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Continuous loudness response to acoustic intensity dynamics in melodies: Effects of melodic contour, tempo, and tonality☆

Kirk N. Olsen [a,*], Catherine J. Stevens [a,b], Roger T. Dean [a], Freya Bailes [c]

[a] The MARCS Institute, University of Western Sydney, Australia
[b] School of Social Sciences and Psychology, University of Western Sydney, Australia
[c] Music Department, University of Hull, United Kingdom

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ABSTRACT

The aim of this work was to investigate perceived loudness change in response to melodies that increase (up-ramp) or decrease (down-ramp) in acoustic intensity, and the interaction with other musical factors such as melodic contour, tempo, and tonality (tonal/atonal). A within-subjects design manipulated direction of linear intensity change (up-ramp, down-ramp), melodic contour (ascending, descending), tempo, and tonality, using single ramp trials and paired ramp trials, where single up-ramps and down-ramps were assembled to create continuous up-ramp/down-ramp or down-ramp/up-ramp pairs. Twenty-nine (Exp 1) and thirty-six (Exp 2) participants rated loudness continuously in response to trials with monophonic 13-note piano melodies lasting either 6.4 s or 12 s. Linear correlation coefficients >.89 between loudness and time show that time-series loudness responses to dynamic up-ramp and down-ramp melodies are essentially linear across all melodies. Therefore, 'indirect' loudness change derived from the difference in loudness at the beginning and end points of the continuous response was calculated. Down-ramps were perceived to change significantly more in loudness than up-ramps in both tonalities and at a relatively slow tempo. Loudness change was also greater for down-ramps presented with a congruent descending melodic contour, relative to an incongruent pairing (down-ramp and ascending melodic contour). No differential effect of intensity ramp/melodic contour congruency was observed for up-ramps. In paired ramp trials assessing the possible impact of ramp context, loudness change in response to up-ramps was significantly greater when preceded by down-ramps, than when not preceded by another ramp. Ramp context did not affect down-ramp perception. The contribution to the fields of music perception and psychoacoustics are discussed in the context of real-time perception of music, principles of music composition, and performance of musical dynamics.

1. Introduction

Music is intimately associated with perceptual and emotional experiences that are influenced by real-time changes in basic acoustic parameters such as intensity (Balkwill & Thompson, 1999; Dean, Bailes, & Schubert, 2011; Krumhansl, 1997; Olsen & Stevens, 2013; Schubert, 2004). Along with its culturally determined components (scale, key, harmony), music makes use of fundamental acoustic attributes such as intensity to trigger the most basic of human responses that may have deep evolutionary roots (Balkwill & Thompson, 1999; Cross, 2001, 2007; Huron, 2006). While music is temporal and dynamic, most studies that consider acoustic intensity as an important variable in the perception of music have involved the control or normalization of intensity so as to concentrate on other features (e.g., Bigand, Vieillard, Madurell, Marozeau, & Dacquet, 2005; Gregory, Worrall, & Sarge, 1996), or the setting of intensity to an overall level of loud or soft (e.g., Ilie & Thompson, 2006). In such studies, the fundamental aspect of intensity in music has been noted as an important perceptual and emotional cue or trigger, but its *dynamic* qualities have been controlled or removed.

More recently, perception of intensity change has begun to be addressed through investigations of loudness and arousal using musical excerpts with real-time continuous response methods and time-series analysis techniques (e.g., Bailes & Dean, 2012; Dean et al., 2011; Ferguson, Schubert, & Dean, 2011). These studies have shown that continuous changes of acoustic intensity are significantly associated with continuous perceptions of both arousal and loudness in music. The present study reports two experiments that extend the focus on loudness and intensity in music. This is achieved by systematically

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* Corresponding author at: The MARCS Institute, University of Western Sydney, Australia Post: Locked Bag 1797 Penrith, NSW 2751, Australia. Tel.: +61 2 9772 6151; fax: +61 2 9772 6040.
E-mail address: k.olsen@uws.edu.au (K.N. Olsen).

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manipulating increases and decreases of intensity change in short melodies and investigating the interaction between intensity change and musical factors such as melodic contour, tempo, and tonality. The measured perceptual outcome here is a continuous real-time judgment of loudness; the psychological attribute of auditory sensation most closely related to continuous acoustic intensity change (Moore, 2003). A continuous measure of loudness allows for the linearity of loudness across the duration of a melody to be investigated and effects of discrete note events on loudness to be examined. Furthermore, if loudness is indeed linear across the duration of a melody, then an 'indirect' measure of loudness change derived from the difference in loudness between beginning and end points of the continuous loudness response can be analysed. The present study undertakes such an analysis in the context of acoustic intensity and loudness change in music, with further experimental manipulations of melodic contour, tonality, and tempo.

1.1. Acoustic intensity change, decruitment, and a bias for auditory looming

Continuous increases of intensity (up-ramp) in an otherwise unchanging sound can indicate that the source of the sound is approaching or "looming", whereas a continuous decrease of intensity (down-ramp) implies that the sound source is receding. From experiments using relatively simple up-ramp and down-ramp stimuli matched on frequency, duration, range, and region of intensity change, up-ramps relative to down ramps are perceived to be louder (Stecker & Hafter, 2000; Susini, McAdams, & Smith, 2007), longer (Grassi & Darwin, 2006; Ries, Schlauch, & DiGiovanni, 2008), and as changing more in loudness (Bach, Neuhoff, Perrig, & Seifritz, 2009; Neuhoff, 1998, 2001; Olsen, Stevens, & Tardieu, 2010). In particular, Neuhoff and colleagues argue that greater perceived changes of loudness in response to relatively short pure tone, square-wave, and synthetic vowel up-ramps is evidence of an adaptive perceptual bias to increasing intensity and looming auditory motion. This bias may function to allow organisms extra time in the environment to respond to a looming and potentially threatening event.

On the other hand, greater perceived changes of loudness in response to down-ramps have been reported from a series of more psychoacoustic studies that challenge the 'looming conjecture' (e.g., Canévet & Scharf, 1990; Canévet, Scharf, Schlauch, Teghtsoonian, & Teghtsoonian, 1999; Canévet, Teghtsoonian & Teghtsoonian, 2003; Olsen & Stevens, 2010; Pastore & Flint, 2011; Teghtsoonian, Teghtsoonian & Canévet, 2005). One example is the phenomenon termed 'decruitment', where loudness falls more rapidly as the continuous linear decrease of intensity in a relatively long down-ramp approaches a mid-to-low (<40 dB SPL) offset level (Canévet & Scharf, 1990; Canévet, Scharf, & Botte, 1985; Scharf, 1983). This effectively results in a greater magnitude of loudness change for down-ramps than up-ramps because up-ramps elicit only a slight reciprocal 'upcruitment' effect (Canévet & Scharf, 1990; Canévet, Teghtsoonian, & Teghtsoonian, 2003). Perceptual adaptation has been proposed as a candidate mechanism with cognitive factors shown to also play a significant role (Canévet & Scharf, 1990; Schlauch, 1992).

The difference in results between these two main groups of studies is likely explained by the fact that they use two different measures of loudness change underpinned by different mechanisms. Studies reporting greater perceived loudness change for up-ramps use a 'direct loudness change' measure that is biased by a recency-in-memory effect (Olsen et al., 2010; Susini et al., 2007). In these studies, loudness change is recorded as a single post-stimulus judgement of change that is heavily weighted on the end-level of the dynamic stimulus and not its entire intensity-change profile (Susini, Meunier, Trapeau, & Chatron, 2010; Teghtsoonian, Teghtsoonian, & Canévet, 2005). The 'indirect' measure used in decruitment studies calculates loudness change from the ratio of discrete loudness magnitude estimates at the onset and offset of each stimulus. As a result, end-level recency bias is removed but loudness change is not directly measured per se. Susini et al. (2007) attempted to reconcile this issue by measuring loudness change continuously using an analogical/categorical scale. The benefit of a continuous measure is that it is sensitive to moment-to-moment loudness impressions corresponding to continuous changes of intensity inherent in up-ramp and down-ramp stimuli. This is particularly important in our investigation of loudness change in a musical context where listeners' real-time experience is key. Moreover, data seemingly equivalent to magnitude estimates at stimulus onset and offset can be extracted from a continuous loudness measurement to calculate a new measure of indirect loudness change. From such a measurement, Susini et al. reported that loudness change was numerically greater in response to 1 kHz pure tone down-ramps relative to up-ramps. However, these differences were not significant, probably because of a low sample size ($N = 15$) and likely lack of statistical power.

One characteristic of these experiments is that reduced and unnatural psychoacoustic stimuli such as pure-tones, square-waves, synthesized vowel, and white noise are used. These sounds are essentially unchanging over time. In music, increases and decreases of intensity and the experience of increasing and decreasing loudness constitute musical crescendi or decrescendi. A simple musical sequence such as a monophonic melody contains discrete note onsets that signify individual events within a continuous stimulus presentation. Extrapolating from constrained psychoacoustic experiments to ecological contexts is not straightforward and the possible implications require direct investigation. Indeed, it is not known whether the mechanism(s) underlying loudness in response to intensity change using single continuous tones are applicable to stimuli that comprise discrete events throughout a dynamic intensity presentation. It is the primary focus of the present study to extend the time-course and musicality of previous psychoacoustic research on loudness and intensity change by presenting a range of composed melodies and measuring continuous loudness throughout each melodic presentation. From the continuous data, an indirect measure of loudness change will be calculated as the difference between the loudness rating at the point in which the participant begins to respond to a particular direction of intensity change, and the loudness rating at melody offset. As a result, we can investigate whether loudness change in music is perceived as greater in response to increasing intensity (crescendo), or whether an effect such as decruitment applies to perception of decreasing intensity (decrescendo) within complex stimuli comprising of discrete events. Given that our indirect measure of loudness change derived from continuous data is similar to indirect measures derived from magnitude estimates in decrutiment studies (e.g., Canévet & Scharf, 1990; Canévet et al., 2003; Teghtsoonian et al., 2005), our conservative hypothesis is the latter, where down-ramps are perceived to change more in loudness than up-ramps. In addition to acoustic intensity change, the interaction with tempo, tonality, and melodic contour in a musical context will be investigated for the first time to combine the domains of psychoacoustics and music perception with our underlying focus on perceived loudness change.

1.2. Intensity, melodic contour, tempo, and tonality

The use of melodies in the present study allows for the manipulation of concurrent changes of melodic pitch contour and acoustic intensity; that is, ascending or descending directions of melodic change that vary either congruently (in the same direction) or incongruently (in the opposite direction) with increases and decrease of intensity. From methods such as speeded sorting, restricted classification, and dissimilarity scaling (Garner, 1974), auditory dimensions such as frequency/pitch and intensity/loudness have been shown as integral rather than separable (Melara & Marks, 1990a,b). Paradigms investigating dimensional interactions have almost always measured post-stimulus judgements. In such experiments, participants are asked to respond to one dimension (e.g., frequency/pitch) while ignoring systematic variations of another dimension (e.g., intensity/loudness). If variations in the 'unattended' dimension affect performance on the dimension of interest, the two are said to be integral and may be perceived holistically,