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Comparison between global loudness and loudness change ratings for increasing sounds

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Loudness change has been recently studied for tones with linearly varying levels. The published results by different authors revealed that direct ratings of loudness change for increasing sounds are higher compared to decreasing sounds. Interpretations of the results were different between Neuhoff's (1998) and Teghtsoonian et al's (2005) studies. The latter ones showed that judgments of loudness change were affected by the intensity at the end of the increasing sounds whereas Neuhoff claimed for a bias for rising sounds. Other studies by Canévet et al (2003) and Susini et al (2007) did not show any significant difference when judgement of loudness change were obtained indirectly by computing the ratio between estimated loudness at the beginning and the end of the sweep. On the other hand, direct judgments of the global loudness in the study by Susini et al revealed also that the judgments were affected by the end loudness of the increasing sounds. The assumption of the present article is that direct ratings of loudness change in Neuhoff's study are confounded with a global impression of loudness. Thus, three experiments were performed in order to test this methodological assumption. In the two first experiments, indirect and direct estimation of loudness change of increasing levels of synthetic vowel sounds and1-kHz tones for several ramp ranges of either two sizes (15, 30 dB) were obtained by magnitude estimation respectively for two groups of 16 participants. In the third experiment, a third group of 16 participants estimated the global loudness of the same stimuli also by magnitude estimation. Results of the first experiment reveal a difference between indirect and direct estimations. Indirect estimations are significantly different for ramp sizes of 15 and 30 dB and are independent of the end level, whereas direct estimations are not. In addition, direct estimations of loudness change show the same trend than the global loudness estimations according to the end level. These results suggest, as assumed, that direct ratings would rather measure a global impression of loudness than a loudness change.

1 Introduction

An important number of studies have recently investigated loudness of sounds that increase and decrease continuously in level. In his first study comparing increasing and decreasing sounds, Neuhoff (1998) asked participants to rate loudness change using a single direct estimation on a line by positioning a cursor along a scale. Teghtsoonian et al. (2005) replicated partly Neuhoff's experiment asking also participants to rate directly loudness change, but using a magnitude estimation method. In the 1998 Neuhoff's study, four different ranges of levels (from 60 to 90dB SPL) with only one ramp size (15 dB) were used; in the 2001 study, he used two different ranges of level with a 30-dB ramp size; and in Teghtsoonian et al.'s study, four and three ranges (from 30 to 90dB SPL) were used respectively with a 15 and 30-dB ramp size. In both studies, the duration of the ramps was 1.8 s. It was revealed that direct ratings of loudness change for up-ramp sounds were higher compared to down-ramp sounds. Neuhoff explained this overestimation as a bias for rising tones corresponding to a survival advantage for detecting an approaching sound source. On the other side, Teghtsoonian et al. explained this loudness change overestimation by an effect of the end level that affect ratings; a direct loudness change estimation is higher for an up-ramp sound (e.g. 60 to 80dB SPL) because it ends with a higher level than the equivalent down-ramp sound (e.g. 80 to 60dB SPL). In a recent study using a scale similar to the one used by Neuhoff, Olsen et al. (in press) have found that loudness change for up-ramps lasting 1.8 and 3.6 s with a ramp size of 20dB is greater for a high region of level changes (e.g. 70 to 90dB SPL) compared to a low region (e.g. 50 to 70dB SPL). This result reveals that direct loudness change ratings for up-ramps are much more affected by region of level changes (and as a consequence by end level) rather than by ramp size. It was hypothesised that the method used - direct ratings of loudness change - is more sensitive to the end level than to the ramp size, especially for up-ramps (Teghtsoonian et al., 2005).

In another study by Canévet et al. (2003), loudness change ratings were obtained indirectly using separate magnitude estimation of the starting and ending levels of ramps lasting 1.8, 10 and 50 s. Two ramp sizes were tested (15 and 30dB). Loudness change, defined as the ratio between the start and the end loudness estimations, was found not to be significantly different between up-ramps and down-ramps. The major significant difference was obtained between the two ramp sizes - indirect loudness change was higher for the 30-dB ramp size as it could have been expected -, whereas the same ramp sizes were found to be only slightly different based on direct loudness change ratings in Teghtsoonian et al.'s study. Indirect loudness change ratings were also obtained using continuous loudness ratings (Susini et al., 2007). The measure of the indirect loudness change was extracted from the recorded profiles of the continuous loudness estimations of up and down ramps with duration of 2, 5, 10 and 20 s. As in the previous study (Canévet et al., 2003), indirect ratings of loudness change do not reveal any significant perceptual difference between an up and down ramp. In the same study, direct ratings of the global loudness - the overall loudness impression - of the corresponding up and down ramps were obtained. Results showed that direct ratings were significantly higher for up than for down ramps, whatever the ramp duration. In addition, for the same up-ramp size (20dB), direct ratings of global loudness and end loudness increase significantly with duration. Thus it was assumed as for direct ratings of loudness change that global loudness is strongly affected by the end level of an up-ramp.

In conclusion, for up-ramps, results of the different studies show that, on the one hand, direct ratings, used to measure global loudness and loudness change, are strongly dependant on end level rather than on ramp size, and on the other hand, indirect ratings, used to measure loudness change, are dependant on ramp size – as it could have been expected. On the other side, it was hypothesised by Susini et al's (2007) that direct ratings of loudness change in Neuhoff's and Teghtsoonian et al's studies are confounded with direct ratings of global loudness for up-ramps, both heavily influenced by end level. A complementary hypothesis is that the perceptual phenomena corresponding to loudness change measured respectively by the two procedures, direct and indirect ratings, are not the same. However, these hypotheses are based on different published studies, often differing in significant detail. Therefore, in order to examine these assumptions, direct and indirect ratings of loudness change, and direct ratings of global loudness have to be compared in a common experimental setup.

In the present study, three experiments examining up-ramps were performed in the same experimental set-up. In the first experiment, a group of 16 participants estimated the global loudness of up-ramps by the method of magnitude estimation. In the second experiment, another group of 16 participants was instructed to estimate the amount of loudness change by magnitude estimation as in Teghtsoonian et al's (2005) study. Finally, in the last experiment, indirect estimations of loudness change were obtained by a similar procedure than the one used in Canévet et al's (2003) study. In order to compare our results with those from previous studies considering ramp size and end level effects, similar configurations of the control parameters were chosen. In addition, two different sounds (synthetic vowel and 1-kHz tone) were tested with the same ramp duration (1.8 sec) as in Neuhoff's (1998) and Teghtsoonian et al's (2005) studies. In the present article, two assumptions are examined:

- direct ratings of loudness change and global loudness are heavily dependant on end level,
- indirect ratings of loudness change are mainly dependant on ramp size.

In a primarily experiment, loudness scales for the synthetic vowel and the 1-kHz pure tone were obtained in order to compare ratings for each group of participants.

2 Loudness scale

Loudness functions for the synthetic vowel sound and the 1-kHz tone, measured by magnitude estimation, were first collected for the three groups of participants.

Three groups of 16 participants with ages ranging from 14 to 59 years, with a mean of 31 participated in the experiment. Each group performed the primarily experiment (loudness scale) and then rated the same up-ramps in one of the three experimental conditions described below. Participants were randomly allocated to each group.

The synthetic vowel sound was based on Klatt's (1980) algorithm with a fundamental frequency of 100 Hz and three formant frequencies (450, 1450 and 2450 Hz) as in Neuhoff's (1998) study. Ten steady state stimuli over a duration of 500 msec, and a rise and fall of 30 msec were randomly presented nine times following the procedure used by Canévet et al. (2003) in order to reduce any assimilation effect (see Cross, 1973, for a review).

Loudness estimations (geometric mean magnitude estimates, $N=16$ for each group) follow a power function of sound pressure with an exponent of 0.39, 0.38 and 0.41 for the 1-kHz tone, and 0.40, 0.37, 0.36 for the vowel sound respectively for the three groups of participants. The curves obtained have the usual shapes. Functions are represented in figures 1 and 2 respectively for the 1 k-Hz tone and the vowel sound.

3 Experiments

The same stimuli were presented to the three groups of participants. Stimuli were the 1-kHz tone and the vowel sound ramped with a linear increasing level variation in decibels over a duration of 1.8 sec as in Neuhoff's (1998) and Teghtsoonian et al's (2005) studies. There was no plateau at either the beginning or the end of the ramp. There were two ramp sizes: 15 and 30 dB. Seven regions of level changes were presented for the 15-dB ramp size: 45-60, 50-65, 55-70, 60-75, 65-80, 70-85, and 75-90 dB; and four for the 30-dB ramp size: 45-75, 50-80, 55-85, and 60-90 dB.

The stimuli were rated by each group in three different experimental conditions. In the first experiment, direct ratings of global loudness were obtained for each up-ramp. In the second and the third experiments, direct and indirect ratings of the loudness change were respectively obtained.

3.1 Direct rating of global loudness

The first group of participants were asked to assign a number to their global loudness impression for each ramp.

3.2 Direct rating of loudness change

The second group of participants were asked to assign a number to the amount of loudness change, as it was asked in Teghtsoonian et al's (2005) study.

3.3 Indirect rating of loudness change

The third group of participants were asked to assign a number to the end loudness of each up-ramp. Estimations of start loudness were extracted from the loudness scale obtained for theses group of participants. Then indirect ratings of loudness change were defined as the ratio between the end and the start loudness estimations for each ramp as in Canévet et al's (2003) study.

4 Results

The effects of the parameters ramp size and end level (region of loudness change), as well as type of sound (1-kHz tone and vowel sound), were evaluated in ANOVAs of log judgments. Three 15-dB ramps were omitted in each analysis (45-60, 50-65, and 55-70 dB), since there was no matching 30-dB with the same end level, whereas they are represented in figures 1 and 2. Measures obtained in the three experiments are compared with the loudness function of each individual group (bold lines in figures 1 and 2).

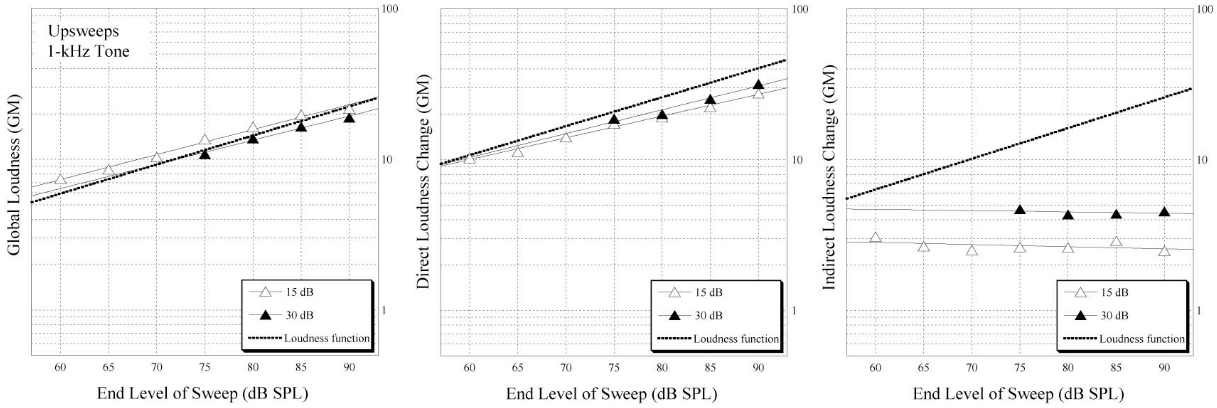

Figure 1: Ratings for the 1-kHz up-ramp tones as a function of end level for 15 or 30-dB ramp sizes and a duration of 1.8 sec. a) Direct ratings of global loudness obtained for the first group of participants (left panel), b) direct ratings of loudness change obtained for the second group of participants (middle panel), and c) indirect ratings of loudness change for the third group of participants (right panel). The bold lines represent the magnitude estimation function for loudness of a 1-kHz tone, respectively for the three groups of participants (values of the exponent are: 0.39, 0.38 and 0.41).

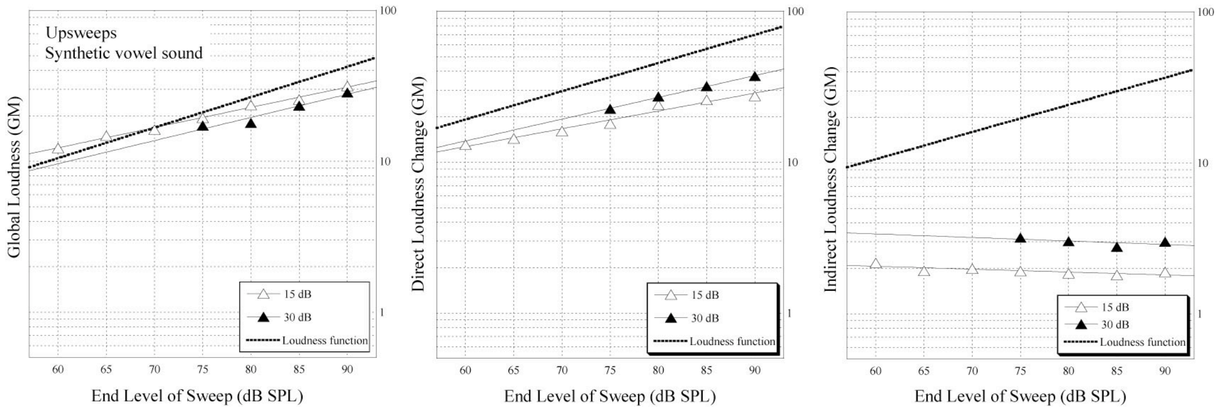

Figure 2: Ratings for the vowel up-ramp sounds as a function of end level for 15 or 30-dB ramp sizes and a duration of 1.8 sec. a) Direct ratings of global loudness obtained for the first group of participants (left panel), b) direct ratings of loudness change obtained for the second group of participants (middle panel), and c) indirect ratings of loudness change for the third group of participants (right panel). The bold lines represent the magnitude estimation function for loudness of the vowel, respectively for the three groups of participants (values of the exponent are: 0.40, 0.37, 0.36).

4.1 Direct rating of global loudness

Figure 1.a and figure 2.a present ratings of global loudness for the two ramp sizes as a function of end level respectively for the 1-kHz tone and for the vowel sound.

The figures show clearly that the global loudness increases with end level quite similarly for the two ramp sizes, and follows the loudness function for the 1-kHz tone. Figure 1.a shows that global loudness of a 1-kHz up-ramp is similar to the loudness of a steady state sound (loudness function) presented at a level equivalent to the end level of the ramp. The analysis of variance reveals a significant major effect of end level ($F(3, 45) = 37.7$, $p<0.0001$), and no interaction between type of sound and end level, which means that the end level effect is independent of the type of sound. However, the slope of the linear regression of the global loudness ratings and the power function are slightly different, especially for the vowel (0.32 against 0.39 for the 1-kHz tone, 0.27 against 0.40 for the vowel).

The analysis reveals also a small difference, but significant ($F(1, 15) = 28.9$, $p<0.0001$) between ratings obtained for the two ramp sizes; global loudness ratings for the 15-dB ramp size are higher. This latter result is coherent with the fact that for two up-ramps ending at the same level, there is more energy over the same duration for a dynamic of 15-dB (e.g. 75-90 dB) compare to a dynamic of 30-dB (e.g. 60-90). Finally, the analysis reveals no significant interaction between ramp size and the other factors implying that the difference between the two ramp sizes is valid independently of the type of sound and the end level.

4.2 Direct rating of loudness change

Figure 1.b and figure 2.b present direct ratings of loudness change for the two ramp sizes as a function of end level respectively for the 1-kHz tone and for the vowel sound.

The curves show profiles quite similar to those found for the global loudness, revealing a little effect of the ramp size and an important influence of the end level. In the present task, it was asked to rate loudness change, and thus, it was expected to have similar ratings of loudness change for up-ramps with the same ramp size irrespective of end level (e.g. [70-85] or [75-90] dB). However, the analysis of variance reveals again a major significant effect of the end level ($F(3, 45) = 26.7$, $p<0.0001$). This result is consistent with the results obtained by Teghtsoonian et al. (2005). The deviation between the slopes of the linear regression of the direct ratings of loudness change and the slopes of the loudness function obtained for the second group of participants (0.30 against 0.38 for the 1 kHz and 0.26 against 0.37 for the vowel) is greater than the one observed for the global loudness experience; slopes are less steep especially for the vowel.

Thus, even if the effect of end level is significant, ratings of loudness change are less dependent to the end level, especially for the vowel. This latter result is confirmed by a small, but significant, interaction between type of sound and end level ($F(3, 45) = 4.3$, $p<0.01$).

On the other hand, the analysis reveals a significant effect of ramp size ($F(1, 15) = 8.8$, $p<0.01$), but unlike for global loudness, ratings of loudness change are higher for the 30-dB ramp size, which seems normal as it was asked to estimate loudness change. However, this effect is much smaller than the end level effect discussed previously. Finally, there is a small interaction between type of sound and ramp size ($F(1, 15) = 4.8$, $p<0.05$), implying that the dynamic effect depends on the type of sounds. Inspection of figure 1.b and 2.b shows that the difference between 15 and 30-dB ramp sizes is lower for the 1-kHz tone.

4.3 Indirect rating of loudness change

In the third experiment, loudness change was not measured directly as in the second experiment, but it was evaluated as the ratio of separate loudness ratings of the start and end levels. Loudness estimation of the start level was supposed to be equivalent to the loudness of a steady state sound presented at a level equivalent to the start level of the up-ramps; therefore this value was extracted from the loudness function obtained for the third group during the primarily experiment. As loudness of the end level, it was rate by participants of this group for each up-ramp by the method of magnitude estimation. Figures 1.c and 2.c present indirect ratings of loudness change. It is clear that profiles of the curves are very different to those obtained for direct ratings of loudness change.

Results reveal that indirect ratings of loudness change are much higher for the 30-dB ramp size. In addition, the regression lines for the 30 and 15-dB ramp sizes are parallel, and the value of the slopes is nearly zero, which means that indirect ratings for a given ramp size are similar irrespective of end level. These results are corroborated by the analysis of variance revealing an important significant effect of the ramp size parameter ($F(1, 15) = 236.4$, $p<0.0001$) and no effect for the end level, as for the interactions. On average, loudness change for a 30-dB ramp size is 1.6 times greater than for a 15-dB ramp size. This ratio is similar to the one obtained by Canévet et al (2003) between up-ramps of 45-75 and 60-75 dB.

5 Conclusion

Results of the three experiments performed using the same experimental setup confirm the assumptions that were based on the results from different studies about loudness of sounds that increase continuously in level:

- Direct ratings of loudness change and global loudness are indeed heavily dependant on end level. However, both measures are slightly affected by the size of the ramp. For two up-ramps with the same duration and ending at the same level; global loudness is higher for a ramp-size of 15-dB compared to a ramp-size of 30-dB, which is coherent with the fact that there is more energy in the first one; inversely, loudness change is higher for a ramp-size of 30-dB which is coherent with the fact that participants were asked to rate this variation. Anyway, the described effect of the ramp size was small compared to the effect of the end level when in an experimental procedure requiring a direct estimation.

- Indirect ratings of loudness change are only dependant on the ramp size; loudness change is higher for a ramp-size of 30-dB, and it is invariant with the end level. The difference between ramp sizes of 30 and 15 dB is largely higher (ratio of 1.6) compared to the difference obtained with direct ratings of loudness change.

In conclusion, the comparison of the results from the three experiments reveals that:

- The perceptual phenomena corresponding to loudness change measured respectively by the two procedures, direct and indirect ratings, are not the same.
- Direct ratings of loudness change and global loudness for up-ramps are both heavily influenced by end level, but small differences between these two measures regarding ramp size do not confirm completely our assumption that direct ratings of loudness change may be confounded with direct ratings of global loudness for up-ramps.

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