Effect of the ISI on the asymmetry in global loudness between upramp and downramp sounds in a paired comparison experiment

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Some recent works dealing with the loudness of dynamic sounds showed that sounds that increase continuously in level (up-ramps) are perceived with a greater loudness change or global loudness than opposite down-ramps, although they only differ in direction. The understanding of sensory and cognitive mechanisms involved in the loudness of increasing and decreasing sounds is still a burning issue. In all the studies reporting this effect, estimations were made directly at the end of one ramp in single-stimulus paradigms or using a short ISI (Inter Stimulus Interval) between two ramps in paired-stimulus paradigms. In the present study, global loudness was measured using a paired comparison method. The influence of the ISI was examined for ramps that differed in direction, dynamic and maximum level. Results show that judgments (1) are dominated by the maximum level of a ramp, (2) are mainly independent of the direction of the first ramp of the pair and that, (3) asymmetries between up-ramps and down-ramps are reduced with a longer ISI. The Neuhoff evolutionary hypothesis explaining these asymmetries by an overestimation of up-ramps is discussed in regard to these results.

1 Introduction

Many recent studies investigating the loudness of dynamic sounds have been focused on the “bias for rising tones” revealed by Neuhoff [2]: in some conditions, an increasing sound – an up-ramp – is judged louder than a decreasing symmetric sound – a down-ramp. In Neuhoff preliminary experiment, listeners were asked to evaluate the loudness change of different ramps lasting 1.8 s using a visual analogue scale (VAS), labeled as "no change" and "large change" at the further points of the scale. Up-ramps were judged significantly higher than opposite down-ramps when they were either 1-kHz pure tones or complex vowel tones although they contained the same actual change in level. Neuhoff argues that “in a natural environment this overestimation could provide a selective advantage, because rising intensity can signal movement of the source towards an organism.” Teghtsoonian et al. [11] found asymmetries in favor of up-ramps in loudness change estimations of 2-s 1-kHz pure tones ramps. Their results reveal also that loudness change evaluation of up-ramps highly depends on the end level of the up-ramp, more than on its actual change in level. Consequently, they argued that the “bias for rising tones” was more a “bias for end levels”. In a more recent study, Susini et al. [8] confirmed that this bias exists in direct estimations of both loudness change and global loudness of up-ramps.

In all the studies reporting an overestimation of loudness change or global loudness of up-ramps compared to down-ramps, the way the judgment was made was not taken into consideration. In some studies, loudness change or global loudness was evaluated using a direct estimation after the end of each ramp by the means of a direct rating on a scale or by a magnitude estimation [2, 5, 9], whereas in other studies a paired comparison was performed where the inter-stimulus interval (ISI) was kept constant and equals to 0.5 s [3, 4].

Single-stimulus paradigms does not allow controlling carefully the moment when the judgment is made and therefore does not permit to investigate how the loudness impression of a ramp is stored in memory. Thus in the current study, it was decided to run a paired-comparison experiment in order to examine the effect of the ISI on loudness asymmetry between up- and down-ramps. In the present paper, two different values of ISIs have been studied: 0.5 s – value that was used in previous studies – and 8 s. The aim was thus to determine whether the asymmetry between up- and down-ramps is based on a short-term or a long-term persistent process. In other words, does the intensity of the loudness asymmetry between up- and down-ramps is the same after few seconds? In a recent study focused on the loudness of up-rams [10], it was shown that the “bias for end levels” caused by the end level of an up-ramp is time persistent, at least until 8 sec, which was the highest time delay considered by the authors. Thus, in the current study, it can be hypothesized that asymmetry between up- and down-ramps might be time persistent. Indeed, this asymmetry was previously explained by a perceptive or a cognitive overestimation of up-ramp compared to down-ramp tones; but judgments of up-ramps are now found to be consistent over time [10]. As far as we know, this is the first time that the ISI is considered in a study dealing with loudness of increasing and decreasing tones. It will therefore help to discuss deeper sensory and cognitive mechanisms as well as procedural evaluation biases which can be involved into loudness asymmetry between up- and down-ramps.

2 Experiment

In this experiment, two sounds were presented to the participant and he/she has to tell which sound was louder. The first sound is called the test tone, and the second one, the probe tone. Both, the test tone and the probe tone were varied between trials. The percentage of time the probe tone was perceived louder than each test tone was calculated. Moreover, this measure was done for two ISIs.

2.1 Participants

A group of 10 volunteered participants (7 men; 3 women) took part in this experiment. They were aged from 21 to 38 years old (median: 28 years old). No participant reported having hearing problems. They gave their informed consent prior to the experiments and were paid for their participation.

2.2 Stimuli

The stimuli (test and probe tones) were 1-kHz pure tones up-ramps and down-ramps with a linear onset and offset of 12 ms. Duration of the ramps was 2 s. The test tone was either a linear increasing ramp with a dynamic range of 15 dB (65 to 80 dB SPL) or the symmetrical decreasing ramp (80 to 65 dB SPL). The probe tones were linear increasing up-ramps and down-ramps with different dynamic (10, 15, 20 or 25 dB) and maximum level (75, 80 or 85 dB). The ramps used as test and probe tones in the experiment are given in Table 1.

2.3 Apparatus

The stimuli used were generated at a sampling rate of 44.1 kHz with 16-bit resolution using the Max-MSP software. Sounds were converted by RME Fireface 800 soundcard. Stimuli were amplified by a Lake People G-95 Phoneamp amplifier and presented diotically over a Sennheiser HD250Linear 2 headphone. Participants were seated in a double-walled IAC sound-isolation booth. Levels were calibrated using a Brüel & Kjær 2238 Mediator sound-level meter placed at a distance of 4 cm from right (left) earphone. The experiment was run using the PsiExp v2.5 experimentation environment including stimulus control, data recording, and graphical user interface [7].

Table 1: Ramps used as test and probe tones in the experiment.

Test tones	*Probe tones*
[65-80 dB SPL]	[60-75 dB SPL]
[80-65 dB SPL]	[60-80 dB SPL]
	[65-80 dB SPL]
	[70-80 dB SPL]
	[60-85 dB SPL]
	[65-85 dB SPL]
[65-80 dB SPL]	[75-60 dB SPL]
[80-65 dB SPL]	[80-60 dB SPL]
	[80-65 dB SPL]
	[80-70 dB SPL]
	[85-60 dB SPL]
	[85-65 dB SPL]

2.4 Procedure

A paired-comparison experiment was performed. For each trial, the test tone and the probe tone were presented successively using two different inter-stimulus intervals (ISI): 0.5 s or 8 s. Participants had to report which one was perceived with the highest loudness. They were asked to consider the entirety of the sounds to make their judgment, i.e. to make a comparison in terms of *overall loudness* or *global loudness*. The test tone and the probe tone were randomly chosen. Two trials were separated by a 4-sec interval. The ramps used for test and probe tones are mentioned in Table 1. For each participant, the whole experiment was divided into 2 sessions (one for ISI = 0.5 s, another for ISI = 8 s) within both the test tone and the probe tone were randomly varied between trials. Each session lasted approximately one hour. The sessions were scheduled on different days.

For the whole experiment, 11 estimations were collected for each condition *Test Tone - ISI - Probe Tone* and for each participant. Thus, during each session, participants listened to 264 sounds (1 ISI * 2 Test Tones * 12 Probe Tones * 11 presentations). A training session with 10 test and probe tones was performed before the first session in order to familiarize participants with the global loudness comparison task.

3 Results and discussion

3.1 Analysis of the data

In each trial, listeners had to compare in terms of global loudness two ramps. Every combinations were tested : the first ramp (the test tone) was either the [65-80 dB SPL] increasing ramp or the [80-65 dB SPL] decreasing ramp, which participants had to compare with the second ramp (the probe tone) which region of level changes, dynamic and direction of level changes varied in each trial (cf. Table 1). To analyze the answers given by participants, we compare how often the second sound was perceived louder than the first sound in each condition *Test Tone - ISI - Probe Tone*. An analyze of variance (ANOVA) considering these proportions was performed to examine effects and interactions of the different factors: the direction of the level change of the test tone, the ISI and the direction of level change, the region of level change, and the dynamic of the probe tone in different conditions:

- when the dynamic of the probe tone was 15 dB;
- when the dynamic of the probe tone was 20 dB;
- when the maximum level of the probe tone was 80 dB, which corresponds to the maximum level of the test tones used.

Surprisingly, the ANOVA did not reveal any effect of the direction of level change of the test tone. The proportions were qualitatively greater when the test tone was the down-ramp than the up-ramp but this effect was not significant. Perhaps it is due to an order effect in loudness paired-comparison. Indeed, it has been shown that the second sound of a pair is judged louder than the first one [6], this might have reduce the effect of the direction of level change of the test tone. Then, in order to withdraw this effect, an indirect analysis was done to compare up-ramps and down-ramps probe tones without considering the test tone.

Thus, the results are analyzed independently of the direction of level change of the ramp used as the test tone. In figures 1, 2 and 3, the proportion of probe tones perceived louder than test tones are presented, whatever the direction of the test tone was, for dynamic ranges of 15 and 20 dB respectively in figures 1 and 2, and for dynamic ranges of 10, 15, and 20 dB with the same end and start level (80 dB SPL) respectively for the up- and down-ramps. . On the left part of the figures, the results are shown for the 0.5-s ISI and on the right part for the 8-s ISI.

3.2 Probe tones with 15-dB dynamics

First, we consider only the conditions where the probe tone had a dynamic of 15 dB.

As expected, the region of level change was found to produce the main effect on the proportion of probe tones perceived louder than test tones ($F(1,9)=142.42$, $p<0.0005$): for the [60-75] region of levels, probe tones are judged softer compared to the test tones, whatever the direction of the probe tone is; for the [65-80] region of levels, it depends on the direction of the probe tone, and on the value of the ISI. In figure 1, it can be observed that the [65-80 dB SPL] up-ramp probe tone is perceived louder than the test tone; this loudness difference is similar for both ISI values. As the region of level change is the same in this case ([65-80]) for the probe and the test tones, the observed difference can be explained by the fact that the test tone is presented in both directions (up and down), and compared to a probe tone presented exclusively in the up direction. Moreover, we can also notice that the [80-65 dB SPL] down-ramp probe tone is perceived softer than the test tone at ISI=0.5 s, and as loud as the test tone at ISI=8 s. Thus, the difference between up- and down-ramp diminishes with ISI. This result will be discussed in particular below for [65-80] ramps.

Globally, compared to the down-ramp probe-tones, the up-ramps probe-tones are more often perceived louder than the test tone ($F(1,9)=8.72$, $p<0.05$); but this effect depends on both the region of level ($F(1,9)=22.33$ $p < 0.005$) and the ISI ($F(1,9)=5.5$ $p < 0.05$). For the [60-75] region of levels, results show that the observed difference between up- and down-ramp probe tones is small, but significant, and diminishes for ISI=8 s. For the [65-80] region of levels, the asymmetry between up- and down-ramp probe tones can be seen at first glance as a “bias for end levels” for up-ramps which is persistent over time, that is to say that global loudness impression for up-ramps is biased by the end level of the ramp for both values of ISI. However, as it was confirmed by the results of an ANOVA, the intensity of the difference between up- [65-80 dB SPL] and down-ramp [80-65 dB SPL] probe tones depends on the ISI. More precisely, a contrast analysis shows that, for up-ramp probe tones, there is no significant difference between the 0.5-s and the 8-s ISI conditions. This result confirms that the “bias for end level” for up-ramps is persistent over time with more or less the same intensity, which is in agreement with previous results [10]. At the opposite, there is a significant difference between the two ISIs when probe tones are down-ramps: the down-ramp probe tones are perceived less loud for the shortest ISI ($p<0.05$). Therefore, the asymmetry between up- [65-80 dB SPL] and down-ramp [80-65 dB SPL] probe tones is significantly reduced with the ISI because down-ramps are less underestimated for longer ISI values.

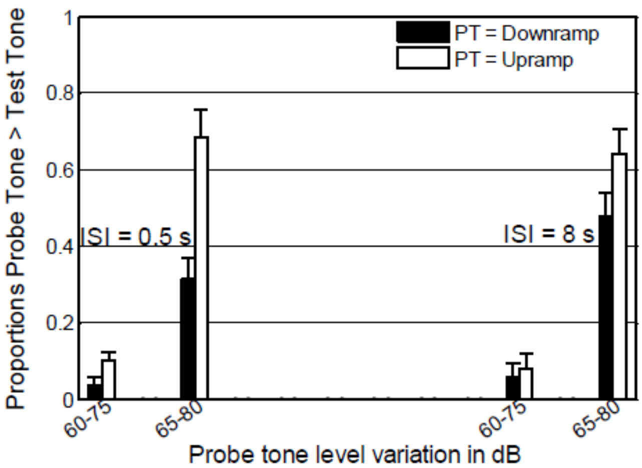

Figure 1: Mean proportion of probe tones perceived louder than test tones at ISI = 0.5 and 8 s when the dynamic of the probe tones was 15-dB. Error bars represent standard error of the mean.

3.3 Probe tones with 20-dB dynamics

Figure 2 shows the results for probe tones with a dynamic of 20 dB. Similar effects as those mentioned in the previous paragraph are observed. Results show that the region of level change was found once again to produce the main effect on the proportion of probe tones perceived louder than test tones ($F(1,9)=274.4$, $p<0.0005$); for the [65-85] region of levels, probe tones are judged louder compared to the test tones, whatever the direction of the probe tone is; for the [60-80] region of levels, it depends on the direction of the probe tone. These observations are confirmed by the results of an ANOVA showing that globally the difference between up- and down-ramp probe tones is significant ($F(1,9)=7.64$, $p<0.05$) with however a significant interaction between the direction and the region of level change of the probe tone ($F(1,9)=22.35$, $p<0.005$). Indeed, as for the results obtained for the 15-dB dynamic, it is clear that the maximum level (Max) of a ramp (up or down) has the dominant effect on the loudness comparison between the probe and the test tones whatever the direction of the probe tone ramp is; for the 15-dB dynamic, the probe tones (up and down) with the [60-75] region of levels (Max=75 dB SPL) are judged less loud than the test tones with the [65-80] region of levels (Max=80 dB SPL); for the 20-dB dynamic, the probe tones with the [65-85] region of levels (Max=85 dB SPL) are judged louder than the test tones with the [65-80] region of levels (Max=80 dB SPL). On the other hand, when the maximum level is the same (Max=80 dB SPL) for the probe tone (respectively for a region of levels of [65-80] for the 15-dB dynamic, and [60-80] for the 20-dB dynamic) and the test tone (respectively [65-80] dB SPL), the direction of the probe tone has an effect on the loudness comparisons: the proportion of probe tones perceived louder than test tones is significantly larger for the up-ramp than for the down-ramp. In addition, as for the 15-dB dynamic, the difference between up- and down-ramp diminishes with the ISI.

This later result, specifically for probe and test tones with the same maximum level (80 dB SPL) is confirmed by the ANOVA revealing neither any global effect of the ISI on the results nor any significant interaction of the ISI with the direction of level change of the probe tone, but a second order interaction between the ISI, the region and the direction of level change of the probe tone. In addition, a contrast analysis shows that, there is, in one hand, no significant difference between the 0.5-s and the 8-s ISI conditions for up-ramp probe tones, and on the other hand, a significant difference between the two ISIs for down-ramp probe tones. Therefore, once again, the asymmetry between up- [60-80 dB SPL] and down-ramp [80-60 dB SPL] probe tones is significantly reduced with the ISI because down-ramps are less underestimated for longer ISI values.

The ANOVA reveals one main difference with results obtained for the 15-dB dynamic; there is a significant interaction between the direction of the test tone and the ISI that was not found in the 15-dB dynamic condition ($F(1,9)=8.3$, $p<0.05$). In addition, this interaction depends on the region of level change of the probe tones ($F(1,9)=12.6$, $p<0.01$)). The probe tone is judged louder when compared to the decreasing test tone than to the increasing test tone at ISI = 0.5 s, and the reversed effect is obtained at ISI = 8 s. This is observed in the [60-80] conditions, but not in the [65-85] conditions.

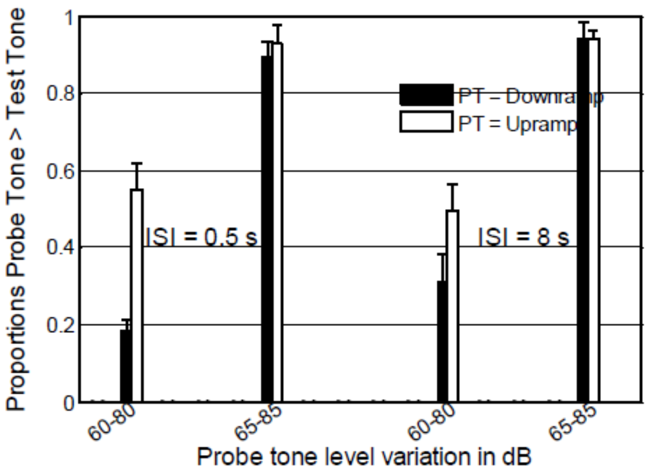

Figure 2: Mean proportion of probe tones perceived louder than test tones at ISI = 0.5 and 8 s when the dynamic of the probe tones was 20 dB. Error bars represent standard error of the mean.

3.4 Probe tones with a maximum level of 80 dB

In the previous sections (§3.2 and §3.3), the asymmetry between up- and down-ramp probe tones was highlighted when probe and test tones were presented with the same maximum level (80 dB SPL). This section examines this case for three dynamics (respectively [60-80], [65-80] and [70-80] dB SPL) and for the two ISIs (respectively 0.5 and 8 s). The results are presented in Figure 3. Observations of the figure reveals that 1/ loudness of the probe tones, for both directions, compared with the test tones increases with the dynamic (the lower the dynamic is, the higher loudness is), 2/ the asymmetry between up- and down-ramp probe tones is obtained for the three dynamics, 3/ this asymmetry diminishes, in one hand, with the ISI (it is less important for ISI=8 s), and on the other hand, with the dynamic (it is less important for the 10-dB dynamic than for the 15-dB, and for the 15-dB than for the 20-dB). An ANOVA confirms those effects. The main significant effect is obtained for the effect of the dynamic on loudness of the probe tones ($F(2,18)=60.16$, $p<0.0005$). The second effect concerns the ramp direction of the probe tones: loudness of up-ramp probe tones are significantly larger than loudness of down-ramp probe tones ($F(1,9)=14.69$, $p<0.005$). There is also a significant interaction between the ramp direction and the dynamic of the probe tone ($F(2,18)=3.78$, $p<0.05$). In other words, the intensity of the loudness difference between up- and down-ramp probe tones depends on the dynamic of the probe tone. Thus, the dynamic has two main effects: while the dynamic of the probe tones decreases, the loudness of up- and down-ramp probe tones increases, and the asymmetry between up- and down-ramp probe tones diminishes. The first effect can be explained by the fact that reducing the dynamic of a ramp, while keeping constant its maximum level and its duration, increases the overall physical energy of the stimulus; in the present study, the increase in ratings is about 20% between the 20-dB and the 15-dB dynamics and about 15% between the 15-dB and the 10-dB dynamics as mentioned above. The second effect provides an interesting explanation concerning the asymmetry between up- and down-ramps; indeed, reducing the dynamic of a ramp actually makes the stimuli closer to a constant tone with a sound pressure level corresponding to the maximum level of the ramp (up and down). Therefore, the "dynamical" characteristic is progressively lost as well as the asymmetry between up- and down-ramps. In others words, it looks like the effect of the ramp direction disappears as the sound converges toward a constant tone.

In addition, the ANOVA reveals a significant interaction between the direction of the probe tone and the ISI ($F(1,9)=7.1$, $p<0.05$); the effect of the direction is dependant on the ISI. As it was already shown in §3.2 and §3.3, a contrast analysis reveals a significant loudness increase for down-ramps and no change for up-ramps between the two ISIs ($p<0.05$). Therefore, for the three considered dynamics (respectively 10, 15, and 20 dB), the asymmetry between up- and down-ramp probe tones is significantly reduced with the ISI because down-ramps are less underestimated for longer ISI values, although up-ramps are equally estimated.

A significant interaction between the direction of the test tone and the ISI was also revealed by the ANOVA ($F(1,9)=11.89$, $p<0.01$). This result indicates that ratings made after a decreasing test tone were higher when the ISI was 0.5 s and not when ISI was 8 s.

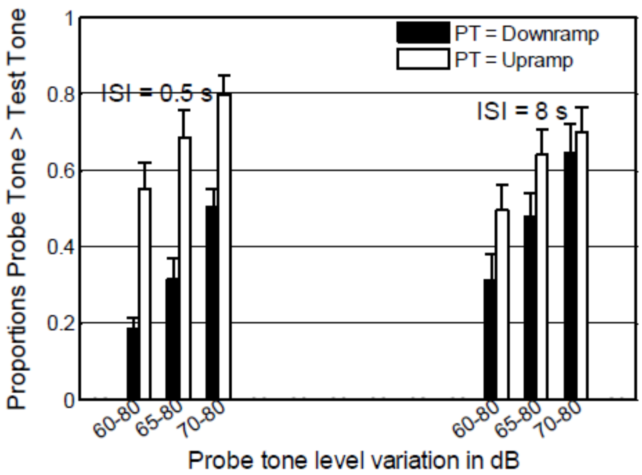

Figure 3: Mean proportion of probe tones perceived louder than test tones at ISI = 0.5 and 8 s when the maximum level of the probe tones was 80 dB. Error bars represent standard error of the mean.

4 Conclusion

In the present study, several interesting conclusions on the *global loudness* comparison between increasing and decreasing sounds can be drawn.

First, results showed that the comparison of loudness between ramps is dominated by the maximum level of the compared ramps: the [65-80] test tone was perceived more than 90% of times louder than the probe tone when followed by a [60-75] up- or down-ramp, whereas the effect is reversed for a [65-85] up- or down-ramp. This dominant effect of the maximum level is constant over the two ISIs.

Second, when the maximum level of the two compared ramps is the same, the ramp having the smallest dynamic is perceived louder for both directions. This effect was also shown for global loudness judgments of up-ramps using magnitude procedures in Susini et al. (2010), but the effect was apparently smaller even if it is difficult to compare results obtained by different experimental procedures.

Third, when both the maximum level and the dynamic of the two ramps are the same, the up-ramp is perceived louder than the opposite down-ramp: this is the “bias for end levels” occurring for up-ramps [8, 11].

Fourth, the asymmetry between up- and down-ramps is significantly reduced with a longer ISI. This is the newest result provided by the present study. Results show that this reduced asymmetry over time is independent of the “bias for end levels”. Indeed, the effect of the end level on the global loudness of up-ramps is not significantly different over time in the present study, which confirms other recent results by Susini et al. (2011). Interestingly, the present results show that the asymmetry between up- and down-ramps diminishes significantly due to variations of the global loudness of down-ramps over time: loudness of down-ramps is less underestimated few seconds (8 s) after the end of the stimulus than when estimated just after (0.5 s).

These results suggest that up-ramps loudness are governed by a “bias for end levels” which is persistent over time, and that down-ramps loudness are governed by a “bias for falling tones” which is less strong after few seconds. It was shown in a previous study that the “bias for end levels” for up-ramps was not based on a short-term memory process but rather on a time persistent process [8, 10]. At the opposite, based on the present results, it could be hypothesized that this “bias for falling tones” is a short-term memory process.

However, the understanding of the respective role of both sensory and cognitive mechanisms involved into this effect remains unclear while perceptual and procedural biases cannot yet be controlled carefully, as the influence of the presentation order of the ramps in a paired comparison experiment and the effect of the first ramp that can bias the loudness impression of the start portion of the second ramp of the pair. This study is a another step for understanding loudness asymmetries between up- and down-ramps, but further experiments have to be undertaken to explain this “bias for falling tones” and to confirm that it is responsible for the asymmetry between up- and down-ramps when judged shortly after the end of the compared ramps.

Finally, the present experiment reveals also that some perceptual biases might also exist when using a paired-comparison procedure. Indeed, in some conditions, the ratings depended on the direction of level change of the test tone and the ratings were higher when the test tone was the decreasing tone; but in other conditions, it did not.

Acknowledgments

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References

[1] 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), 339-345 (2003)

[2] J. G. Neuhoff, “Perceptual bias for rising tones”, *Nature* (395), 123-124 (1998)

[3] J. G. Neuhoff, “An Adaptive Bias in the Perception of Looming Auditory Motion”, *Ecological Psychology* (13), 87-110 (2001)

[4] K. N. Olsen, C. J. Stevens, J. Tardieu, “Loudness Change in Response to Dynamic Acoustic Intensity”, *Journal of Experimental Psychology* (36), 1631-1644 (2010)

[5] R. E. Pastore, J. Flint, “Magnitude judgments of loudness change for discrete, dynamic, and hybrid stimuli”, *Atten. Percept. Psychophys.* (73), 886-907 (2011)

[6] B. Sharf, “Loudness summation under masking”, *J. Acoust. Soc. Am.* (33), 503-511 (1961)

[7] B. Smith, “Psiexp: an environment for psychoacoustic experimentation using the IRCAM musical workstation”, *Society for Music Perception and Cogintion Conference'95*, University of California, Berkeley (1995)

[8] P. Susini, S. Meunier, R. Trapeau, J. Chatron, “End level bias on direct loudness ratings of increasing sounds”, *J. Acoust. Soc. Am. EL* (128), n° 4, 163-168 (2010)

[9] P. Susini, S. McAdams, B. Smith, “Loudness asymmetries for tones with increasing and decreasing levels using continuous and global ratings”, *Acta Acustica United with Acustica* (93), 623-631 (2007)

[10] P. Susini,, E. Ponsot, S. Meunier, “End-level dependency of loudness of increasing sounds: a time persistent effect”, *Forum Acusticum*, Aalborg (2011)

[11] R. Teghtsoonian, M. Teghtsoonian, G. Canévet, “Sweep-induced acceleration in loudness change and the “Bias for rising intensities”, *Perception & Psychophysics* (67), 699-712 (2005)