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Perceptual overestimation of rising intensity: Is stimulus continuity necessary?

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Abstract. A "perceptual bias for rising intensity" (Neuhoff 1998, *Nature* **395** 123 – 124) is not dependent on the continuous change of a dynamic, looming sound source. Thirty participants were presented with pairs of 500 ms steady-state sounds corresponding to onset and offset levels of previously used dynamic increasing- and decreasing-intensity stimuli. Independent variables, intensity-change direction (increasing, decreasing), intensity region (high: 70 – 90 dB SPL, low: 50 – 70 dB SPL), interstimulus interval (ISI) (0 s, 1.8 s, 3.6 s), and timbre (vowel, violin) were manipulated as a fully within-subjects design. The dependent variable was perceived loudness change between each stimulus item in a pair. It was hypothesised that (i) noncontinuous increases of intensity are overestimated in loudness change, relative to decreases, in both low-intensity and high-intensity regions; and (ii) perceptual overestimation does not occur when end-levels are balanced. The hypotheses were partially supported. At the high-intensity region, increasing stimuli were perceived to change more in loudness than decreasing-intensity stimuli. At the low-intensity region and under balanced end-level conditions, decreasing-intensity stimuli were perceived to change more in loudness than increasing-intensity stimuli. A significant direction × region interaction varied as a function of ISI. Methodological, sensory, and cognitive explanations for overestimation in certain circumstances are discussed.

1 Introduction

Acoustic cues such as intensity, reverberation, interaural time delay, and Doppler-shifted frequencies provide key information for auditory motion perception (Jenison 1997). However, the dynamic characteristic of intensity change is arguably the most effective for perceived motion in depth (Neuhoff 2004). From the perspective of a listener, a continuous increase in intensity (termed hereafter an up-ramp) can represent, among other things, a 'looming' (or approaching) sound source, whereas a continuous decrease in intensity (termed hereafter a down-ramp) is characteristic of a receding sound source. An assumption in studies of these dynamic stimuli is that up-ramps hold greater perceptual salience than down-ramps. Here we investigate this assumption further by focusing on one particular area of psychophysical investigation: the relationship between acoustic intensity dynamics and perceptual overestimation of loudness change.

1.1 *An adaptive bias to looming auditory motion*

An ecological perspective supports the notion that up-ramps are perceptually salient because an approaching sound source in the environment elicits faster processing and appropriate responsive actions to what may be a potentially threatening event (Neuhoff 2001). A receding stimulus does not demand the same behavioural priority. Therefore, behavioural biases in response to looming versus receding motion may provide an advantage for organisms able to 'err on the side of caution' when a sound source approaches (Neuhoff 2004). For example, in the visual domain humans underestimate the time-to-contact of apparent real-world looming objects, expecting contact significantly earlier than actual contact (Schiff and Oldak 1990).

In the auditory domain, humans overestimate loudness change in response to up-ramp tonal stimuli, relative to down-ramps (Neuhoff 1998). Specifically, 1.8 s up-ramp pure tones and a 1.8 s up-ramp synthetic vowel (/ə/—sounds like the 'a' in 'about') are perceived to change significantly more in loudness than 1.8 s down-ramps, even though each dynamic stimulus covered the same decibel (dB SPL) range. The perceptual overestimation has not been observed with white noise, but has recently been recovered with a violin timbre (Olsen et al, in press). The overestimation of loudness change for pure tone and vowel up-ramps is claimed to be an evolutionarily significant adaptive perceptual bias for rising intensities (Neuhoff 1998, 2001).

1.2 *Adaptive bias or response bias?*

The evolutionary significance of loudness-change overestimation in response to up-ramp stimuli is not without its critics. For example, there is evidence that perceived differences in loudness between up-ramps and down-ramps lie in the underestimation of continuous decreases in intensity (Stecker and Hafter 2000). That is, the gradual decay of a down-ramp may be treated by the perceptual system as prolonged environmental reverberation. As a result, a portion of the decay may be 'ignored' and eliminated from subsequent judgments of loudness. This 'cognitive decay suppression' hypothesis has received renewed attention in the context of experiments in which subjective duration in response to continuous intensity change was measured (DiGiovanni and Schlauch 2007; Grassi and Darwin 2006).

On the other hand, the overestimation of loudness change for up-ramps may reflect a judgment based on the end-level of each stimulus, and not the entire dynamic sweep (Teghtsoonian et al 2005); that is, the more intense the end-level, the greater the perceived change. The dynamic, continuous aspect of intensity change in an up-ramp stimulus may not be necessary to elicit perceptual overestimation. Rather, stimulus end-level may be the cue underlying differences in perceived loudness change between up-ramps and down-ramps. An end-level bias could explain an underestimation of loudness change in response to down-ramps and underpin the 'cognitive decay suppression' hypothesis mentioned above (Stecker and Hafter 2000). Variables such as intensity-change continuity and effects of intensity region and stimulus end-level are investigated in the present study.

Specifically, we ask: (i) is the continuous aspect of intensity change necessary for a bias for rising intensity, as defined as an overestimation of loudness change in response to up-ramps, relative to down-ramps?; and (ii) what effect does a 'bias for end-levels' have on perceptual overestimation in response to non-continuous intensity change? After investigating these questions, we will be in a better position to attribute any differences in perception of looming versus receding acoustic intensity to the dynamic and continuous aspect of intensity change.

1.3 *Intensity-change continuity*

Inherent in Neuhoff's (1998, 2001) conception of the 'bias for rising intensities' is the continuous intensity change of a looming auditory stimulus. From an ecological perspective, if only onset and offset intensity levels are presented and the continuous 'looming' aspect of intensity change is replaced with silence, the overestimation of loudness change in response to up-ramp stimuli will be eliminated. From an end-level bias perspective, the perceptual overestimation should remain. Here, we test these two competing hypotheses by investigating loudness change in response to noncontinuous intensity-change stimuli. For example, a 1.8 s up-ramp stimulus used in previous experiments (eg Neuhoff 1998; Olsen et al, in press) covering a 70 – 90 dB SPL sweep region is replaced in the present study by a 500 ms steady-state sound at 70 dB SPL, followed by 1.8 s of silence, and then by a second 500 ms steady-state sound at 90 dB SPL. Figure 1 presents a schematic representation of an up-ramp (a) and the noncontinuous intensity-change counterpart used in the present experiment (b).

As can be seen in figure 1, one notable difference between the two modes of stimulus presentation lies in the absence of a 500 ms steady-state plateau at the beginning and end of the up-ramp. In the noncontinuous intensity-change manipulation,

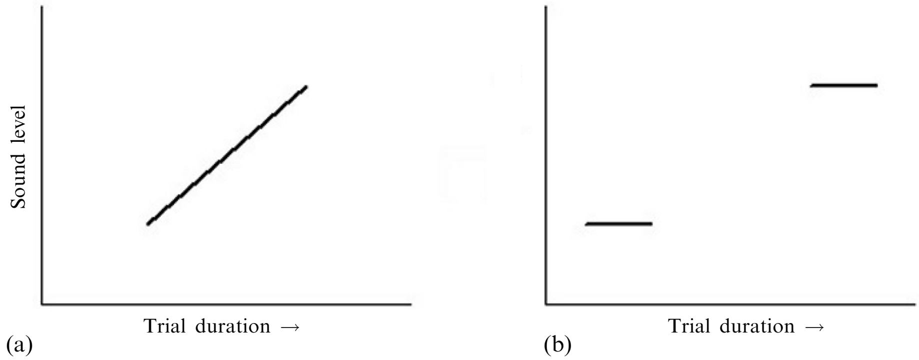

Figure 1. (a) Schematic representation of the continuous intensity change of an up-ramp stimulus used in Neuhoff (1998) and Olsen et al (in press), and the noncontinuously increasing stimulus in the present experiment (b). The lines represent the intensity and duration of the sound. Note that noncontinuous stimuli are presented as 500 ms onset and 500 ms offset intensity levels of the up-ramp; the dynamic, continuous aspect of the up-ramp is replaced with silence.

it is necessary to present a plateau onset and offset to allow participants time to perceive the loudness of each item. When using continuous intensity-change stimuli, Neuhoff (1998) and Olsen et al (in press) did not present the equivalent 500 ms plateaus. However, Teghtsoonian et al (2005) reported no significant differences between plateau versus no-plateau conditions in their investigation of loudness in response to continuous stimuli. Therefore, this methodological difference should not have a significant bearing on the comparability of previous results with those obtained with noncontinuous intensity-change stimuli.

To our knowledge, an experiment with a noncontinuous intensity change has not been undertaken in relation to the perceptual bias for rising intensities. Experiments on the accelerated loss of loudness in response to down-ramp stimuli (or 'decruitment') have incorporated noncontinuous-intensity-change stimuli (Canévet and Scharf 1990). Results of these experiments provide evidence of an underestimation of end-level loudness in response to long-duration (up to 180 s) continuous down-ramps, relative to perceived loudness of the same end-level presented in isolation; that is, without the preceding continuous decrease of intensity heard from a down-ramp stimulus. However, no report championing an adaptive perceptual bias in response to continuous, dynamic increases in intensity has used such an important control experiment. Nevertheless, in the context of a loudness-change paradigm, recent research on end-level effects using dynamic stimuli presented in different regions of intensity change is relevant here.

1.4 *Intensity-region and end-level differences*

First, there is evidence that perceived loudness change in response to up-ramps increases as the region of intensity-change increases (Olsen et al, in press; Teghtsoonian et al 2005). For example, up-ramps are perceived to change significantly more in loudness at a 70 – 90 dB SPL region, relative to up-ramps at a 50 – 70 dB SPL region (Olsen et al, in press). However, in both regions the difference in perceived loudness change between up-ramps and down-ramps is significant. Here we used noncontinuously increasing- and decreasing-intensity stimuli in a low (50 – 70 dB SPL) and high (70 – 90 dB SPL) region of change. We expected that noncontinuously increasing-intensity stimuli would be overestimated in loudness change, relative to decreasing-intensity stimuli in both regions, because the end-level of each increasing stimulus in each region was 20 dB SPL greater than the end-level of the corresponding decreasing stimulus.

Second, if differences in end-level are driving the overestimation of loudness change in response to up-ramps, then no difference in perception would be predicted for up-ramps and down-ramps with the same end-level (eg 70 dB SPL). No significant differences in perceived loudness change has been observed with the 1.8 s vowel stimulus used by Neuhoff (1998) with balanced end-level comparisons between 50 – 70 dB SPL up-ramps and 90 – 70 SPL down-ramps (Olsen et al, in press). Thus, a 'bias for end-levels' may explain the overestimation of loudness change reported by Neuhoff (1998). However, when stimulus duration increases from 1.8 s to 3.6 s, overestimation of loudness change in response to up-ramps under balanced end-level conditions has been recovered (Olsen et al, in press). An end-level bias therefore does not completely explain these data with up-ramps and down-ramps. More likely, duration-specific sensory and cognitive mechanisms play a significant role in any residual perceptual overestimation when end-level artifacts are controlled. For example, at shorter stimulus durations (< 1 s), asymmetries in neural persistence have been reported to explain, in part, overestimation of subjective duration and loudness in response to up-ramp stimuli (DiGiovanni and Schlauch 2007; Ries et al 2008). As stimuli extend beyond 1 s, recency (Susini et al 2002, 2007) may interact with sensory mechanisms and influence the effect of end-level differences.

1.5 *Aim, design, and hypotheses*

The aim here was to further investigate the overestimation of loudness change reported by Neuhoff (1998) and Olsen et al (in press) by introducing noncontinuous intensity-change stimuli. In addition to the question of increasing versus decreasing noncontinuous intensity change, the effect of intensity region (50 – 70 dB SPL and 70 – 90 dB SPL) and end-level differences was investigated. The duration of continuous intensity change in dynamic up-ramp and down-ramp stimuli used in previous studies was replaced with an ISI of silence. Each trial consisted of a pair of 500 ms steady-state sounds with intensity levels corresponding to the onset and offset levels of each intensity region. Each pair of 500 ms sounds was separated by 0 s, 1.8 s, or 3.6 s ISI.

The experiment was realised as a $2 \times 2 \times 3 \times 2$ within-subjects design: intensity direction (increasing, decreasing), intensity region (high: 70 – 90 dB SPL; low: 50 – 70 dB SPL), ISI (0 s, 1.8 s, 3.6 s), and timbre (vowel, violin). The rationale for timbre as an independent variable (IV) is detailed elsewhere (Olsen et al, in press). A no-change control condition (70 – 70 dB SPL) was also presented at each level of ISI and timbre. Perceived loudness change between each pair was measured with a computer-based visual analogue scale (VAS) programmed in the Music Experiment Development System (MEDS) (Kendall 2000). Taking the perspective that the greater end level of increasing-intensity stimuli is sufficient to elicit an overestimation of loudness change, relative to decreasing-intensity stimuli, it was hypothesised that:

Hypothesis 1: Increasing-intensity stimuli are perceived to change more in loudness than decreasing-intensity stimuli;

Hypothesis 2: Overestimation of loudness change in response to increasing-intensity stimuli, relative to decreasing-intensity stimuli, is observed in low- and high-intensity regions;

Hypothesis 3: Perceived loudness change is equivalent in response to increasing-intensity and decreasing-intensity stimuli with balanced end-levels of 70 dB SPL.

2 Method

2.1 *Participants*

The sample consisted of thirty adult participants recruited from the University of Western Sydney (twenty-seven females and three males; mean, $M = 19.87$ years, SD $= 3.55$ years, range $= 18 – 36$ years). All reported normal hearing. Six participants had received minimal individual musical training ($M = 2.00$ years, SD $= 0.71$ years, range $= 1 – 3$ years).

2.2 *Stimuli and equipment*
Vowel and violin timbres were used. The generation of vowel stimuli began with a 500 ms steady-state synthetic vowel (/ə/) from a Klatt synthesiser (Klatt 1980) with the default sampling frequency of 8 kHz. A recorded violin sound (default sampling frequency of 44.1 kHz) from a LogicPro (version 7.2.3) EXS24 integrated sampler was used for the 500 ms steady-state violin stimuli. Each 500 ms steady-state item was then imported into Audacity (version 1.3.3) sound-editing program and 10 ms fade-in and fade-out ramps were incorporated to remove any onset/offset clicks. Exact intensity measurements were made with an Ono Sokki LA-1210 Sound Level Meter microphone placed 13 mm from the centre of the headphone speaker element. Individual items were paired to create increasing, decreasing, and no-change intensity conditions with each ISI of silence (0 s, 1.8 s, 3.6 s) at both intensity regions (low: 50–70/70–50 dB SPL; high: 70–90/90–70 dB SPL). All vowel stimuli were characterised with the C_3 fundamental frequency (130.81 Hz) to correspond closely to the vowel stimuli used by Neuhoff (1998) and Olsen et al (in press). As the frequency range of the violin does not extend to C_3, the C_4 fundamental frequency (261.63 Hz) was used. The experiment was conducted in a sound-attenuated booth, and stimuli were presented binaurally through Sennheiser HD25 headphones.

2.3 *Procedure*
Participants first read an experiment information sheet, gave written informed consent, and received standardised instructions. Participants were presented with pairs of 500 ms steady-state sounds and were asked to (i) focus on the loudness of the first sound and the loudness of the second sound; and (ii) respond to the difference in loudness between the two sounds as quickly and as accurately as possible. Loudness change between each item in each trial was inferred from this difference.[(1)] They responded using a revised version of the VAS reported in Neuhoff (1998). Participants used a computer mouse to slide a cursor to one of two ends of the VAS marked as 'no difference' at the far left and 'large difference' at the far right of the bipolar scale. The order of the bipolar anchors on the VAS was reversed for every other participant to distribute any response bias towards a particular end of the scale. Six practice stimuli were first presented to participants, followed by five blocks of 30 randomised experimental trials. The experiment took approximately 30 minutes.

3 Results
All statistical comparisons were within-subjects with η_p^2 as a measure of effect size (Cohen 1973). Loudness change between increasing- and decreasing-intensity trials was of primary conceptual interest. Perceived loudness change was measured with the VAS, where a score of 0 represents no perceived change in loudness between the first and second 500 ms item in each trial, and a score of 50 represents a large perceived change in loudness between the first and second 500 ms item. As there was no significant timbre-×intensity direction interaction ($F_{1,29} = 1.58$, $p > 0.05$, $\eta_p^2 = 0.05$), vowel and violin timbres were collapsed across conditions in the following analyses. Descriptive statistics for each condition after collapsing the timbre factor are shown in table 1.

It was first hypothesised that increasing-intensity stimuli are perceived to change more in loudness than decreasing-intensity stimuli. This hypothesis was supported. A significant main effect of intensity direction shows that increasing-intensity stimuli ($M = 28.60$, $SD = 5.49$) were perceived to change significantly more in loudness than decreasing-intensity stimuli ($M = 26.16$, $SD = 5.27$) ($F_{1,29} = 17.66$, $p < 0.001$, $\eta_p^2 = 0.38$).

[(1)] See Canévet et al (1999), Neuhoff (1999), and Olsen et al (in press) for a discussion on the benefits, potential shortcomings, and future directions of measuring loudness change in response to dynamic presentations of acoustic intensity.

Table 1. Descriptive statistics (mean with SD in parentheses) for judged loudness change in visual analogue scale units (timbre collapsed).

ISI/s	Intensity region	Direction of intensity change		
		increasing	decreasing	no-change control
0	low	21.11 (8.66)	24.14 (10.53)	2.37 (2.78)
	high	36.69 (6.61)	33.97 (6.11)	
1.8	low	18.09 (7.34)	21.76 (8.22)	1.87 (2.13)
	high	37.03 (7.61)	26.48 (6.99)	
3.6	low	18.38 (7.73)	23.98 (8.89)	3.55 (3.26)
	high	40.31 (5.61)	26.64 (6.88)	

Note: ISI = interstimulus interval—duration of silence between two 500 ms steady-state items that changed across a low region (50 – 70 dB SPL), high region (70 – 90 dB SPL), or no-change control (70 – 70 dB SPL).

Second, it was hypothesised that overestimation of loudness change in response to increasing-intensity stimuli is observed in low- and high-intensity regions. A significant intensity direction × intensity-region interaction ($F_{1,29} = 92.23$, $p < 0.001$, $\eta_p^2 = 0.76$) provides partial support for this hypothesis. As can be seen in figure 2, increasing-intensity stimuli were perceived to change significantly more in loudness than decreasing-intensity stimuli in the high-intensity region. However, in the low-intensity region, decreasing-intensity stimuli were perceived to change significantly more in loudness than increasing-intensity stimuli.

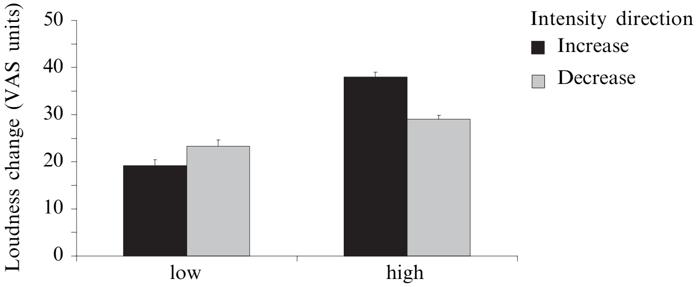

Figure 2. Mean reported loudness change in visual analogue scale (VAS) units for increasing-intensity and decreasing-intensity stimuli as a function of low-intensity region (50 – 70 dB SPL) and high-intensity region (70 – 90 dB SPL). Error bars represent SEM.

There was a significant three-way intensity-direction × intensity-region × ISI interaction ($F_{1,29} = 38.79$, $p < 0.001$, $\eta_p^2 = 0.57$). As illustrated in figure 3, a posteriori analyses (ie increasing-intensity versus decreasing-intensity in the low region over three ISIs, and increasing-intensity versus decreasing-intensity in the high region over three ISIs) with a Bonferroni-adjusted α of 0.008 (0.05/6 analyses) revealed that at an ISI of 0 s, no significant difference in loudness change between increasing-intensity and decreasing-intensity stimuli occurred in the high-intensity region ($F_{1,29} = 4.82$, $p = 0.036$, $\eta_p^2 = 0.14$) or the low-intensity region ($F_{1,29} = 6.25$, $p = 0.018$, $\eta_p^2 = 0.18$). However, as the ISI increased to 1.8 s, increasing-intensity stimuli were perceived to change significantly more in loudness than decreasing-intensity stimuli in the high-intensity region ($F_{1,29} = 88.77$, $p < 0.001$, $\eta_p^2 = 0.75$), but decreasing-intensity stimuli were perceived to change significantly more in loudness than increasing-intensity stimuli in the low-intensity region ($F_{1,29} = 10.15$, $p = 0.003$, $\eta_p^2 = 0.26$). This direction × region result remained as the ISI doubled to 3.6 s for the high-intensity region ($F_{1,29} = 198.40$, $p < 0.001$, $\eta_p^2 = 0.87$) and the low-intensity region ($F_{1,29} = 14.58$, $p = 0.001$, $\eta_p^2 = 0.33$).

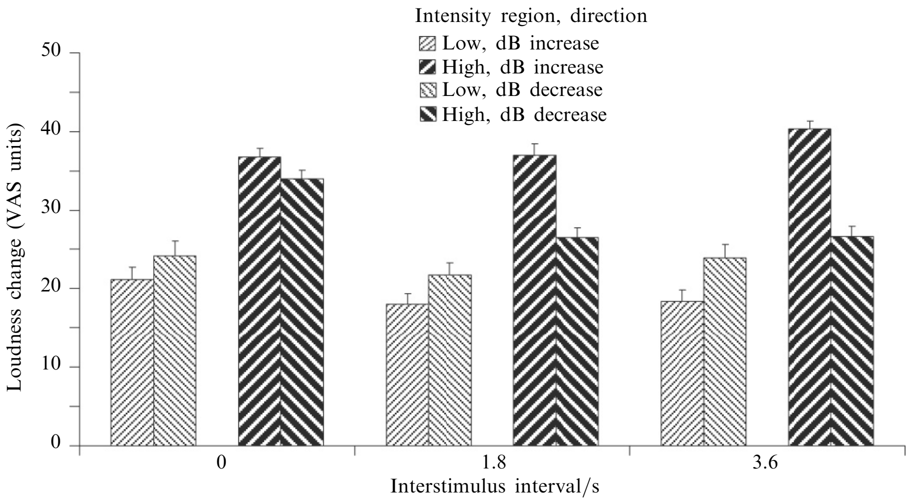

Figure 3. Mean reported loudness change in visual analogue scale (VAS) units for increasing-intensity and decreasing-intensity stimuli as a function of intensity region (low: 50 – 70 db SPL; high: 70 – 90 dB SPL) and interstimulus interval. Error bars represent SEM.

Finally, it was hypothesised that perceived loudness change is equivalent when comparing increasing-intensity and decreasing-intensity stimuli when end levels are balanced at 70 dB SPL. This hypothesis was not supported: 90 – 70 dB SPL decreasing-intensity stimuli ($M = 29.03$, $SD = 4.65$) were perceived to change significantly more in loudness than 50 – 70 dB SPL increasing-intensity stimuli ($M = 19.19$, $SD = 6.60$) ($F_{1,29} = 123.17$, $p < 0.001$, $\eta_p^2 = 0.81$). As shown in figure 4, this result did not vary significantly as a function of ISI.

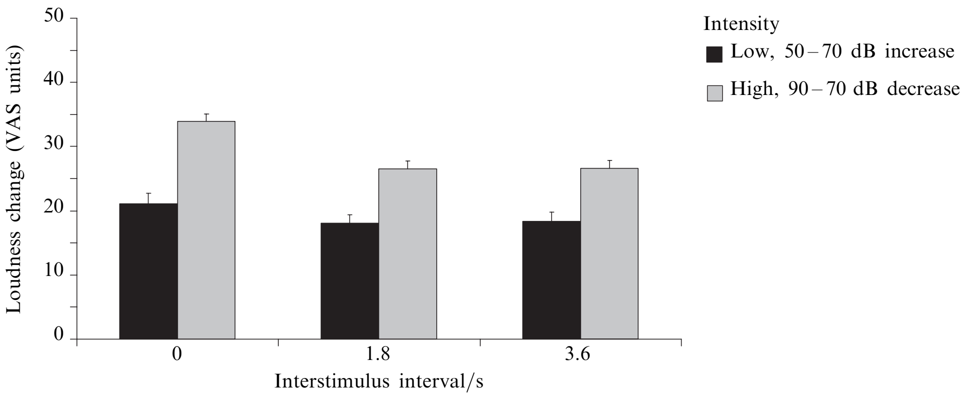

Figure 4. Mean reported loudness change in visual analogue scale (VAS) units for increasing-intensity and decreasing-intensity stimuli with balanced end levels of 70 dB SPL. Results are shown as a function of interstimulus interval. Error bars represent SEM.

4 Discussion

In our experiment we investigated acoustic intensity-change continuity in relation to the 'adaptive' perceptual bias to rising intensities (Neuhoff 1998), defined as an overestimation of loudness change in response to continuous rising (up-ramp) versus falling (down-ramp) acoustic intensity. In support of the first hypothesis, the overestimation of loudness change in response to up-ramp stimuli reported in Neuhoff (1998) was recovered when intensity change was presented noncontinuously. Therefore, perceptual overestimation in this paradigm is not dependent on the continuous change of a dynamic looming sound source; noncontinuous increases elicit overestimations of loudness change. Although neurological studies report that a 'looming-specific' neural network may have evolved to direct attention to the location and movement of a looming sound source (eg Bach et al 2008; Hall and Moore 2003; Seifritz et al 2002), adaptive links made between an evolved perceptual bias and looming auditory motion with the use of a psychophysical measure such as loudness change are tentative (cf Neuhoff 2001).

In partial support of the second hypothesis, the higher end-level of increasing-intensity stimuli in the 70 – 90 dB SPL intensity region was sufficient to elicit a significant overestimation in loudness change, relative to 90 – 70 dB SPL decreasing-intensity stimuli. This is not surprising, considering that the increasing-intensity trials ended on an offset level 20 dB SPL higher than the corresponding decreasing-intensity trials. However, counter to the prediction, 70 – 50 dB SPL decreasing-intensity stimuli were overestimated in loudness change, relative to 50 – 70 dB SPL increasing-intensity stimuli. The end-level hypothesis predicts that increasing-intensity stimuli are perceived to change more in loudness than decreasing-intensity stimuli, regardless of the region of intensity change. The ecological perspective would predict no difference because intensity change was not dynamic and continuous. This intensity-region-specific result is difficult to explain. Decruitment (Canévet and Scharf 1990) and its underlying mechanisms of simple and/or induced loudness adaptation would apply if intensity change was continuous, as decruitment is specific to medium and low intensity regions. As intensity change was noncontinuous, this explanation is not applicable.

Low-region increasing-intensity (50 – 70 dB SPL) and high-region decreasing-intensity (90 – 70 dB SPL) stimuli with balanced end-levels (70 dB SPL) were compared. Opposing the hypothesis, decreasing-intensity stimuli were perceived to change more in loudness than increasing-intensity stimuli across all ISIs (figure 4). In experiments in which paired comparisons of auditory stimuli were used, a short sound presented after a previously more intense sound is perceived to be softer than if heard in isolation (Epstein 2007; Yoshida et al 2006). In each 90 – 70 dB SPL decreasing-intensity trial in the present study, the first steady-state item was always 20 dB SPL greater than the second. If the initial high-intensity burst of the first item led to a reduction in loudness in response to the second item, then the perceived difference between the two items would be greater than in the corresponding increasing-intensity stimuli. It is likely that a sensory mechanism such as forward masking from the initial high-intensity item in a decreasing-intensity pair can explain these differences at short ISIs (ie 0 s ISI conditions) (Arieh and Marks 2003; Oxenham 2001).

At the relatively long 1.8 s and 3.6 s durations the impact of forward masking is likely to become smaller. At these longer durations, cognitive constraints, such as limitations in short-term memory, are likely to contribute and, subsequently, responses may rely to some degree on the average intensity of stimuli in a trial. For example, in the balanced end-level comparison, the 90 – 70 dB SPL decreasing-intensity stimuli had an average of 80 dB, whereas the 50 – 70 dB SPL increasing-intensity stimuli had an average of 60 dB. Average intensity is one explanation of the overestimation of loudness change for decreasing-intensity stimuli under balanced end-level conditions as ISIs became longer. Therefore, direct judgments of loudness change over increasing stimulus durations may be influenced not only by the direction, size, or region of intensity change, but also by the global loudness 'impression' of that stimulus. This impression may reflect, in part, the influence of average intensity over the duration of stimulus presentation. The question how the global impression of loudness (or perceived average intensity) may confound direct measures of loudness change awaits further empirical investigation. Future studies will benefit from a complement of loudness measures that address the issues of global loudness and loudness change, in conjunction with continuous on-line measures such as those used in Susini et al (2007). This will lead to a greater understanding of how the choice of paradigm affects differences in dynamic intensity perception at different points of the perceptual process.

A potential limitation lies in the use of trials with and without a period of silence between each paired item. The change of intensity between the first and second 500 ms item in 0 s ISI conditions was close to instantaneous (accounting for the 10 ms ramps at the end of the first item and the beginning of the second). These two items in a trial could have been perceived as one continuous stimulus. The change in intensity between the first and second 500 ms item in 1.8 s and 3.6 s ISI conditions was interrupted by a silent interval long enough for participants to perceive two independent items. As can be seen in figure 5, the perception of loudness of the second item in 0 s ISI conditions was immediately relative to the first because of the continuity of the two sounds. In the 1.8 s and 3.6 s conditions, participants perceived the loudness of the second sound immediately relative to silence (ie threshold of hearing in quiet). Perceived loudness change between two stimulus items may be affected by the intensity of the immediate context in which the second item is judged.

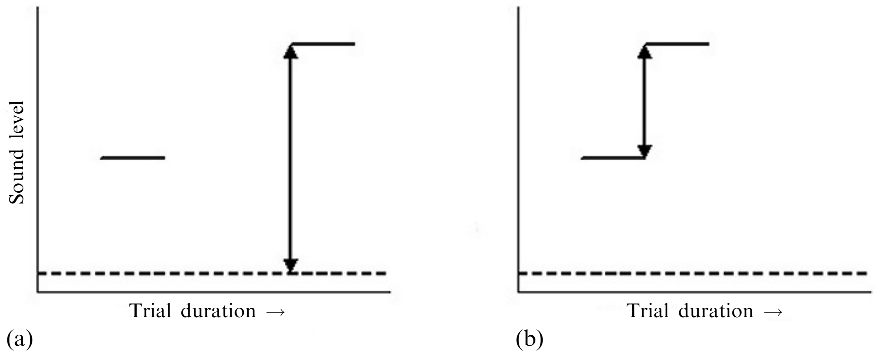

Figure 5. Schematic representation of two noncontinuous increasing-intensity trials presented at an ISI duration (a) > 0 s and (b) 0 s. Solid lines represent the intensity and duration of the sound and the dashed line represents an arbitrary threshold of hearing in quiet. Vertical arrows depict the difference in intensity immediately preceding the second item in each trial. At 0 s ISI, the second item is perceived in the immediate context of the first item. As ISIs become >0 s, the second item is perceived in the immediate context of silence (threshold in quiet).

The difference between an audible stimulus or silence directly preceding the second item in paired stimulus comparisons explains why there was a significant overestimation of loudness change for increasing-intensity trials in 1.8 s and 3.6 s ISI conditions shown in figure 3, but not for 0 s ISI conditions: participants were able to veridically perceive intensity change between two items immediately following each other. As ISI increased, significant differences in perceived loudness change were recovered and likely affected by (i) the rapidly decreasing temporal window of short-term memory in response to the first item; and (ii) perceived loudness of the second item relative to an immediately preceding silent period (1.8 s and 3.6 s ISIs), as opposed to an immediately preceding auditory stimulus (0 s ISI). In future research we will investigate these hypotheses by manipulating the ISI between two items and using noise to control for the difference of intensity between two items versus one item and auditory threshold in quiet.

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