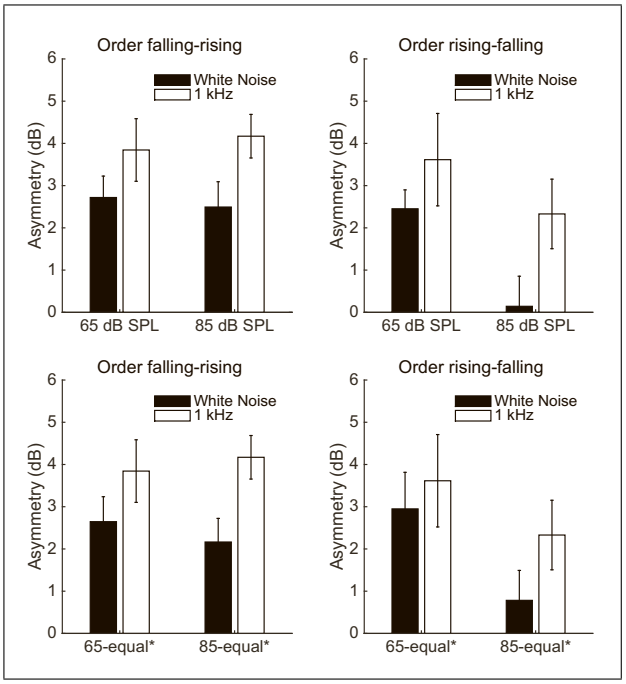

Figure 2. Loudness asymmetries derived from the loudness matches between rising and falling ramps, obtained for 1-kHz tones and for white noises. They correspond to the signed level differences between falling and rising tones at equal-loudness in each configuration (Asymmetry (dB) = $L_{\text{falling}} - L_{\text{rising}}$); i.e., positive asymmetries indicate that the falling sound was matched higher in level than the rising sound to be perceived with equal-loudness. These asymmetries are presented as a function of the pair order (rising-falling or falling-rising, as indicated in the title of each plot) and the maximum of the intensity-region at which the ramps were presented. Upper panel: tones and noises varied in similar intensity regions (i.e., in 50–65 dB SPL and 70–85 dB SPL regions). Lower panel: tones and noises varied in intensity-regions equalized in loudness (i.e., in 50–65 equal* and 70–85 dB equal* regions; see the text for details). Error bars correspond to SEM.

3.2. Results

The loudness asymmetries obtained in the main part of the experiment in the different intensity-regions and orders are plotted in Figure 2, for tones (white bars) and noises (black bars). In the upper panel, the asymmetries are presented in *non-equalized* regions, i.e., using loudness matches obtained for both tones and noises in the 50–65 dB SPL and the 70–85 dB SPL intensity-regions. In the lower panel, the asymmetries are presented in *equalized* regions, i.e., using the matches for tones in the 50–65 dB

SPL and the 70–85 dB SPL regions (from the upper panel) and the white noises presented in the 50–65 equal* and 70–85 equal* regions (obtained from the tone/noise loudness matching preliminary experiment; see above).

Two rmANOVAs were conducted separately to compare these asymmetries in *non-equalized* regions and in *equalized* regions respectively, using 2 × 2 × 2 (Spectrum, Intensity-Region, Order) factorial designs. In *non-equalized* regions, the asymetries were found to be significantly greater for 1-kHz tones than for white noises; Spectrum was significant [$F(1, 17) = 15.786$, $p < .001$, $\eta_p^2 = .481$]. The statistical analysis also showed a significant effect of Intensity-Region [$F(1, 17) = 6.362$, $p = .022$, $\eta_p^2 = .272$] and a significant Intensity-Region × Order interaction [$F(1, 17) = 6.543$, $p = .020$, $\eta_p^2 = .278$]. The asymmetry was lower in the 85-dB SPL region compared to the 50–65-dB SPL region when the rising ramp was followed by a falling ramp. This latter interaction was found for both tones and noises, as indicated by a non-significant Order × Intensity-Region × Spectrum interaction ($p > .05$). In *equalized* regions, the same conclusions were reached: the analysis revealed a significant effect of Spectrum [$F(1, 17) = 9.622$, $p = .006$, $\eta_p^2 = .361$], Intensity-Region $F(1, 17) = 7.831$, $p = .012$, $\eta_p^2 = .315$] and a significant Intensity-Region × Order interaction [$F(1, 17) = 4.515$, $p = .048$, $\eta_p^2 = .210$]. Again, the Order × Intensity-Region × Spectrum interaction was not significant ($p > .05$).

Additional one-tailed t-tests were conducted to determine whether the loudness asymmetries in each condition (Spectrum, Intensity-Region, Order) were significant or not. These analyses were done separately in equal and non-equal regions. The p-value threshold for significance was corrected using Bonferonni at the α level of .05 (.05/8 = .00625). The asymmetries were significantly higher than zero (i.e., $Ps < .05$) in all but two conditions, when the noises were presented in the rising-falling order in the 70-85 dB SPL region [Mean = 0.1 dB (SD = 3.0); $t(17) = 0.200$, $p = .422$] and in the 70–85-equal* region [Mean = 0.8 dB (SD = 3.0); $t(17) = 1.107$, $p = .142$].

3.3. Discussion

In the preliminary tone/noise loudness equalization experiment, considerable differences between participants' loudness tone/noise equalization judgments were found, as it was already reported in studies on spectral loudness summation (e.g. [40, 41, 42]). For most of the participants, the tone/noise level differences measured in the present experiment were lower than what has been reported in previous studies with broadband (environmental and pink) noises measured with adjustment methods (e.g. [46, 47]). These differences probably primarily come from the fact that we did not account for the frequency characteristics of the headphones and that no free-field equalization was made. However, the only concern was that the sounds were matched in loudness on an individual basis, which is what was done.

The purpose of this second experiment was to further explore the effect of the intensity-region on the magnitude of the asymmetries, based on the results of Experiment 1. A two-interval loudness-matching task was employed in Experiment 2. A significant decrease of the asymmetry in the highest intensity-region was obtained when the sounds were presented in the rising-falling order, but not when the sounds were presented in the opposite order (i.e. in the falling-rising order) both in the analyses conducted on *equalized* and *non-equalized* regions. This decrease was obtained with both tones and noises, as indicated by non-significant Order × Intensity-Region × Spectrum interactions. In other words, this decrease occurred only in a specific context, i.e., when the two sounds were loud and matched in pairs in that particular order. In a previous study on 1-kHz tones, loudness asymmetries, inferred from a loudness matching roving-intensity experiment were found to be significantly reduced in high intensity-regions (65-80-dB SPL) compared to other lower regions [7]. It is likely that this influence of the intensity-region on the asymmetry was actually caused by a significant decrease in the rising-falling presentation order but not in the other presentation order. However, we can unfortunately not check this assumption since Time-Order Errors affect loudness matches in roving-intensity paradigms (for details, see [7]). Which factors could be responsible for the present Order × Intensity-Region interaction? When loud rising and falling sounds separated by a small ISI (500 ms) are compared in loudness in a same pair and when the loudest portions of these sounds are contiguous (i.e., the sounds are presented in the rising-falling order), it can reasonably be assumed that participants are able to shift their attention to the loudest portions of the stimuli, thus paying less attention to their specific profile (rising or falling). It is important to notice that the decrease of the asymmetry measured in this configuration cannot be attributed to any peripheral mechanism because the neural response of a sound decays within a few milliseconds after its offset (e.g. [48]). Thus, the intensity of the rising sound is no longer accessible at a peripheral stage when the second sound (falling) begins, suggesting that the effect could rather be attributed to a higher-level (cognitive or attentional) mechanism where the loudness comparisons of rising and falling sounds are mediated by their order of presentation when presented in high intensity-regions.

Furthermore, smaller but still significant asymmetries were observed for white noises compared to 1-kHz tones. The same outcome was reached whether the comparison was done in *non-equalized* regions or in *equalized* regions, which suggests that the spectral content of these sounds has a specific influence on their subsequent asymmetries, regardless of their inherent loudness difference at equal intensity[2]. Nevertheless, significant positive asym-

[2] One could argue that a different conclusion would have been reached if equal-loudness regions had not been inferred from individualized loudness equalization experiment but rather from the use of current loudness models, because these models would have provided lower intensity-regions. However, this is not likely since the intensity had no effect on white noise asymmetries in the falling-rising order. It might only be possible that the asymmetries for white noises would have been slightly

metries were observed between rising and falling noises in many conditions, which contrast with the results of the first experiment where the asymmetry, evaluated by looking at the main effect of Direction in the ANOVA, was found to be significant for tones solely. This result suggests that the size of the asymmetries measured for broadband noises could actually be affected by the experimental procedure employed, since the loudness asymmetries were inferred from a direct loudness estimation task in the first experiment and from a loudness-matching task in the second experiment. Consistently, no significant asymmetries in loudness change were observed with direct scaling methods [8], whereas smaller (compared to tones) but significant asymmetries were found in pairwise comparisons [20]. This would indicate that the measurement method and the presentation context could potentially affect the measured asymmetries for noises, as opposed to what was reported for 1-kHz tones [7]. Finally, it is worth mentioning that the asymmetries obtained for 1-kHz tones in the different conditions of this second experiment fall within a 2–5 dB range, which is highly consistent with what was obtained in an equivalent experiment previously conducted (see Experiment 2 A presented in [7]).

4. General discussion and conclusion

The aim of the present study was to explore how the global loudness asymmetries observed between 2-s rising and falling sounds varied across different spectral contents and intensity-regions. Based on the large amount of literature exploring the perception and the coding of "looming" and "receding" sounds, showing that tonal "looming" stimuli are treated as special by the brain (e.g. [21]), greater asymmetries were expected for pure tones compared to noises. The two psychophysical experiments of this study supported this hypothesis at least in part, showing with different methods that loudness asymmetries for broadband noises (white noises or pink noises) were always significantly smaller than asymmetries for pure tones of various frequencies. More specifically, the first experiment showed similar asymmetries across pure tones ranging from 250Hz to 8kHz and no asymmetries for white noises and pink noises. This emphasizes the particular role of the spectral structure (structured vs. random) on global loudness ratings, similarly to what was observed on loudness change [8, 20]. The asymmetries obtained for the broadband noise in Experiment 2 were smaller than the asymmetries obtained for the 1-kHz tones; they were however significant in most of the conditions. This point is further discussed below. In short, rising / falling sounds having a random spectral structure, such as broadband noises, differ less in global loudness than do rising / falling tonal sounds[3].

Quantitative estimates of the asymmetries (in dB) were derived from the second loudness-matching experiment. Although the size of these asymmetries was found to depend on the condition, they were, on average, 3.3 dB for tones and 2.3 dB for noises. We evaluated to which extent a typical loudness model could account for such values, and more specifically how the observed spectral-content peculiarities could be predicted. As done in a previous study [7], the maxima of Long-Term-Loudness (LTL) patterns obtained from Glasberg & Moore model [49] were used as global loudness predictors. Asymmetries predicted for pure tones, across all frequencies and intensities, were always between 1.2 and 1.3 dB; asymmetries predicted for broadband noises were always around 1.1 dB. Thus, this model consistently underestimates the size of the asymmetries and cannot account for the significant dissimilarities observed between tonal stimuli and broadband noises (these asymmetries indeed come from the two contiguous AGCs employed in the model to compute LTL, see [7]).

How can the present results then be related with Neuhoff's evolutionary interpretation? According to Neuhoff, rising tonal stimuli have to be treated specifically and to be given higher priority in order to provide us better preparation for potentially dangerous approaching objects. He argued that this effect was not observed for random spectral structures because most of the sounds produced by single approaching sound sources in our environment present a non-random, structured spectral content, whereas broadband noises present random spectral characteristics similar to "more dispersed phenomena such as wind or rain" [8]. In that sense, broadband noises, being less salient than spectrally structured sounds, would not be able to produce a "sufficiently naturalistic cue for a looming percept" [23]. Based on the present results, several limits of this hypothesis can be pointed out:

1. The asymmetry between rising and falling-intensity sounds seems to be reduced at higher compared to lower intensity-regions, a particularity that is not addressed in Neuhoff' s hypothesis.
2. Although the asymmetries obtained with noises in Experiment 2 were significantly smaller than the asymmetries obtained with 1-kHz tones, they were however significant in many conditions. Simply arguing that tonal stimuli produce asymmetries whereas noises do not is probably not sufficient. Moreover, many natural and environmental sounds exhibiting random spectral structures close to pink noises have also to be treated with high priority (e.g., natural sounds such as rocky screes or snow avalanches, sounds produced by approaching trains or cars). Thus, from a biological point of view, the potential underlying mechanisms responsible for the observed asymmetries are probably more complex

greater in the rising-falling order, more particularly in the high intensity-region.

[3] Another experiment conducted in the lab using a Magnitude Estimation procedure also showed significant asymmetries in global loudness between /ə/ vowels having rising versus falling-intensity profiles (the stimuli were created using Klatt synthesizer [57] and were similar to those used in Neuhoff 's seminal study [8], with a fundamental frequency at 100 Hz and formants at 450, 1450 and 2450 Hz), consistent with what was observed with pure tones, which emphasizes the present distinction made between tonal and broadband stimuli.

than a simple harmonic/non-harmonic sound differentiation.

The first point needs to be studied in more details; in particular we still need to understand why the magnitude of the asymmetry in global loudness depends on the intensity-region of the stimuli as well as their presentation order when two-interval paradigms are employed. In the present study, smaller asymmetries were obtained when the ramps were in rather high intensity-regions (maximum intensities higher than 80 dB SPL). This effect was already observed in a previous study [7] but was not specifically addressed. Experiment 1 indicated that the effect could be observed both for tones and noises. In Experiment 2, the intensity-region had also a significant influence for both tones and noises but only when the pair was composed of a rising-stimulus followed by a falling-intensity stimulus. The fact that those asymmetries can be reduced with increased intensity-region, but only in certain specific contexts, suggests that other high-level processes could potentially interact with the parent "direction-sensitive" mechanism. The second point stated above can also be further discussed using physical consideration of sound propagation. Indeed, the effect of atmospheric attenuation with distance on sound intensity depends on frequency. In that sense, potentially dangerous sources of natural broadband noises present intensity-variations that depend on the frequency regions: faster intensity-variations are observed at high spectral regions compared to low spectral regions [39]. In a study of Gordon et al. where time to arrival (TTA) and urgency ratings of rising narrow-band noises was investigated, narrow-band noises with center frequencies above 250 Hz were rated with greater urgency and were found to cause more TTA underestimation than lower-frequencies noises [39]. The authors argued that high-frequency components, being more affected by atmospheric conditions and distance than low-frequency components, have to be treated with greater priority because they provide a direct message informing the imminent arrival of a potentially dangerous approaching source. Therefore, one interesting perspective to further examine the evolutionary hypothesis proposed by Neuhoff would be to investigate (i) whether global loudness asymmetries for tones are reduced when frequencies below 250 Hz are used and (ii) whether ecologically structured intensity-varying broadband noises used by Gordon et al. induce greater global loudness asymmetries compared to random white noises or pink noises. This would suggest that behavioral asymmetries between rising- and falling-intensity sounds do not depend on the spectral content per se (noise/tone) but rather depend on the degree of "looming" that rising-intensity sounds might produce. The physical characteristics of the stimuli determining this impression of "looming" thus have to be assessed specifically.

All in all, the present results provide converging evidence to assume that the "direction-sensitive" mechanism, i.e., producing asymmetries in global loudness judgments, could indeed be due – at least in part – to the specific neural pathways followed by "looming" stimuli (e.g. [15, 18] because, as for many others but related phenomena, the degree of organization in the spectral content of the sound is found to reinforce these asymmetries. However, other, probably high-level processes related to the presentation order and the absolute intensity of the stimuli are found to mediate this mechanism and would need to be explored further. Although the view that an intrinsic dissimilar coding might be responsible for the behavioral asymmetries between rising and falling sounds lasting a few seconds is particularly interesting, a systematic study is needed to determine whether they fully arise from these inherent sensory or high-level (e.g. cortical) coding differences or whether they also reflect robust changes in observer's decision criteria or judgment strategies (e.g., [50]). Combining neuroimaging and behavioral experiments on both humans and animals to better explore the respective contribution of sensory biases and intrinsic biological coding differences underlying these asymmetries constitutes a promising direction for future research (e.g. [51]). Current loudness models such as Glasberg and Moore's [49] cannot predict these asymmetries in global loudness, probably because they reflect low-level coding and peripheral auditory processes derived from the use of stationary sounds or amplitude-modulated sounds. As noted by Grimm et al. [52] concerning the loudness of fluctuating sounds, even though these types of non-linear effects are rather small (less than 5 dB), these mechanisms deserve particular attention because they carry important information about the processes underlying global loudness evaluation of complex time-varying sounds. Further efforts have to be made to provide a full comprehension of how other features specific to rising and falling sounds, such as their duration and their slope (i.e., their rate of change), are integrated into global loudness judgments and affect this mechanism sensitive to the direction of sound intensity.

Acknowledgement

The authors would like to thank Guillaume Lemaitre and Michaël Vannier for helpful suggestions. This work was supported by the project LoudNat funded by the French National Research Agency (ANR-11-BS09-016-01).

References

[1] S. Kuwano, S. Namba: Continuous judgment of level-fluctuating sounds and the relationship between overall loudness and instantaneous loudness. Psychological research **47** (1985) 27–37.

[2] P. Susini, S. McAdams, B. Smith: Global and continuous loudness estimation of time-varying levels. Acta Acustica united with Acustica **88** (2002) 536–548.

[3] M. D. Turner, B. G. Berg: Temporal limits of level dominance in a sample discrimination task. The Journal of the Acoustical Society of America **121** (2007) 1848–1851.

[4] R. A. Lutfi, C. J. Liu, C. Stoelinga: Level dominance in sound source identification. The Journal of the Acoustical Society of America **124** (2008) 3784–3792.

[5] V. M. Richards, Y. Shen, C. Chubb: Level dominance for the detection of changes in level distribution in sound

streams. The Journal of the Acoustical Society of America **134** (2013) EL237–EL243.

[6] E. Ponsot, P. Susini, G. Saint Pierre, S. Meunier: Temporal loudness weights for sounds with rising and falling intensity profiles. The Journal of the Acoustical Society of America **134** (2013) EL321–EL326.

[7] E. Ponsot, P. Susini, S. Meunier: A robust asymmetry in loudness between rising-and falling-intensity tones. Attention, Perception and Psychophysics **77** (2015) 907–920.

[8] J. G. Neuhoff: Perceptual bias for rising tones. Nature **395** (1998) 123–124.

[9] K. N. Olsen, C. J. Stevens, J. Tardieu: Loudness change in response to dynamic acoustic intensity. Journal of Experimental Psychology: Human Perception and Performance **36** (2010) 1631.

[10] K. N. Olsen, C. J. Stevens: Perceptual overestimation of rising intensity: Is stimulus continuity necessary? Perception **39** (2010) 695.

[11] M. Grassi, C. J. Darwin: The subjective duration of ramped and damped sounds. Perception and Psychophysics **68** (2006) 1382–1392.

[12] S. Meunier, M. Vannier, J. Chatron, P. Susini: Asymmetry in perceived duration between up-ramp and down-ramp sounds as a function of duration. The Journal of the Acoustical Society of America **136** (2014) EL166–EL172.

[13] R. S. Schlauch, D. T. Ries, J. J. DiGiovanni: Duration discrimination and subjective duration for ramped and damped sounds. The Journal of the Acoustical Society of America **109** (2001) 2880–2887.

[14] A. A. Ghazanfar, J. G. Neuhoff, N. K. Logothetis: Auditory looming perception in rhesus monkeys. PNAS **99** (2002) 15755–15757.

[15] E. Seifritz, J. G. Neuhoff, D. Bilecen, K. Scheffler, H. Mustovic, H. Schächinger, R. Elefante, F. Di Salle: Neural processing of auditory looming in the human brain. Current Biology **12** (2002) 2147–2151.

[16] D. A. Hall, D. R. Moore: Auditory neuroscience: The salience of looming sounds. Current Biology **13** (2003) R91–R93.

[17] J. X. Maier, A. A. Ghazanfar: Looming biases in monkey auditory cortex. The Journal of neuroscience **27** (2007) 4093–4100.

[18] D. R. Bach, H. Schächinger, J. G. Neuhoff, F. Esposito, F. Di Salle, C. Lehmann, M. Herdener, K. Schffler, E. Seifritz: Rising sound intensity: an intrinsic warning cue activating the amygdala. Cerebral Cortex **18** (2008) 145–150.

[19] L. D. Rosenblum, A. P. Wuestefeld, H. M. Saldana: Auditory looming perception: Influences on anticipatory judgments. Perception **22** (1993) 1467–1467.

[20] J. G. Neuhoff: An adaptive bias in the perception of looming auditory motion. Ecological Psychology **13** (2001) 87–110.

[21] D. R. Bach, J. G. Neuhoff, W. Perrig, E. Seifritz: Looming sounds as warning signals: The function of motion cues. International Journal of Psychophysiology **74** (2009) 28–33.

[22] C. Ho, C. Spence, R. Gray: Looming auditory and vibrotactile collision warnings for safe driving. Proceedings of the 7th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design, No. 83, 2013, 551–557.

[23] F. Leo, V. Romei, E. Freeman, E. Ladavas, J. Driver: Looming sounds enhance orientation sensitivity for visual stimuli on the same side as such sounds. Experimental brain research **213** (2011) 193–201.

[24] M. Grassi, A. Pavan: The subjective duration of audiovisual looming and receding stimuli. Attention, Perception and Psychophysics **74** (2012) 1321–1333.

[25] J. X. Maier, J. G. Neuhoff, N. K. Logothetis, A. A. Ghazanfar: Multisensory integration of looming signals by rhesus monkeys. Neuron **43** (2004) 177–181.

[26] J. X. Maier, C. Chandrasekaran, A. A. Ghazanfar: Integration of bimodal looming signals through neuronal coherence in the temporal lobe. Current Biology **18** (2008) 963–968.

[27] C. Cappe, G. Thut, V. Romei, M. M. Murray: Selective integration of auditory-visual looming cues by humans. Neuropsychologia **47** (2009) 1045–1052.

[28] C. Cappe, A. Thelen, V. Romei, G. Thut, M. M. Murray: Looming signals reveal synergistic principles of multisensory integration. The Journal of Neuroscience **32** (2012) 1171–1182.

[29] S. Tyll, B. Bonath, M. A. Schoenfeld, H. J. Heinze, F. W. Ohl, T. Noesselt: Neural basis of multisensory looming signals. Neuroimage **65** (2013) 13–22.

[30] E. H. Liu, E. Mercado III, B. A. Church: Multidimensional processing of dynamic sounds: more than meets the ear. Attention, Perception and Psychophysics **73** (2011) 2624–2638.

[31] V. Romei, M. M. Murray, C. Cappe, G. Thut: Preperceptual and stimulus-selective enhancement of low-level human visual cortex excitability by sounds. Current biology **19** (2009) 1799–1805.

[32] C. A. Sutherland, G. Thut, V. Romei: Hearing brighter: Changing in-depth visual perception through looming sounds. Cognition **132** (2014) 312–323.

[33] R. E. Pastore, J. Flint: Magnitude judgments of loudness change for discrete, dynamic, and hybrid stimuli. Attention, Perception and Psychophysics **73** (2011) 886–907.

[34] P. Susini, S. Meunier, R. Trapeau, J. Chatron: End level bias on direct loudness ratings of increasing sounds. The Journal of the Acoustical Society of America **128** (2010) EL163–EL168.

[35] R. D. Patterson, M. H. Allerhand, C. Giguere: Time-domain modeling of peripheral auditory processing: A modular architecture and a software platform. The Journal of the Acoustical Society of America **98** (1995) 1890–1894.

[36] G. C. Stecker, E. R. Hafter: An effect of temporal asymmetry on loudness. The Journal of the Acoustical Society of America **107** (2000) 3358–3368.

[37] R. P. Hellman: Loudness, annoyance, and noisiness produced by single-tone-noise complexes. The Journal of the Acoustical Society of America **72** (1982) 62–73.

[38] R Core Team: R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/, 2015.

[39] M. S. Gordon, F. A. Russo, E. MacDonald: Spectral information for detection of acoustic time to arrival. Attention, Perception and Psychophysics **75** (2013) 738–750.

[40] A. K. Anweiler, J. L. Verhey: Spectral loudness summation for short and long signals as a function of level. The Journal of the Acoustical Society of America **119** (2006) 2919–2928.

[41] J. L. Verhey, B. Kollmeier: Spectral loudness summation as a function of duration. The Journal of the Acoustical Society of America **111** (2002) 1349–1358.

[42] J. Hots, J. Rennies, J. L. Verhey: Loudness of subcritical sounds as a function of bandwidth, center frequency, and level. The Journal of the Acoustical Society of America **135** (2014) 1313–1320.

[43] W. Jesteadt: An adaptive procedure for subjective judgments. Attention, Perception and Psychophysics **28** (1980) 85–88.

[44] M. Florentine, T. Poulsen: Temporal integration of loudness as a function of level. The Journal of the Acoustical Society of America **99** (1996) 1633–1644.

[45] H. Levitt: Transformed up-down methods in psychoacoustics. The Journal of the Acoustical Society of America **49** (1971) 467.

[46] J. Schlittenlacher, T. Hashimoto, H. Fastl, S. Namba, S. Kuwano, S. Hatano: Loudness of pink noise and stationary technical sounds. Proceedings of Inter-noise, Osaka, 2011.

[47] J. Schlittenlacher, W. Ellermeier, T. Hashimoto: Spectral loudness summation: Shortcomings of current standards. The Journal of the Acoustical Society of America **137** (2015) EL26–EL31.

[48] R. L. Smith, J. J. Zwislocki: Short-term adaptation and incremental responses of single auditory-nerve fibers. Biological cybernetics **17** (1975) 169–182.

[49] B. R. Glasberg, B. C. Moore: A model of loudness applicable to time-varying sounds. Journal of the Audio Engineering Society **50** (2002) 331–342.

[50] J. J. DiGiovanni, R. S. Schlauch: Mechanisms responsible for differences in perceived duration for rising-intensity and falling-intensity sounds. Ecological Psychology **19** (2007) 239–264.

[51] T. Deneux, L. Francois, S. Sikiric, E. Ponsot, B. Bathellier: Cortical population nonlinearities reflect asymmetric auditory perception in mice. Cosyne 2015 Proceedings, 2015, 169.

[52] G. Grimm, V. Hohmann, J. L. Verhey: Loudness of fluctuating sounds. Acta Acustica united with Acustica **88** (2002) 359–368.

[53] G. Canévet, B. Scharf: The loudness of sounds that increase and decrease continuously in level. The Journal of the Acoustical Society of America **88** (1990) 2136–2142.

[54] G. Canévet, R. Teghtsoonian, M. Teghtsoonian: A comparison of loudness change in signals that continuously rise or fall in amplitude. Acta Acustica united with Acustica **89** (2003) 339–345.

[55] R. Teghtsoonian, M. Teghtsoonian, G. Canévet: Sweep-induced acceleration in loudness change and the "bias for rising intensities". Perception and Psychophysics **67** (2005) 699–711.

[56] K. N. Olsen: Intensity dynamics and loudness change: A review of methods and perceptual processes. Acoustics Australia **42** (2014) 159–165.

[57] D. H. Klatt: Software for a cascade/parallel formant synthesizer. The Journal of the Acoustical Society of America **67** (1980) 971–995.