LOUDNESS ASYMMETRIES FOR TONES WITH INCREASING AND DECREASING LEVELS

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ABSTRACT

Studies of loudness change for tones with linearly varying levels using different loudness rating methods, such as direct estimation or indirect estimation based on the start and end levels, have revealed an asymmetry depending on the direction of change (increasing vs decreasing). The present study examines loudness asymmetry between increasing and decreasing levels for 1-kHz tones over the range 60-80 dB SPL and over four ramp durations (2, 5, 10 and 20 s) using direct global and continuous loudness ratings made by subjects. Three measures extracted from continuous ratings (loudness duration, loudness change, loudness slope), on the one hand, and the global loudness rating, on the other hand are examined and analyzed separately. Measures extracted from continuous ratings do not reveal any significant perceptual asymmetry between an increasing and a decreasing ramp. However, direct estimation of the global loudness is higher for an increasing ramp than for a decreasing ramp. This result can be explained by a short-term auditory memory effect called the "recency effect".

1. INTRODUCTION

The present study deals with loudness asymmetry between sounds of increasing and decreasing levels with the same sound-pressure-level change. Recently, different studies have focused on asymmetry in loudness change ratings obtained by direct estimation [1, 2] or by estimation based on separate loudness ratings of the start and end levels of a linearly varying sound [3, 4]. The same trend has been observed for loudness change ratings by Neuhoff [1] and Teghtsoonian et al. [2] revealing that loudness change is higher for an increasing sound than for a decreasing one when the level changes in a moderate or high range (such as 60-75 or 75-90 dB) However, these authors' interpretations are different. Neuhoff explained the overestimation of the increasing ramp by a survival advantage for detecting an approaching sound source. Teghtsoonian et al. explained it by a strong influence of the end level.

In addition, several studies have revealed that the loudness of continuously increasing sounds grows slightly more rapidly than the predicted loudness of stationary sounds with the same level. This effect has been termed "upcruitment". The same studies reveal that the loudness of continuously decreasing sounds diminishes more rapidly than the predicted loudness of stationary sounds with the same level. This effect has been termed "decruitment" [4].

The goal of the study presented in this paper is to examine the loudness asymmetry between increasing and decreasing levels for 1-kHz tones using single direct global and continuous loudness ratings made by subjects employing a continuous analogical/categorical (A/C) rating scale.

The work will be presented in two parts. In the first experiment, a group of subjects estimated continuously the loudness of stimuli composed of concatenated increasing and decreasing ramps. These results will be compared with those of Canévet et al. [3, 4]. In the second experiment, another group of subjects estimated the global loudness of increasing or decreasing ramps separately. These results will be compared with those of Neuhoff and Teghtsoonian et al. Ramp durations (2, 5, 10, 20 s) are close to values used by Neuhoff (1.8 s) [1] and Teghtsoonian et al. (1.8, 2, 20 s) [2]. The range of levels (60-80 dB SPL) and the type of stimuli (1-kHz pure tones) were chosen to be close to a configuration of variables for which the measurement of loudness change tends to be asymmetric [1, 2].

2. EXPERIMENT 1: CONTINUOUS RATINGS

The aim of this experiment was to examine the loudness asymmetry between increasing and decreasing levels using continuous loudness ratings and to compare results with those of Canévet et al. [4].

2.1. Method

2.1.1. *Stimuli*

Stimulus sequences consisted of four 1-kHz pure tones with time-varying levels. The contours were composed of a 3-s constant-level plateau, followed by increasing (60 to 80 dB) and decreasing (80 to 60 dB) linear ramps of identical duration, and finally another 3-s constant-level plateau. The durations of increasing and decreasing ramps were 2, 5, 10 or 20 s (figure 1). For each sequence, the linear onset and offset ramps of the amplitude envelope were 50 ms in duration.

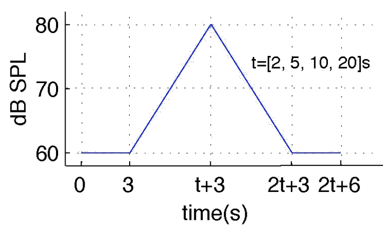

Figure 1. *Stimuli*

2.1.2. *Apparatus*

The present study used an analogical/categorical scaling device (A/C) without force feedback [5, 6]. Briefly, the device combines an analog measurement with several visually presented discrete category labels. In the version used in this study, the range of variation of the cursor was subdivided into seven categories. The labels were very, very loud; very loud; loud; medium; soft; very soft; and very, very soft (see appendix). The lables were presented in French (*très, très fort* to *très, très faible*).
The stimuli used were generated at a sampling rate of 44.1 kHz with 16-bit resolution by a NeXT workstation equipped with IRCAM's ISPW digital-signal-processing card and Max software [7]. The sounds were converted by ProPort digital-to-analog converters. The stimuli were amplified by a Yamaha P2075 stereo amplifier and presented diotically over a Sennheiser HD420 headset. Subjects were seated in a double-walled IAC sound-isolation booth. Levels were calibrated using a Brüel & Kjær 2238 Mediator sound-level meter. The experiment was run using the PsiExp v2.5 experimentation environment including stimulus control, data recording, and graphical user interface [8].

2.1.3. *Procedure*

The subjects listened attentively to the sound sequences and continuously estimated the temporal evolution of their loudness with the device, associating at each moment a position along the analogical/categorical scale equivalent to the perceived level. The subject triggered the successive presentations by pressing a key on the computer keyboard. Stimuli were presented only once, in a different random order for each subject.

2.1.4. *Subjects*

A group of 15 subjects participated in the experiment (12 men, 3 woman, mean age = 26 yr, SD = 4 yr). No subject reported having hearing problems.

2.2. Results

The continuous rating profiles obtained (Figure 2.a) are similar to those obtained in a previous study with the same device and the same stimulus sequences (see [5]). In the present study, continuous rating profiles were separated into two continuous loudness profiles corresponding to the increasing and decreasing ramps (ramp direction) for durations of 2, 5, 10 and 20 s (ramp duration). Then, maximum and minimum values were extracted for each profile and each subject. Max is the maximum value of the profile and corresponds to the perceived change from an increasing to a decreasing ramp (see Figure 2.b). Min(I) and Min(D) are the minimum values for the increasing and decreasing parts of the profile, respectively. These values correspond to the loudness estimation of the 3-s plateaux at 60 dB at the beginning and end of each stimulus, respectively. They are indicated by circles in Figures 2.b and 2.c.
Three additional measures were calculated independently from increasing and decreasing parts of the profiles (Figure 2.c): Ld (Loudness duration) is the continuous rating profile duration. Lc (Loudness change) is the difference between start and end values of the rating profile. Ls (Loudness slope) is the slope obtained by a linear regression onto continuous ratings.

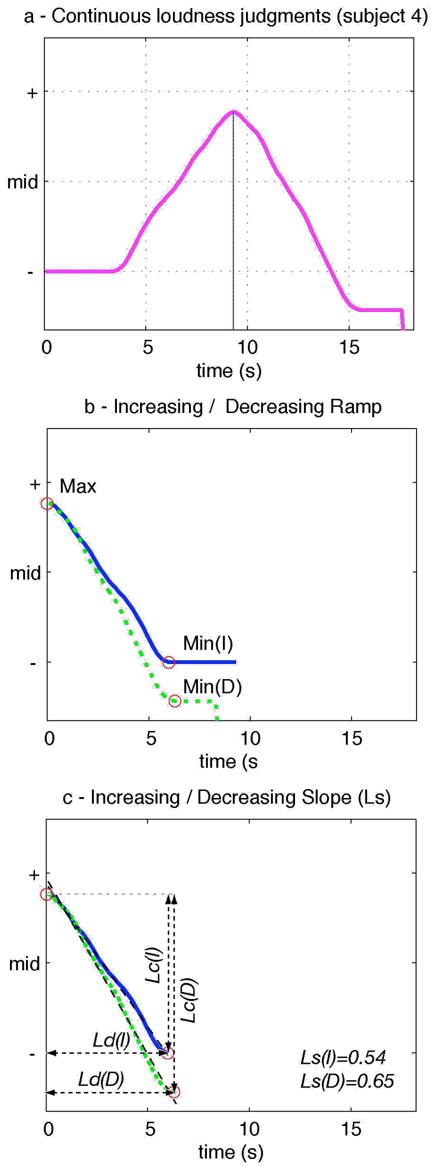

Figure 2. *a) Continuous loudness profile obtained by subject 4 for a ramp duration of 5 s. b) Superposition of increasing and decreasing profiles. c) Slopes obtained by linear regression of the continuous rating profiles.*

Several repeated-measures analyses of variance (ANOVA) were performed with factors ramp duration (4 levels) and ramp direction (2 levels).

2.2.1. *Loudness duration (Ld)*

The ratio between the continuous rating profile duration (Ld) and the ramp duration for the increasing and decreasing parts would be equal to 1.0 if profile durations were identical to ramp durations. For the short ramp duration (2s), the profile duration is significantly higher, but when ramp duration increases, the ratio approaches 1.0 whatever the ramp direction ($F(3, 42) = 34.8$, $p < 0.0001$, e=0.46). The ANOVA reveals no effect of ramp direction ($F(1, 14) = 0.18$, NS) nor an interaction between duration and direction ($F(3, 42) = 2.65$, NS).

2.2.2. Loudness change (Lc)

Loudness change expressed as the number of scale categories increases significantly with ramp duration ($F(3, 42) = 15.9$, $p < 0.0001$) but the effect of direction is not significant ($F(1, 14)=2.50$, NS) and does not interact with ramp direction ($F(3, 42)=2.56$, NS).
Figure 3 presents Min(I), Max, and Min(D) as a function of ramp duration. The value of Min(I) is constant across ramp durations (upward triangles) ($F(3, 42) = 0.23$, NS). The value of Min(D) seems to decrease slightly with the ramp duration (downward triangles), but the effect is not significant ($F(3, 42) = 2.70$, NS). Finally, only Max increases significantly across the four ramp durations ($F(3, 14) = 14.6$, $p < 0.0001$, e=0.70).

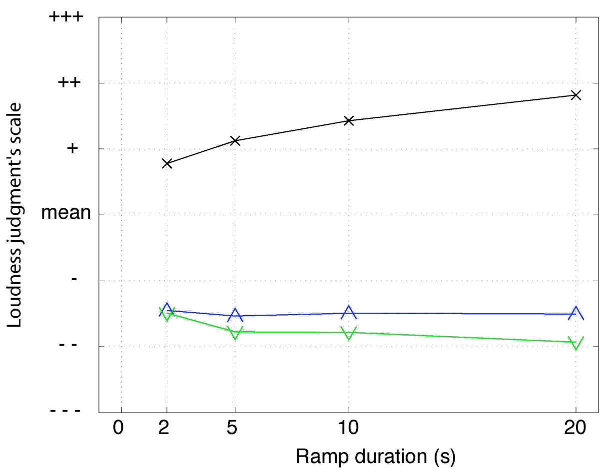

Figure 3. *Min(I) (upward triangles), Max (crosses), and Min(D) (downward triangles) as a function of the ramp duration.*

2.2.3. Loudness slope (Ls)

Average values for Ls are presented in Figure 4 for each ramp duration as a function of ramp direction.

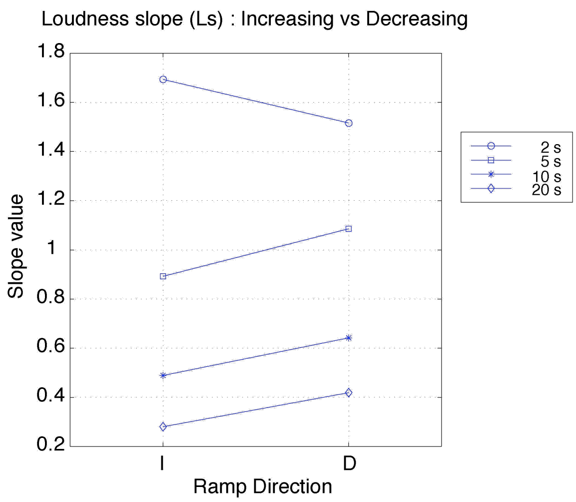

Figure 4. *Loudness slope (Ls) values calculated by linear regression of both increasing (I) and decreasing (D) rating profiles for each ramp duration.*

Of course, loudness slope increases significantly with ramp duration ($F(3, 42) = 32.2$, $p < 0.0001$, e=0.41), but the most interesting result is the significant interaction between ramp duration and ramp direction ($F(3, 42)=3{,}31$, $p < 0.05$, e=0.58). The loudness slope of a decreasing ramp is higher than that of an increasing ramp for durations of 5, 10 and 20 s. The inverse is true for a ramp duration of 2 s.

2.3. Discussion

An analogical/categorical (A/C) method was used in this study to record continuous loudness ratings associated with increasing and decreasing 1-kHz tones with an identical level range of 60-80 dB and ramp durations of 2, 5, 10, and 20 s. Three measures (Ld, Lc, Ls) were calculated individually for the increasing (I) and decreasing (D) parts of the response profiles as a function of ramp duration.
The profile duration (Ld) is equivalent to the physical ramp duration for values of 5, 10 and 20 s, whatever the ramp direction. However, a rapid change in level (2 s) seems to be overestimated in duration in the continuous rating profiles. The overestimation obtained for the short ramp duration can be explained by the reaction time observed in such continuous rating tasks, which depend on the type of stimulus and on the subject. The average reaction time for the device used here is about 0.9 s [5, 6].
The loudness change (Lc) measure is the difference between start and end rating. In a way, Lc is a measure similar to the loudness change calculated by Canévet et al. [4], defined as "the ratio between end-of-sweep and initial estimations" obtained by magnitude estimation. In the present study, for level changes in the interval 60-80 dB, the Lc measure reveals that the rated change of loudness increases as a function of ramp duration, but there is no significant difference between increases and decreases. For a 1-kHz tone and level changes in the 60-75 dB range, Canévet et al's [4] results reveal no significant difference between increases and decreases, nor for across-ramp durations, except for a slight increase with duration for a 4-kHz tone. In the present study, increase of loudness change with duration is strongly correlated with the end loudness (Max) of the increasing ramp. This "upcruitment" effect seems greater in our study than in Canévet et al's study [4] and may be a result of the continuous rating method. In a previous study [5], a similar level drift appeared in the continuous loudness ratings for an increasing ramp (60 to 80 dB) as a function of the ramp duration using the same A/C device as well as a cross-modal matching device. A level drift appeared also in the global loudness rating performed at the end of the ramp whether or not a continuous rating task was performed before the global rating. This latter point indicates that the drift in ratings is not merely a consequence of the continuous rating task.
The end loudness of the decreasing ramp, Min(D), in Figure 3 tends to decrease slightly with duration in agreement with the decruitment effect, but not significantly in the present study. It has been stated that the decruitment effect occurs for 1-kHz tones starting at a moderate level (70 dB) and decreasing continuously to a low level (40 dB) with a ramp duration of 20 s [2]. Among other variables, the effect diminishes when the ramp duration decreases below the 10-20 s range and when the end level of the decreasing ramp is above the 40-50 dB range [4, 9]. This latter result explains why the decruitment effect is not significant with the range of levels used in the present study (80-60 dB).
Finally, neither Ld nor Lc measures reveal any perceptual asymmetry between the increasing and decreasing ramps. Only the loudness slope measure (Ls), calculated by linear

regression of rating profiles, reveals a difference depending on the ramp duration. Indeed, results indicate that continuous loudness ratings change more sharply for an increasing ramp than for a decreasing one when the ramp duration is 2 s, and inversely, when the ramp duration is 5, 10 or 20 s. This result in favor of a perceptual difference between an increasing and a decreasing ramp depending on the ramp duration needs to be confirmed using a different continuous rating method.

3. EXPERIMENT 2: GLOBAL RATING

The aim of this experiment was to examine the loudness asymmetry between increasing and decreasing levels using global loudness ratings and to interpret results in terms of an auditory memory effect.

3.1. Method

3.1.1. Stimuli

Stimulus sequences consisted of eight 1-kHz tones with time-varying levels: four increasing ramps (60 to 80 dB) and four decreasing ramps (80 to 60 dB) with ramp durations of 2, 5, 10 or 20 s each having a 3-s plateau at 60 dB at the beginning or end, respectively (Figure 5). For each sequence, the onset and offset ramps were 50 ms in duration.

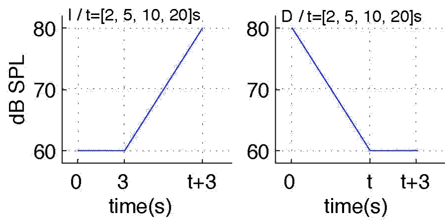

Figure 5. *1-kHz tones with time-varying levels: four increasing ramps (I) and four decreasing ramps (D) with ramp durations of 2, 5, 10 or 20 s, respectively.*

3.1.2. Apparatus

The apparatus was identical to that of Experiment 1.

3.1.3. Procedure

The subjects simply listened to the eight sound sequences and rated their global loudness over the entire duration at the end of the sequence using the same A/C scaling device. Stimuli were presented once each in random order.

3.1.4. Subjects

A group of 15 subjects participated in the experiment (11 men, 4 woman, mean age = 24 yr, SD = 3 yr). No subject reported having hearing problems.

3.2. Results

An analysis of variance with the global rating as dependent variable was performed to examine the effects of ramp duration, ramp direction and their interaction. The main effect of ramp direction is highly significant ($F(1, 14) = 35.03$ $p<0.0001$, $e=0.86$). Figure 6 shows clearly that the global loudness rating is higher for an increasing than for a decreasing ramp.

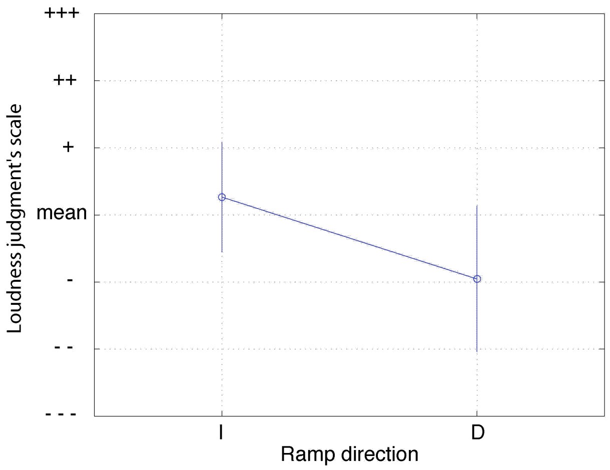

Figure 6. *Global loudness for increasing and decreasing ramps. Mean of ratings by 15 subjects over four ramp durations.*

The main effect of ramp duration is not significant, but its interaction with ramp direction is ($F(3, 42)=3.51$, $p<0.05$, $e=0.86$). It thus appears that the effect of the duration is present but it varies as a function of the ramp direction. Indeed there is a smaller difference between directions at 2 s than at the other durations. Figure 7 presents global ratings obtained for increasing and decreasing ramps as a function of duration. Separate ANOVAs on increasing and decreasing stimuli show that the global rating of increasing ramps increases as a function of duration ($F(3, 14)=8.25$, $p<0.0005$, $e=0.91$), and small, nonsignificant variations appear for decreasing ramps ($F(3, 14)=0.88$, NS).

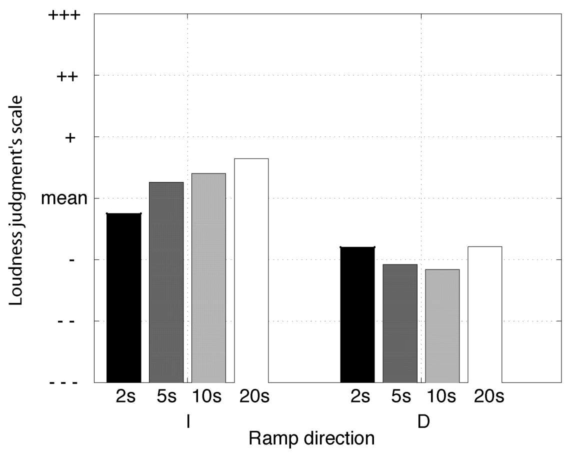

Figure 7. *Global loudness for increasing (I) and decreasing (D) ramps for each ramp duration.*

3.3. Discussion

In the second experiment, only a single, direct global loudness rating was made using the A/C method at the end of four increasing and four decreasing ramps. The ramps corresponded to a linear level variation from 60 to 80 dB and from 80 to 60 dB, respectively, with ramp durations of 2, 5, 10, and 20 s. This experimental paradigm is similar to paradigms used by Neuhoff [1] and by Teghtsoonian et al. [2]. In the first one, subjects were asked “to mark on a line the point representing the loudness change of the sweep, where the left end was defined as *very small* and the right end as *very large”*. In the second one, subjects were asked “to assign a number to *the amount of loudness* change perceived in each sweep”. The target “loudness change” is of course different from the target of the present study, “global loudness”, but all paradigms require a single, direct estimation, which is different from the estimation based on separate loudness ratings of the start and end levels like our Lc measure or the ratings made by Canévet et al.'s [3, 4] subjects to examine the decruitment effect. Therefore results concerning direct global loudness ratings obtained in the present study can be compared with those obtained from direct “loudness change” estimations by Neuhoff [1] and by Teghtsoonian et al. [2].

Results reveal that the global loudness rating is higher on average for an increasing than for a decreasing ramp, whatever the ramp duration. The same trend has been observed for loudness change ratings by Neuhoff [1] and Teghtsoonian et al. [2], although interpretations are different as mentioned in the introduction.

Finally, global loudness ratings reveal a perceptual asymmetry between increasing and decreasing ramps. Previous results [5] showed that the global loudness of a nonstationary 1-kHz tone depends on the dominant event in the loudness profile, but also on its temporal position relative to the end of the sound sequence, most likely related to a short-term auditory memory effect called the "recency effect". The latter effect seems primarily to be related to the temporal energy distribution. Thus the global loudness is judged higher when the highest-level peak is situated at the end rather than at the begining of a sound sequence. From this point of view, the global loudness difference between an increasing and a decreasing ramp can be explained by the recency effect as was proposed by Höger et al. [10].

4. CONCLUSION

Loudness change and loudness duration measures extracted from continuous ratings do not reveal any perceptual asymmetry between an increasing and a decreasing ramp except the fact that loudness change is steeper for an increasing ramp than for a decreasing one when ramp duration is 2 s. The reverse is true for longer duration ramps. More importantly, the measures do not reveal any decruitment effect which is in agreement with Canévet's results for a range of levels such as those used in the present study (80-60 dB).

The major conclusion is that global loudness ratings tend to increase with the duration of the increasing ramp, and in the other, it is higher for an increasing ramp than for a decreasing one. This fact is in agreement with recent results by Teghtsoonian et al. [2] concerning rating of loudness change revealing that global loudness ratings tend to vary with the end loudness. Finally, a short auditory memory effect, recency effect, is a possible explanation for the global loudness difference between an increasing and a decreasing linear ramp.

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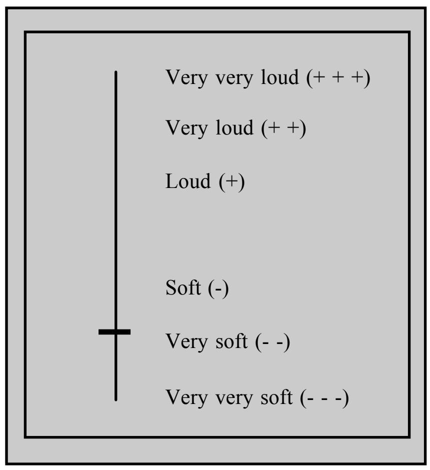
6. APPENDIX



Analogical/categorical scale on the continuous response device.