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Loudness Asymmetries for Tones with Increasing and Decreasing Levels Using Continuous and Global Ratings

Patrick Susini, Stephen McAdams*, Bennett K. Smith*
Institut de Recherche et de Coordination Acoustique/Musique (STMS-IRCAM-CNRS), 1 place Igor Stravinsky, F-75004 Paris, France. susini@ircam.fr

Summary
Loudness change has been studied for tones with linearly varying levels using different loudness rating methods, such as direct estimation or indirect estimation based on the starting and ending levels. The published results reveal an asymmetry depending on the direction of change (increasing vs. decreasing), the range of levels (high vs. low), and on the loudness rating method involved. 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 two additional loudness ratings: continuous ratings and global ratings. A continuous analogical/categorical (A/C) rating scale was used, which consisted of an analog scale subdivided into seven discrete categories labeled from *very, very loud* to *very, very soft*. Two measures are obtained, examined and analyzed separately: indirect and direct loudness measures that correspond to the loudness change extracted from continuous ratings and the overall loudness impression, respectively. Loudness changes do not reveal any significant perceptual asymmetry between an increasing and a decreasing ramp. In addition, results do not reveal any "decruitment" effect, i.e. the loudness of a continuously decreasing tone changes more rapidly as a function of sound pressure level, which is in agreement with previous results for this range of levels. On the other hand, direct estimation of the global loudness, i.e. an overall loudness rating of the stimulus, is higher for an increasing ramp than for a decreasing ramp. This result is in agreement with previous studies and can be described by a memory process dominated by the ending level.

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1. Introduction

A large number of studies have been done on the loudness of stationary sounds. Traditional procedures of loudness evaluation (see [1] for a review) and measurement [2, 3] yield reliable and robust results for sounds presented at a constant level. Since S.S. Stevens' studies, it is well known that the loudness of a 1000-Hz pure tone is a power function of the sound pressure with an exponent value equal to 0.6 [1, 4]. On the other hand, few studies have been performed on the loudness of sounds that change in level over time spans larger than a few seconds. So we know little about the loudness of non- stationary sounds. However, the two major studies on the loudness of non-stationary sounds investigated sounds that increase and decrease continuously in level [5, 6, 7, 8, 9, 10, 11, 12, 13], as well as the relation between continuous and global evaluations of long-duration sound sequences [14, 15, 16, 17, 18, 19]. The present study deals with the former case, considering two kinds of loudness evaluation as in the latter case, i.e., a continuous and a global evaluation. This paper examines the loudness asymmetry between increasing and decreasing levels by analyzing two kinds of impressions: an instantaneous one at each moment during the sound variation and a global one at the end of the sound.

In the studies undertaken by Canévet [5] and Canévet *et al.* [6], the loudness of a continuously increasing 1000-Hz tone has been found to change as a function of sound-pressure level in approximately the same manner as the loudness of a 1000-Hz tone presented at different steady levels. However, the loudness grows slightly more rapidly than expected, although the effect is small. This effect is called "upcruitment" by Canévet *et al.* [6] or Sweep-Induced Enhancement (SIE) by Teghtsoonian *et al.* [12]. On the other hand, the loudness of a continuously decreasing 1000-Hz tone changes more rapidly as a function of sound pressure level, especially at levels below 40 dB. This latter result is called "decruitment" or Sweep-induced Fading (SIF) by the same authors and is greater than the upcruitment effect. It may be related to an auditory adaptation at low levels, i.e., a decline in the loudness that be-

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* Current address: CIRMMT, Schulich School of Music, McGill University, 555 Sherbrooke St. W., Montreal, QC, Canada H3A 1E3.

comes greater as threshold is approached. This effect appears for continuously decreasing 4-kHz and 1-kHz tones [11], starting at medium levels (e.g., about 60 dB) and ending at low levels (e.g., below 40 dB). The effect is usually not as clear with noise sounds as with pure tones [6, 12]. Results reported by Schlauch [13] reveal an identical effect for such low-level conditions and a smaller one for high-level conditions. In summary, the decruitment effect diminishes for moderate level changes such as 75 to 60 dB [11] or high level changes such as 90 to 50 dB [13], and for sweep durations below the region of 10 to 20 s, but disappears at the shortest duration of 1 s [9]. Thus, under several conditions the loudness of continuously decreasing levels diminishes more rapidly than loudness of continuously increasing levels. This result reveals an asymmetry in loudness changes in favour of decreasing levels. In other words, the loudness change of decreasing levels is amplified compared to that of increasing levels.

In contrast, a study by Neuhoff [7] reveals that loudness change is higher for an increasing sound than for a decreasing one. This asymmetry occurred with synthetic vowel sounds and 1000-Hz tones, but not with broadband noises. Neuhoff describes this result as a bias for rising tones and explains this bias by a survival advantage for detecting an approaching sound source. This effect appears for level changes in the interval between 60 and 90 dB with a duration of 1.8 s. For such conditions, results reported by Canévet *et al.* [11] do not reveal any loudness differences between increasing and decreasing levels. The major distinction between Canévet et al's and Neuhoff's studies is the difference between the judgment methods. In fact, in the study by Neuhoff loudness change ratings were obtained using a single direct estimation on a line by positioning a cursor along a scale. The left end of the scale was defined as "no change" and the right end as "large change". In contrast, many of the studies on decruitment or SIF undertaken by Canévet *et al.* used loudness ratings based on separate magnitude estimation of the starting and ending levels of a linearly varying sound. The loudness change is thus defined as the ratio between the ending and starting ratings [11]. Recently, Teghtsoonian *et al.* [12] considered the case in which loudness change is judged directly, in a similar way to Neuhoff's task, but using magnitude estimation. The stimuli were a 1000-Hz tone and a broadband noise. Levels changed in the interval between 30 and 90 dB with a duration of 1.8 s. Results disclosed the same trend as for Neuhoff's results revealing that loudness change judged directly is higher for an increasing than for a decreasing sound when the level changes in a moderate to high range (such as 60–75 or 75–90 dB). Teghtsoonian *et al.* explained this result by a strong influence of the end level. In other words, direct judgments of loudness change are higher when level is increasing than decreasing, but these judgments are indistinguishable from judgments of the loudness at the end of the increasing ramp. The latter interpretation is closely related to the results obtained in studies investigated on the relation between continuous and global loudness evaluation of non-stationary sounds revealing that global loudness judgments are influenced by the loudness at the end of the sound sequence [19, 20].

Finally, it seems that the two main conflicting results, in favour of a decreasing ramp in one case, and in favour of an increasing ramp in the other, are strongly dependent on the procedure for measuring loudness change: indirect estimation by evaluating the start and end of the ramp versus direct estimation by evaluating the overall ramp. One hypothesis is that the perceptual phenomenon measured by the two procedures is not the same, as argued by Neuhoff [8]. Considering these previous studies, the goals of the study presented in this paper are:

- to examine the question of loudness asymmetry between increasing and decreasing levels using relatively new measures – indirect measures extracted from continuous loudness ratings, and global loudness impressions – and
- to examine what is estimated by a direct loudness measurement, e.g., average loudness, loudness change or end loudness.

Two experiments were performed. In the first experiment, stimuli were composed of concatenated increasing and decreasing ramps. A group of subjects estimated continuously the loudness of the increasing and the decreasing ramps. This is similar to our everyday experience. For example, a car is judged to be louder and louder as it approaches, and softer and softer as it moves away from the listener. Each moment corresponds to an instantaneous loudness impression and is part of a loudness profile, a record of the level fluctuation estimation with time. Thus instantaneous loudness is used to extract indirect ratings of the loudness change as well as the loudness duration. Loudness duration is the duration of the continuous rating profile and is measured to check whether subjects are influenced by errors of habituation when judging continuously an increasing and a decreasing ramp. Such errors are known to occur with the method of limits when the subject tends to develop a habit of repeating the same response as the stimulus is gradually changed (Gescheider, 1976; p. 30). A similar effect could occur in the case of continuous ratings of loudness in slowly changing stimuli. Continuous loudness judgments are obtained using a continuous analogical/categorical method [16, 19] presented in the first part. In the second experiment, another group of subjects estimated the global loudness of increasing and decreasing ramps separately. Direct loudness ratings are extracted. In both experiments, the range of levels (60–80 dB SPL) and the type of stimuli (1-kHz pure tones) as well as the ramp durations (2, 5, 10, 20 s) were chosen to be close to a configuration of variables for which the measurement of loudness change tended to be symmetric in the Canévet *et al.* study [11] when using indirect measurements, and asymmetric in Neuhoff [7] and Teghtsoonian *et al.* [12] when using direct measurements. The results are compared with those obtained by Canévet *et al.* in the first part with those obtained by Neuhoff and Teghtsoonian *et al.* in the second part.

2. Experiment 1: Continuous ratings

Although most studies have examined the loudness of short-duration stationary or long-duration non-stationary sounds using single direct-rating methods, several studies have examined the loudness of time-varying sounds using continuous rating methods [14, 15, 16, 18, 19]. The goal of this first experiment is to measure the loudness change of increasing and decreasing ramps using continuous loudness estimations. In the next section, the continuous analogical/categorical (A/C) method [16, 19] used to obtain continuous loudness estimations is presented. Then loudness change and loudness duration are calculated indirectly. Loudness duration is measured here to examine whether there is a tendency for subjects to develop a habit of making the response past the end of an increasing or a decreasing ramp, which we term an error of habituation.

2.1. Method

2.1.1. Stimuli

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

2.1.2. Apparatus

The analogical/categorical scaling device (A/C) includes a cursor connected to a potentiometer and mounted on a small rectangular box. The cursor is displaced in a continuous manner by the subject along a 20-cm analog scale visually subdivided into seven discrete categories (Figure 2). The labels of the categories are *very, very loud*; *very loud*; *loud*; *mid*; *soft*; *very soft*; and *very, very soft*. The labels were presented in French (*très, très fort* to *très, très faible*). The labels will be represented in figures by symbols +++ for very, very loud, ++ for very loud, etc… An output voltage corresponds to the position of the cursor and allows the continuous recording of the listener's judgment. The rectangular box is placed on a table just in front of the subject's seat.

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 [21]. 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 [22].

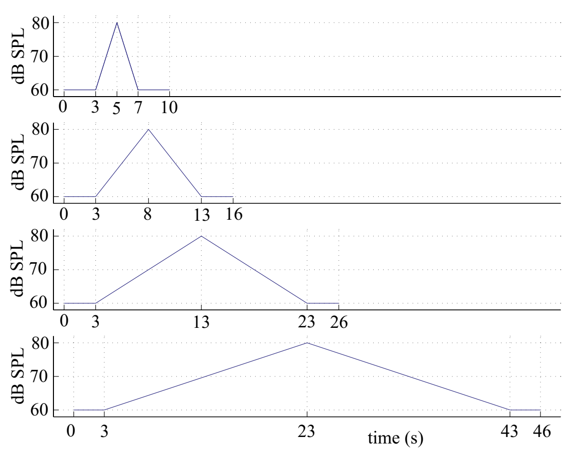

Figure 1. 1-kHz tones with time-varying levels: four stimuli composed of increasing then decreasing ramps with ramp durations of 2, 5, 10 or 20 s.

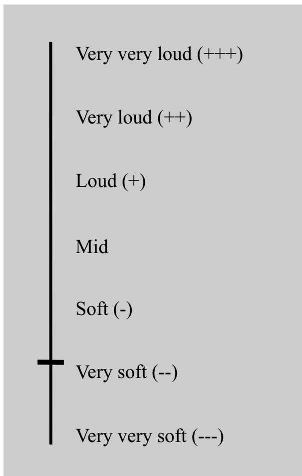

Figure 2. Analogical/categorical scale on the continuous response device.

2.1.3. Procedure

The subjects were asked to listen attentively to the sound sequences and to estimate continuously the temporal evolution of the 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 each in a different random order for each subject. Before starting, subjects performed a training trail by continuously evaluating a 1-kHz tone composed of three peaks with a maximum level at 80 dB SPL. The increasing and decreasing ramps forming each peak were 5 s or 10 s in duration. The duration was chosen at random for each subject. The two plateau between the three peaks had a duration of 10 s and a constant level of 60 dB SPL. Each stimulus started and ended with a 3-s plateau at 60 dB SPL.

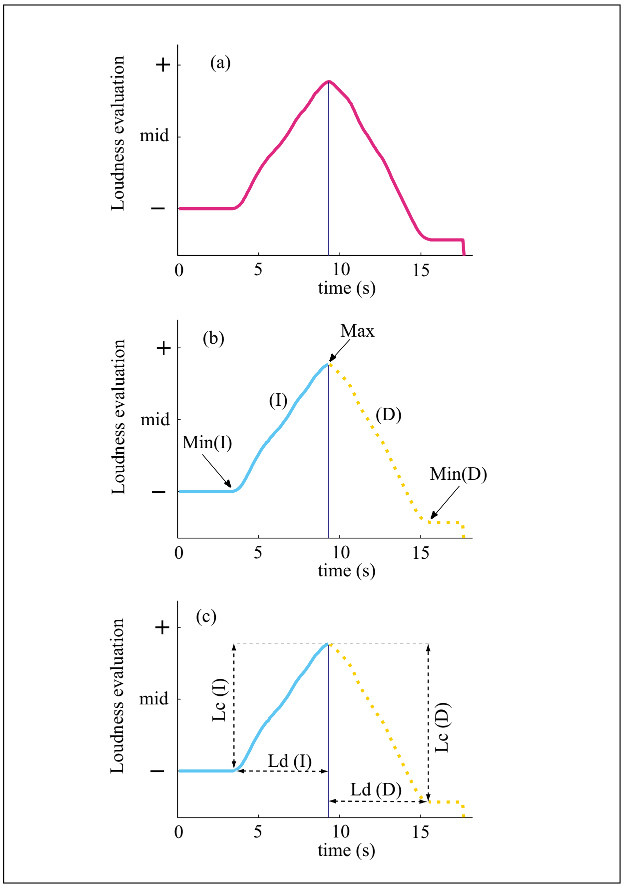

Figure 3. a) Continuous loudness profile obtained by subject 4 for a ramp duration of 5 s. b) Increasing ramp (I), continuous line, and decreasing ramp (D), dotted line. Max, Min(I) and Min(D) values of the loudness profile are indicated for the increasing and decreasing parts. c) Loudness change (Lc) and loudness duration (Ld) measures are indicated for each ramp type (I, D).

2.1.4. Subjects

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

2.2. Results

The continuous rating profiles obtained (Figure 3a) 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, three instantaneous loudness estimations were extracted:

- the maximum value (Max) of the continuous loudness judgments, which corresponds to the perceived transition point from increasing to decreasing levels (see Figure 3b),
- the two minimum values (Min(I) and Min(D)) respectively for increasing and decreasing parts of the continuous loudness profile. In other words, those two values correspond to the loudness estimation of the two 3-s plateau at 60 dB SPL.

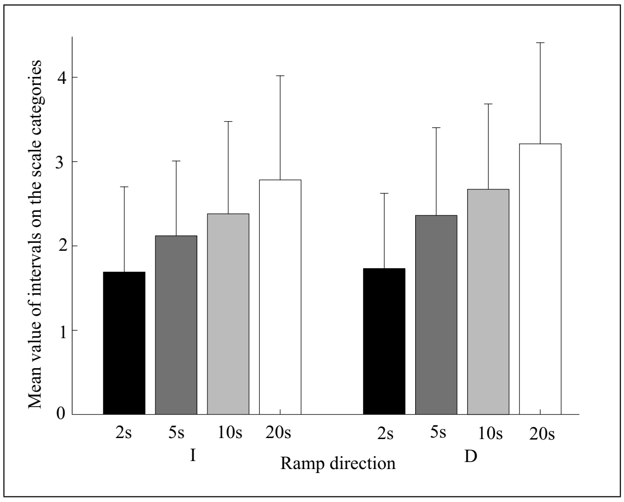

Figure 4. Loudness change (Lc): absolute difference between start and end ratings, (Max-Min(I)) and (Max-Min(D)), for increasing and decreasing ramps of 2, 5, 10 and 20 s. Mean of ratings by 15 subjects for the four ramp durations. The vertical bars represent ±1 SD of the mean.

The three values are indicated in Figure 3b and may be seen as similar to the use of magnitude estimates of loudness taken at the start and at the end of an increasing and decreasing ramp. The Max value is equivalent to the end estimate of an increasing ramp and to the start estimate of a decreasing ramp. Finally, the indirect measure of loudness change, labeled Lc in the present article, is calculated by the difference Max-Min(I) and Max-Min(D) for increasing and decreasing ramps, respectively (Figure 3c). This is equivalent to the indirect measure calculated by Canévet *et al.* [11]. The loudness duration, labeled Ld, is obtained similarly (Figure 3c). The Lc value is represented in Figure 4 as a continuous value corresponding to a distance in terms of intervals on the scale categories. For example, the Lc value of a 5-s increasing ramp is 2.15, which means that the difference Max-Min(I) is close to a distance equivalent to two intervals on the scale categories.

By inspection of Figure 4, on the average Lc values increase with ramp duration and seem slightly higher for decreasing than for increasing ramps for durations of 5, 10 and 20 s. A repeated-measures analysis of variance (ANOVA) was performed with two factors: ramp duration (4 levels) and ramp direction (2 levels). The effect of direction is not significant ($F(1,14) = 2.50$, NS). However, Lc increases significantly with ramp duration ($F(3,42) = 15.9$, $p < 0.0001$) and does not interact with ramp direction ($F(3,42) = 2.56$, NS). It is instructive to consider the effect size of the ramp duration factor. The percentage of total variance accounted for by each effect is indicated by the R^2 coefficient. The main effect of ramp duration accounts for about 17% of the total variance.

Figure 5 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) ($F(3,42) = 0.24$, NS, $R^2 = 0.1\%$). The value of Min(D) seems to decrease slightly with the ramp duration (downward triangles), but

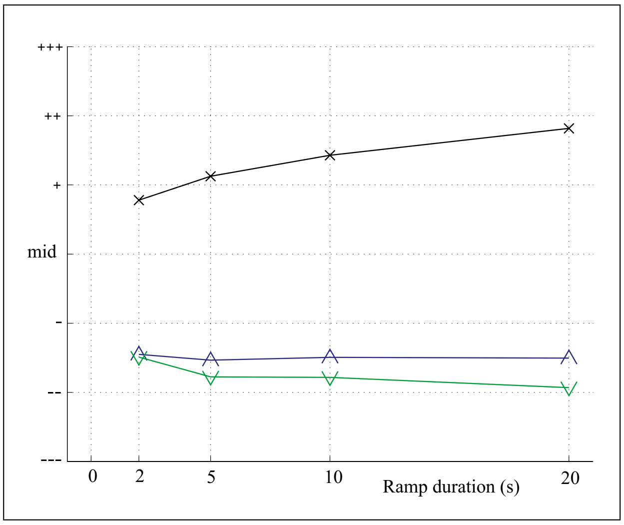

Figure 5. Max (crosses), Min(I) (upward triangles) and Min(D) (downward triangles) values of loudness profiles as a function of the ramp duration. Mean of ratings by 15 subjects for the four ramp durations.

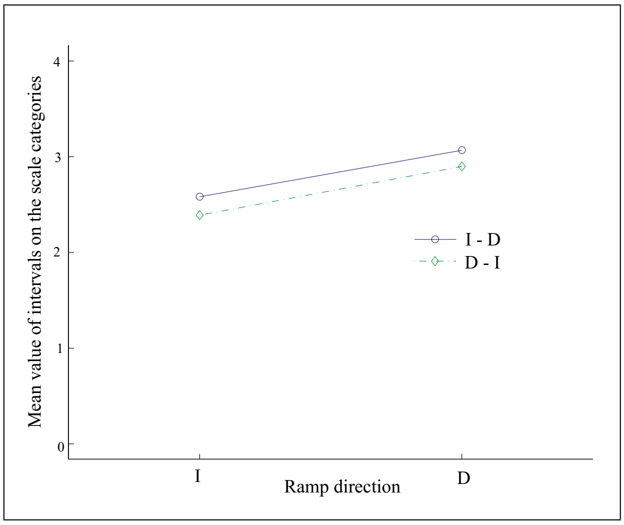

Figure 7. Average loudness change (Lc) for increasing and decreasing ramps with two orders of presentation: an increasing followed by a decreasing ramp (I-D), and a decreasing followed by an increasing ramp (D-I).

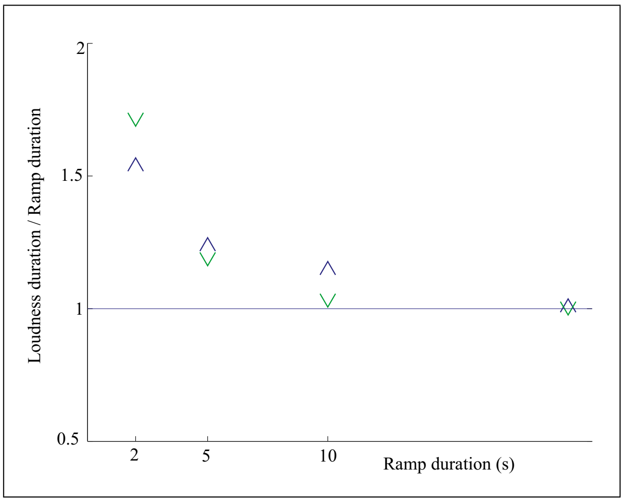

Figure 6. Ratio between the continuous rating profile duration (Ld) and the ramp duration for increasing (upward triangles) and decreasing (downward triangles) profiles as a function of ramp duration. Mean of ratings by 15 subjects for the four ramp durations.

the effect is not significant ($F(3,42) = 2.7$, NS, $R^2 = 5.1\%$). Finally, only Max increases significantly across the four ramp durations ($F(3,14) = 14.6$, $p < 0.0001$). The duration effect for Max values represents 17% of the total variance as was the case for Lc values.

In addition to the loudness change (Lc), the loudness duration (Ld) was measured in order to observe whether any error of habituation appeared depending on ramp direction. Figure 6 presents the ratio between the continuous rating profile duration (Ld) and the physical ramp duration for the increasing and decreasing parts as a function of ramp duration. The ratio would be equal to 1.0 if profile durations and ramp durations were identical. Single sample t-tests show that the ratio is significantly higher for short ramp durations ($p < 0.0005$ for 2 s, $p < 0.001$ for 5 s). A repeated-measures ANOVA reveals no effect of ramp direction ($F(1,14) = 0.18$, NS, $R^2 = 0\%$), nor an interaction between duration and direction ($F(3,42) = 2.65$, NS, $R^2 = 2.4\%$).

2.3. Complementary experiment

In Experiment 1, all stimuli were composed of increasing (60 to 80 dB SPL) followed by decreasing (80 to 60 dB SPL) linear ramps of identical duration, that is to say the same order for each stimulus. Thus it is possible that there are order effects on the comparison of the two directions. In order to check for such effects, a complementary experiment was performed using the same experimental procedure with stimuli presented in the reverse order.

2.3.1. Stimuli

Stimulus sequences consisted of eight 1-kHz pure tones with time-varying levels: four stimuli were the same as in Experiment 1, an increasing ramp followed by a decreasing one (I-D), and the four other stimuli were the reversed versions, a decreasing followed by an increasing ramp (D-I). More precisely, the reversed versions were composed of a 3-s constant-level plateau at 80 dB SPL, followed by decreasing (80 to 60 dB SPL) and increasing (60 to 80 dB SPL) linear ramps of identical duration, and finally another 3-s constant-level plateau at 80 dB SPL.

2.3.2. Subjects

A group of 6 subjects from IRCAM's lab participated in the experiment (6 men, mean age = 37 yr, SD = 3 yr). No subject reported having hearing problems.

2.3.3. Results

In Fiure 7, as in Figure 4, the Lc value is represented in terms of number of intervals on the scale categories. By inspection of Figure 7, on the average Lc values are higher for decreasing than for increasing ramps and seem slightly higher for the I-D order. A repeated-measures ANOVA was performed with three factors: ramp duration (4 levels), ramp direction (2 levels) and presentation order (2 levels). Neither the effect of direction ($F(1,5) = 4.68$, NS), nor the effect of presentation order ($F(1,5) = 1.24$, NS) are significant.

2.4. 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. Fifteen subjects participated in the experiment and individual continuous loudness rating profiles were obtained. Loudness change (Lc) was calculated individually for the increasing (I) and decreasing (D) parts of the response profiles as a function of ramp duration.

Lc is an indirect measure obtained by the difference between instantaneous loudness judgments taken at the beginning and end of a ramp extracted from the response profile. In a way, Lc is a measure similar to the loudness change calculated by Canévet *et al.* [11], defined as "the ratio between end-of-sweep and initial estimations" (p. 343) 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 significantly as a function of ramp duration with a relatively small effect size ($R^2 = 17\%$). On the other hand, there is no significant difference between increases and decreases for both order of presentation. For a 1-kHz tone and level changes in the 60-75 dB range, Canévet et al's [11] results also revealed no significant difference between increases and decreases, nor across ramp durations of 2, 10 and 50 s, except for a slight increase with duration for a 4-kHz tone. In the present study, comparison of Figures 4 and 5 shows that on average Lc and Max values increase as a function of the ramp duration. An analysis of variance reveals that both values increase significantly with the same effect size ($R^2 = 17\%$). This is not the case for Min(I) and Min(D); the mean values are constant across ramp durations. Finally, we can say that loudness change (Lc) depends mainly on the Max value. The end loudness of the decreasing ramp, Min(D) in Figure 5, 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 (60 dB) and decreasing continuously to a low level (40 dB) with a ramp duration of 20 s at least [6, 12]. 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 50 dB. In the present study, results obtained by means of relatively new measures under several conditions do not reveal any decruitment effect, confirming the results of previous studies [11, 12].

The second measure extracted from the response profile for the increasing (I) and decreasing (D) parts is the loudness duration (Ld). This measure was obtained to check for errors of habituation as a consequence of the continuous loudness evaluation procedure used. In addition, errors of habituation may depend on the ramp direction. Indeed, errors of habituation may affect loudness profiles by falsely increasing ascending ratings and/or decreasing descending ratings when listeners continue the trajectory beyond an inflection point or the end of the stimulus. As a result of such an effect, durations of the response profile for the increasing (I) and decreasing (D) parts would be longer than the respective physical ramp durations. Results reveal that loudness duration (Ld) is equivalent to the physical ramp duration for values of 10 and 20 s, whatever the ramp direction. However, a rapid change in level (5 s,2 s) seems to be overestimated in duration in the continuous rating profiles for both ramp directions. 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 [16, 19]. Finally, results do not reveal any error of habituation depending on the ramp direction.

In conclusion, neither loudness change (Lc) nor loudness duration (Ld) measures obtained indirectly reveal any perceptual asymmetry between the increasing and decreasing ramps as was expected from Canévet et al's results [11]. The complementary experiment performed reveals that loudness change (Lc) is also independent of the order of presentation. In addition, the end loudness of the increasing ramp (Max) increases as a function of the ramp duration, while the end loudness of the decreasing ramp (Min(D)) is almost constant.

3. Experiment 2: Direct rating of global loudness

The goal of this second experiment was to examine the question of loudness asymmetry by measuring the loudness of increasing and decreasing ramps using direct loudness ratings as in the Neuhoff [7] and Teghtsoonian *et al.* [12] studies. In the present experiment, direct loudness ratings were obtained using the continuous analogical/categorical (A/C) method as in the first experiment. The main difference between the present study and studies by Neuhoff [7] and Teghtsoonian *et al.* [12], aside from the rating method, is the definition of the direct loudness judgment requested at the end of each stimulus. In previous studies, subjects were instructed to judge the amount of loudness change [7, 12], whereas in the present study, subjects were instructed to judge the global loudness, that is to say the overall loudness of the stimulus. This choice was made in order to examine our results in comparison to findings that global judgments depend more on instantaneous ratings made at the end than at the beginning of a sound sequence [19, 20, 23].

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 8). Increasing and decreasing ramps for durations of 2, 5, 10 and 20 s are denoted I2, I5, I10, and I20, and D2, D5, D10 and D20, respectively. For each sequence, the onset and offset ramps were 50 ms in duration.

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. At the end of each sound sequence, they were asked to rate the global loudness over the entire duration with the A/C scaling device by positioning the cursor appropriately and pressing a key on the computer keyboard to record the position. After the global judgment, the subject triggered the presentation of the next trial by pressing a key. Stimuli were presented once each in random order.

3.1.4. Subjects

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

3.2. Results

Figure 9 presents global ratings obtained for increasing and decreasing ramps as a function of duration. The figure shows clearly that the global loudness rating is higher for an increasing than for a decreasing ramp. An analysis of variance with raw 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 ($F(1,14) = 35$, $p < 0.0001$, $R^2 = 28.4\%$).

The effect of ramp duration is not significant, but its interaction with ramp direction is ($F(3,42) = 3{,}51$, $p<0.05$, $R^2 = 3\%$). It thus appears that the effect of the duration is present but it varies as a function of the ramp direction. Single sample t-tests reveal that duration effect is only significant for the increasing ramp with a duration of 2 s ($p<0.05$, $p<0.05$, $p<0.001$ when compared respectively with durations of 5, 10 and 20s).

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 [7] and Teghtsoonian *et al.*

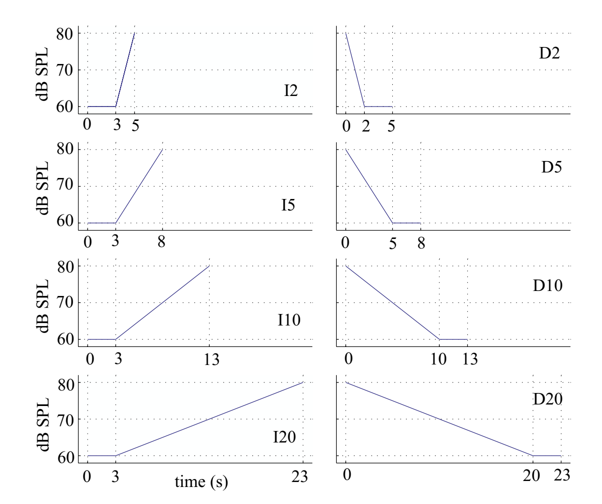

Figure 8. 1-kHz tones with time-varying levels: four increasing ramps (I2, I5, I10, I20) and four decreasing ramps (D2, D5, D10, D20) with ramp durations of 2, 5, 10 or 20 s.

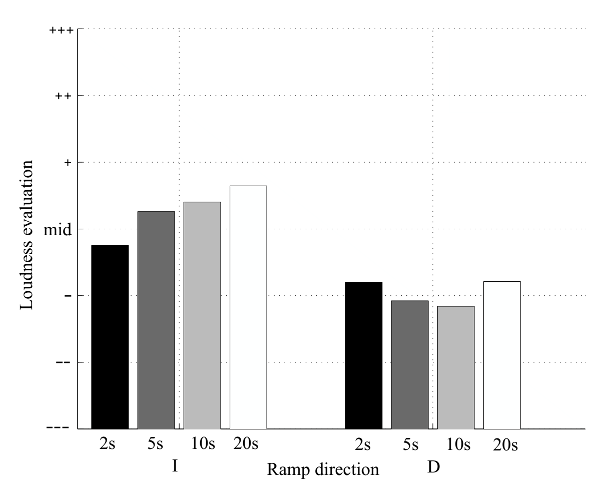

Figure 9. Global loudness for increasing and decreasing ramps for each ramp duration. Mean of ratings by 15 subjects for the four ramp durations.

[12]. In Neuhoff, subjects were asked to mark on a line the point representing the loudness change of the sweep, where the left end was defined as no change and the right end as large change. In Teghtsoonian *et al.*, subjects were asked to assign a number, using a magnitude estimation procedure, 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 the Lc measure used in the present study and like the ratings used by Canévet and colleagues [6, 11]. However, direct global loudness ratings obtained in the present study resemble the findings obtained by direct loudness change estimation in the Neuhoff and Teghtsoonian *et al.* studies, showing that

direct ratings are significantly higher for increasing than for decreasing ramps, whatever the ramp duration. Therefore, direct ratings obtained at the end of the stimuli reveal a perceptual asymmetry between increasing and decreasing ramps for global loudness judgments as well as for loudness change judgments obtained in earlier studies. This asymmetry is in favour of increasing ramps. Teghtsoonian and colleagues proposed that direct ratings are indistinguishable from the end level. In the present study, direct ratings are indeed dependent on the end level as ratings are significantly higher for an increasing ramp. On the other hand, ratings are independent of the ramp duration except for a slight difference for the 2-s increasing ramp. Results obtained in experiment 2 and Teghtsoonian et al's interpretation are closely related to results obtained by Höger and colleagues [20] showing that global loudness judgments of non-stationary sounds are influenced by the loudness at the end of the sound sequence. Similarly, in a study by Susini *et al.* [19], global loudness judgments of a 53-s 1000-Hz varying tone composed of three peaks in level was found to be greater if the highest peak was at the end of the sequence formed by the three peaks. Finally, the study by Gros *et al.* [23] on the perception of time-varying speech quality in telephony shows that overall perceived quality is influenced by quality variations that occur at the middle or at the end of 190-s speech sequences. The last three studies [19, 20, 23] have proposed the hypothesis that global impressions would result from a memory process dominated by the last parts of the sound sequence[1]. Results obtained in the present experiment are in agreement with this hypothesis, and thus loudness asymmetry can be described as the result of a memory process that gives greater weight to the end level, which is always greater in the case of an increasing ramp.

4. Conclusion

Using two additional measures, the present study confirms previous results but at the same time brings a better understanding to the question of loudness asymmetry between increasing and decreasing levels. Two experiments were performed using an analogical/categorical (A/C) method to record continuous loudness ratings, in Experiment 1, and a single loudness rating, in Experiment 2. Indirect and direct loudness measures, respectively, were obtained. The indirect measure is the loudness change (Lc): the difference between instantaneous loudness ratings at the beginning and end of a ramp. The direct measure is the global loudness: the overall loudness impression over the entire duration, rated at the end of the ramp. Stimuli judged by subjects are increasing and decreasing 1-kHz tones with a level range of 60-80 dB and ramp durations of 2, 5, 10, and 20 s.

[1] A similar effect in memory research is defined as a recall advantage for the most recently presented items of a list composed of words or numbers presented orally. This effect is called the "recency effect" and corresponds to a serial recall task [24, 25].

Loudness change (Lc), a measure similar to the loudness change calculated by Canévet and colleagues, does not reveal any perceptual asymmetry between increasing and decreasing ramps for the range of levels used: 60 to 80 dB. By means of a relatively new measure extracted from continuous loudness ratings, this result confirms Canévet et al's [11] results showing no decruitment effect for this level change. On the other hand, the global loudness at the end of the stimuli reveals a perceptual asymmetry between increasing and decreasing ramps, in favour of increasing ramps, which were judged as significantly higher. This result confirms Neuhoff's results, but our assumption is that the difference obtained is a consequence of a memory process in favour of the end level as it was proposed previously by different authors for non-stationary sound sequences [19, 20, 23, 26, 27]. This assumption is also in agreement with Teghtsoonian and colleagues who explain their result by a strong influence of the end level.

Finally, results obtained in the present study by two different loudness measures confirm that Canévet *et al.*'s results in favour of a decreasing ramp, and Neuhoff's results in favour of an increasing ramp, are strongly dependent on the procedure for measuring loudness change. In addition, it may be that the direct judgments of the loudness change in Neuhoff's study are confounded with a global impression heavily influenced by the impression at the end of the stimulus sequence. This assumption needs to be investigated in a future test asking subjects to make direct rating of the degree of loudness change of the same set of stimuli examined in the present study.

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