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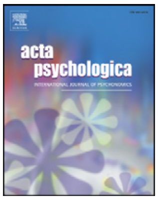

Continuous loudness response to acoustic intensity dynamics in melodies: Effects of melodic contour, tempo, and tonality☆

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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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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, without primary and exclusive access to either dimension when presented concurrently (see also, Neuhoff, 2004).

The integrality of intensity and frequency and their effect on perceived pitch changes has been investigated by Neuhoff and McBeath (1996) in a non-musical context using sine, square, and complex tones. When frequency was held constant across each stimulus presentation, increases of intensity resulted in judgements of rising pitch, and decreases of intensity resulted in judgements of falling pitch. Thompson, Peter, Olsen, and Stevens (2012) investigated the effect of continuous changes of intensity on the perceived size of six- or seven-semitone sequential pitch intervals by using 1 s complex tones. Pitch intervals were perceived to be larger when ascending intervals were coupled with increasing intensity (a congruent frequency/intensity change) relative to decreasing intensity (an incongruent change). A reciprocal investigation to intensity change and pitch perception was undertaken by Neuhoff, McBeath, and Wanzie (1999), who experimentally manipulated changes of frequency and intensity, but measured a discrete direct judgement of loudness change. Stimuli were 4 s square-wave tones that either increased or decreased in frequency, in conjunction with increases or decreases of intensity. Results indicated that congruent changes of frequency and intensity (i.e., ascending pitch interval coupled with an up-ramp) led to significantly greater ratings of loudness change, relative to incongruent changes of frequency and intensity (i.e., descending pitch interval with an up-ramp). We envisage that similar effects might apply in perceived changes in loudness of musical stimuli such as the melodies used here.

In Experiment 1 of the present study, the four melodies presented are categorized into groups of either ascending or descending melodic (pitch) contour. It is predicted that dimensional integrality effects are not limited to short psychoacoustic stimuli, but will be observed using more complex and real-world dynamic musical stimuli. Specifically: (1) ascending and descending melodic contour will elicit increases and decreases of loudness change, respectively, when intensity is held constant (cf. Neuhoff & McBeath, 1996); and (2) under conditions of concurrent multidimensional stimulus change, frequency/intensity congruence effects on loudness change will be observed, where congruent ascending melodic contour/increases of intensity and descending melodic contour/decreases of intensity will result in greater perceived change in loudness than incongruent concurrent changes of each dimension (cf. Neuhoff et al., 1999).

As with intensity, tempo is another aspect of music that may play a significant role in perceived loudness change. Juslin (2000) studied relationships between performers' intention and listeners' judgments including measures of sound intensity and tempo. He noted the need to consider "continuously changing patterns of tempo and dynamics" (p. 1809). In this respect, Balkwill, Thompson, and Matsunaga (2004) investigated emotional response to music and demonstrated that high levels of loudness and fast tempos were associated with subjective judgments of anger in Western tonal music. 'Anger' is high on the arousal dimension of Russell's (1980) circumplex model of emotion, and real-time perception of arousal is associated with continuous intensity change in music (Dean et al., 2011). In Experiment 2 of the present study, a fast tempo that underpins an increasingly intense musical stimulus may result in greater perceived loudness change than fast-tempo intensity decreases. Alternatively, fast-tempo up-ramps may result in greater perceived loudness change than slow-tempo up-ramps. The interaction between intensity change, tempo, and continuous judgements of loudness change is a research question explored in the present study.

Contrasting with fundamental and temporal acoustic features of music such as intensity change and tempo, the tonal and melodic expectations elicited by a musical piece are likely to be culture-bound and acquired through exposure to particular musical environments. Indeed, Western listeners with little or no formal training in music have implicit knowledge of melodic, harmonic, and rhythmic conventions of their musical environment (Bigand & Poulin-Charronnat, 2006; Schellenberg, Bigand, Poulin-Charronnat, Garnier, & Stevens, 2005; Tillmann, 2005). Culturally conditioned familiarity with consonant tonal music (e.g., major and minor key) results for some in a more pleasant listening experience than with unfamiliar and dissonant atonal music (Kellaris & Kent, 1993). To our knowledge, the direct effect of tonality and intensity change on perceived changes in loudness is yet to be investigated in music. Consequently, in Experiment 2 we manipulate the Western tonal and atonal structure of our melodies to extend research on the emotional effects of tonality and explore the way perception—and perceived loudness specifically—is influenced by tonality that is familiar or unfamiliar.

1.3. The effect of ramp context on loudness change

The context in which intensity change in music is presented (in particular crescendi and decrescendi) plays an important role in music notation, performance, and we argue here, perception. Over 20 years ago, David Huron conducted a series of musicological score analyses of notated dynamic markings in a range of Western classical music and argued for the existence of a ramp archetype: a temporal asymmetry of intensity patterns where musical crescendi are more frequent and cover a greater duration of dynamic change than decrescendi, which are shorter in duration and proportionally less frequent (Huron, 1990). Through association between notated crescendi/decrescendi and rises/falls of intensity ramps, Huron proposed that dynamic markings on a score are correlated with perceptual experiences such as loudness and arousal or attention. Recently, acoustic analyses of electroacoustic music and music from the western classical tradition have investigated realized intensity profiles in a series of studio-composed and live-performed musical excerpts. Specifically, Dean and Bailes (2010b) computationally analyzed acoustic intensity in a variety of electroacoustic music and showed an asymmetry in acoustic intensity, but in the opposite manner to that which Huron (1990, 1991) reported. The frequency of crescendi and decrescendi did not differ from each other. However, crescendi were significantly shorter in duration than decrescendi. This result was supported from further acoustic analyses of performed improvised music (1950s to present) (Dean & Bailes, 2010a), 119 movements of the works of Joseph Haydn, and seven Beethoven sonatas analyzed in Huron (1990) (Dean, Olsen, & Bailes, 2013).

Therefore, although crescendi in certain Classical music are notated to a greater extent than decrescendi, their frequency of occurrence in performance is equal and crescendi are performed for shorter durations. That musical up-ramps are realized in performance at shorter durations than down-ramps may be explicable in perceptual terms and related to their possible differential effects on arousal or attention. In Experiment 1, we investigate this 'ramp context' hypothesis in music and present up-ramp/down-ramp and down-ramp/up-ramp 'hybrid' conditions.

1.4. Aim, design, and hypotheses

Two experiments were designed to investigate intensity change perception in a musical context. The first aim of Experiment 1 was to investigate continuous perception of loudness change in response to controlled increases (up-ramps) and decreases (down-ramps) of acoustic intensity in short melodies. The second aim was to investigate the effect of ramp context on the perception of paired up-ramps and down-ramps. Paired up-ramp and down-ramp melodies enabled up-ramps to be presented in the context of down-ramps, and vice-versa. It is expected that musical up-ramps will be perceived to change more in loudness when presented in the context of (subsequent to) musical down-ramps. The third aim was to investigate congruency effects of intensity change and melodic contour on loudness change; for example, it was expected that increases of acoustic intensity influence loudness change to a greater extent when coupled with a congruent (ascending) melodic contour, and vice-versa for congruent decreases of intensity and descending contour. In Experiment 2, the aim was to investigate the interaction between intensity change, tempo, tonality, and their effect on loudness change in a musical context. Specifically, it was hypothesized that in Experiment 1:

1. Down-ramps are perceived to change more in loudness than corresponding up-ramps (decruitment hypothesis).
2. Loudness change is greater when up-ramps are presented in the context of a down-ramp, relative to up-ramps without dynamic ramp context (ramp context hypothesis).
3. Up-ramps with ascending melodic contour are perceived to change more in loudness than descending contour up-ramps. Furthermore, down-ramps with a descending melodic contour are perceived to change more in loudness than ascending down-ramps (congruency hypothesis).
4. Steady-state-intensity melodies will be perceived to increase in loudness with an ascending contour, and decrease in loudness with a descending contour (dimensional integrality hypothesis).

In Experiment 2, we ask the question:

5. Is the perception of loudness change in response to intensity change in music influenced by tempo or tonality?

Experiment 1 was realized as a 2 × 2 × 2 within-subjects design, with independent variables Intensity Direction (up-ramp, down-ramp), Intensity Range (15, 30 dB SPL), and Melodic Contour (Ascending, Descending). Steady-state trials at 55, 70, and 85 dB SPL were also presented. The decruitment, intensity ramp/melodic contour congruency, and ramp context hypotheses were investigated in Experiment 1. Experiment 2 consisted of a 2 × 2 × 2 within-subjects design, with independent variables Intensity Direction (up-ramp, down-ramp), Tonality (tonal, atonal), and Tempo (slow 64.8 bpm, fast 129.6 bpm). Ramps in Experiment 2 were presented in the regions of 55–70 dB SPL and 70–85 dB SPL, and the influence of tonality and tempo on perceived loudness change was investigated.

2. Method

2.1. Participants

The sample in Experiment 1 consisted of 29 adult participants recruited from the University of Western Sydney (20 females and 9 males; $M = 21.00$ years, $SD = 5.43$, Range = 18–41 years). All reported normal hearing. Three participants had received minimal individual musical training ($M = 1.67$ years, $SD = .58$, Range = 1–2 years). In Experiment 2 the sample consisted of 36 participants recruited from the University of Western Sydney who had not participated in Experiment 1 (34 females and 2 males; $M = 23.19$ years, $SD = 7.62$, Range =18–47 years). All reported normal hearing. Nine participants had received minimal individual musical training ($M = 1.94$ years, $SD = .88$, Range =1–3 years).

2.2. Stimuli and equipment

In Experiment 1, four composed melodies were chosen as stimuli. The first melody was an extract from Roger Dean's post-minimal *Mutase* (Dean, 2008) which uses four melodic transformations of the tonal motive in 13/8 (shown as *Original* in Fig. 1), including the version shown as *Atonal*. For concert purposes, the piece can be played algorithmically, or by one or more instrumentalists, varying their relative phase. For the experiments, the tonal and atonal versions of the melody are played algorithmically at Midi velocity 90 on the physical synthesis software Pianoteq C3 Concert Grand Piano.[1] To vary melodic contour in our experiments, three additional melodies were derived from the original tonal segment, resulting in a (chromatic) inverted (which preserved the interval magnitude of the original, although inverted), retrograde, and inverted retrograde version. These derivatives are not used in the original composition, but rather purely for experimental purposes. As can be seen in Fig. 1, *Original Tonal* and *Inversion Retrograde* versions follow an overall ascending melodic contour, whereas *Retrograde* and *Inversion* melodies follow an overall descending melodic contour. From starting note to end note, ascending melodies increased by 14 semitones (1400 cents) and descending melodies decreased by 14 semitones. Specifically, the overall ascending pitch contour in the *Original* and *Inversion Retrograde* melodies increased by a mean interval size of 1.17 semitones (117 cents) per note event and the proportion of ascending intervals was .67. The descending pitch contour in the *Retrograde* and *Inversion* decreased reciprocally by a mean interval size of 1.17 semitones per note event and the proportion of descending intervals was .67. 'Overall' ascending and descending melodies were chosen for greater ecological validity relative to 100% ascending and descending melodies because, in music, uni-directional melodic contours are rarely performed. Indeed, such contours constitute scales that are mostly used for practice purposes. Table 1 presents the fundamental frequency of each note for all four melodies. Each melody consisted of 13 notes and was played twice in a single ramp trial. The inter-onset interval of each note for the melodies was 240 ms (250 beats per minute). Supplementary Audio Files 1–4 contain the four melodies presented in Experiment 1.

Linear up-ramps and down-ramps were constructed for each melody by audio manipulation of the recorded melodies. In Experiment 1, up-ramps were constructed at 70–85 dB SPL and 55–85 dB SPL regions of intensity change, and down-ramps, 85–70 dB SPL and 85–55 dB SPL regions of intensity change. Three steady-state versions of each melody were also presented at 55 dB SPL, 70 dB SPL, and 85 dB SPL. In Experiment 2, only 15 dB ranges were presented: 55–70 dB SPL and 70–85 dB SPL for up-ramps and 85–70 dB SPL and 70–55 dB SPL for down-ramps. Each region of intensity change was constructed using a custom computer program written in MAXMSP (Version 4.6.3). Minimum and maximum intensity levels for both intensity regions were measured with a Brüel and Kjær Artificial Ear 4152 attached to a Brüel and Kjær Hand-Held Analyser 2250 using Sound Level Meter Software BZ-7222. MAXMSP generated an up-ramp and a down-ramp for each melody using the minimum and maximum levels for each region as onset/offset anchors, and creating a linear intensity change between them. A 2 s steady-state orientation tone was spliced to the beginning of each trial of Experiment 1 and separated from the melody with 500 ms of silence using Audacity (Version 1.3.3). The orientation tones comprised the same timbre as each note in the melody, corresponded to the intensity level at the onset of the melody, and provided participants with an opportunity to calibrate their loudness rating for the beginning of a melody before it started to play. Single ramp trials were therefore 8.9 s in duration including a 2 s orientation tone, 500 ms silence, and a single melody played twice over one ramp direction that lasted 6.4 s. Paired ramp trials (hybrid conditions) were also presented and enabled a ramp context analysis. Up-ramp/down-ramp or down-ramp/up-ramp 'hybrid' stimuli were constructed by splicing together two single ramp trials of the same melody but with combinations of up-ramp/down-ramp or down-ramp/up-ramp (totaling four repetitions of the same melody in each paired ramp trial). Supplementary Fig. 1 presents schematic diagrams for complete single ramp and paired ramp trials. Paired ramp trials were 15.3 s in duration.

Experiment 2 did not present an orientation tone at the beginning of a trial and did not present hybrid conditions. All stimuli were gated with 10 ms fade-in and fade-out ramps to remove any onset/offset clicks. Overall there were 44 stimulus conditions in Experiment 1. The experiment was conducted in a sound attenuated booth and stimuli were presented binaurally through Sennheiser HD25 headphones. The presentation of the experiment was accomplished using a custom written Java application that displayed a loudness scale. Loudness ratings were continuously recorded at a sampling rate of 10 Hz.

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[1] Goebl and Bresin (2003) have investigated the reproducibility of performance of a Yamaha MIDI grand piano—the modeled grand piano we use in PianoTeq 2.2.1 ('C3 Concert Grand Piano'). When comparing the lowest and highest note pitches in the range used in the present study, Goebl and Bresin report a difference of up to ~3–4 dB SPL for notes played at midi velocity 90. This is consistent with the dB SPL variation between notes in our steady-state melodies when measured with 240 ms temporal windows (the duration of each note in Experiment 1). However, the essentially linear slope of our time-series loudness response (see Section 3.1 below) is evidence that deviations in continuous loudness from note-to-note intensity fluctuations are minor and unsystematic.

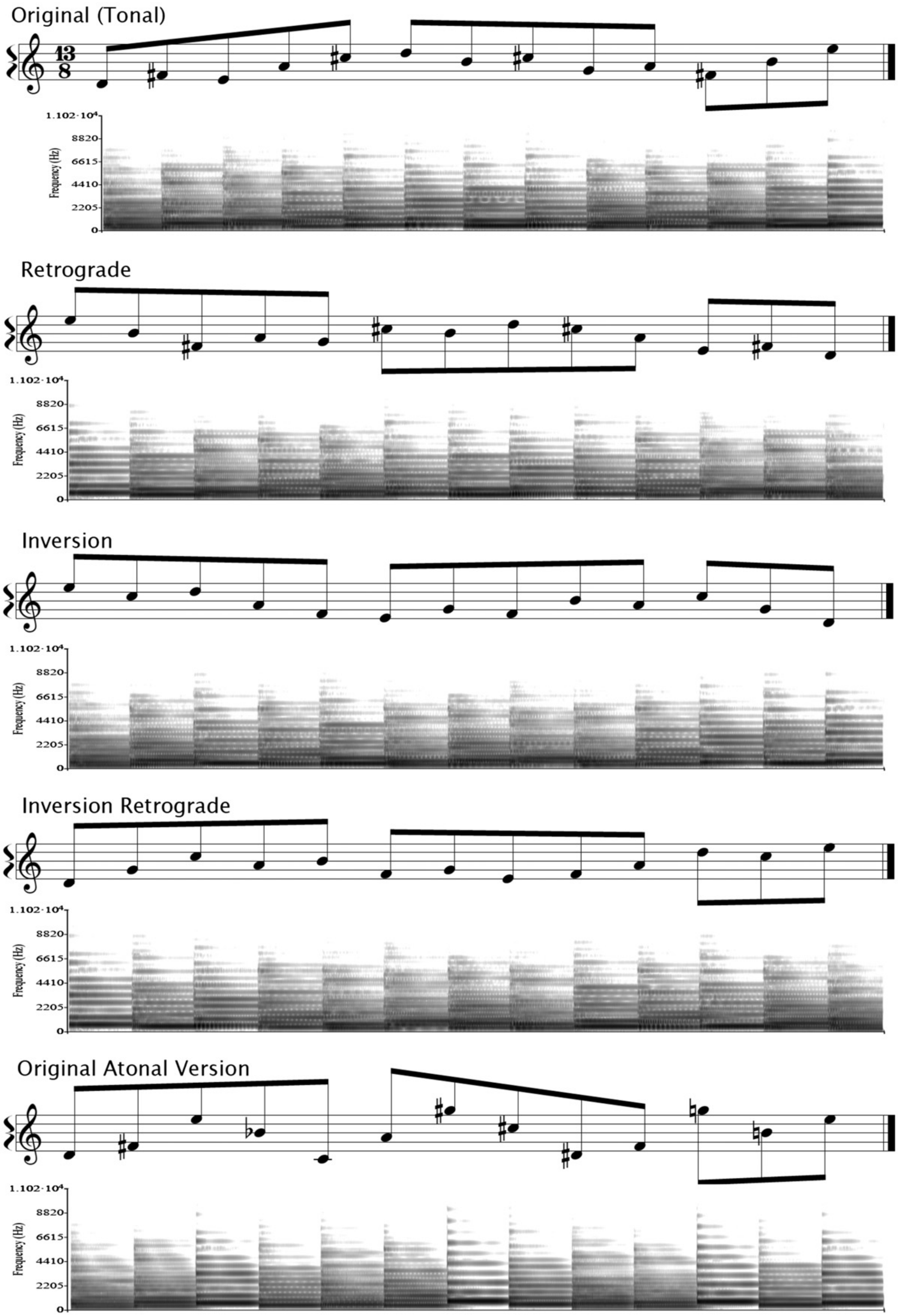

Fig. 1. Notated melodies and corresponding spectrograms presented in Experiment 1 and Experiment 2. *Original Tonal* and *Original Atonal* melodies were taken directly from Roger Dean's composition *Mutase* (Dean, 2008), while the *Retrograde*, *Inversion*, and *Inversion Retrograde* melodies were directly derived with the *Original Tonal* melody but not used in the composition. The representation as $5 + 5 + 3$ (13/8 time signature) for each melody is purely compositional; there are no accents in recordings for empirical use. The first four melodies were used in Experiment 1 with inter-onset intervals (IOIs) of 240 ms. *Original* and *Inversion Retrograde* followed an overall ascending pitch contour. *Retrograde* and *Inversion* followed an overall descending pitch contour. *Original* and *Original Atonal* melodies were presented in Experiment 2 at IOIs of 463 ms and 926 ms for the relatively 'fast' and 'slow' tempo conditions, respectively.

Table 1
Fundamental frequency (Hz) of notes in melodies used for Experiments 1 and 2.

	Note position in melody												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Original	294	370	330	440	554	587	494	554	392	440	370	494	660
Retrograde	660	494	370	440	392	554	494	587	554	440	330	370	294
Inversion	660	523	587	440	349	330	392	349	494	440	523	392	294
Inv. Retrograde	294	392	523	440	494	349	392	330	349	440	587	523	660
Orig. Atonal	294	370	659	466	262	440	830	554	311	349	784	494	659

Note. Original, *Retrograde*, *Inversion*, and *Inversion Retrograde* melodies were presented in Experiment 1; *Original* and *Original Atonal* melodies were presented in Experiment 2.

To investigate the role of tempo and tonality, Experiment 2 used the tonal and atonal segments of *Mutase*, which occur in Sections 1 and 4 respectively in the full piece (Dean, 2008). Table 1 presents the fundamental frequency of each note for the atonal melody and Supplementary Audio File 5 contains an example of the melody (See Appendix for detail on the atonal motive). In Experiment 2, each trial was 12 s in duration and comprised one of two tempi: 64.8 bpm (slow) and 129.6 bpm (fast). The inter-onset intervals of each note for the relatively 'slow' and 'fast' tempo conditions were 926 ms and 463 ms, respectively. Each melody was played twice within a 129.6 bpm trial so the duration of each trial was equivalent, regardless of tempo. Intensity ramps were constructed in an identical manner to those in Experiment 1. There were 20 stimulus conditions in Experiment 2.

2.3. Procedure

Participants first read an experiment information sheet, gave written informed consent and received standardized instructions regarding the task. In Experiment 1, participants were instructed to first rate the loudness of the 2 s orientation tone by placing the mouse on the vertical scale that ranged from 'Soft' to 'Loud', with 'Moderate' signifying the mid-point. The scale ranged from 1 to 100 (soft to loud) and its spatial extent was 110 mm. As there was no orientation tone in Experiment 2, participants were asked to place the cursor at the midpoint of the scale before the melody was presented. As each melody began to play, participants were required to continuously rate the loudness of the melody by moving the mouse cursor anywhere along the scale. The use of a slider to measure continuous loudness has precedence as a measure of real-time perception (Ferguson et al., 2011; Susini, McAdams, & Smith, 2002; Susini et al., 2007). Eight practice trials that presented a range of conditions were first presented for participants to become accustomed to the task. Experiment 1 trials were divided into two fully randomized blocks of all 44 conditions (not including practice trials). Consequently there was a total of 88 trials; two presentations of each condition. Experiment 2 trials were combined into one block of 60 trials. This included 16 conditions of intensity change, tempo, and tonality, in addition to four steady-state control stimuli comprised of each tempo and tonality presented at 70 dB SPL. Therefore, in Experiment 2 each condition was randomly presented three times within the experiment. Each experiment took approximately 30 min to complete.

2.4. Data reduction and analysis

Before analyzing the main dependent variable of perceived loudness change, linear Pearson correlation coefficients were calculated between perceived loudness and time for each up-ramp and down-ramp and steady-state trials of Experiment 1 and Experiment 2. This analysis was designed to investigate the characteristics of the time-series loudness response curves. Given the simple linear result of these correlations for up-ramps and down-ramps (see Section 3.1 below), loudness change in Experiment 1 was calculated by measuring: (1) the loudness rating value at which the continuous rating changed by one rating value on the scale relative to the initial rating at melody onset, and specifically for up-ramp and down-ramp conditions, a loudness rating change in the direction congruent to the intensity change of the stimulus; and (2) the loudness value at melody offset. The difference between these two discrete loudness ratings was defined as 'perceived loudness change' and was calculated as a number in the region of 0–100, where 0 represents no perceived change in loudness, and 100 represents a large perceived change in loudness. This measure captures the magnitude of loudness change 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. Supplementary Fig. 2 shows an example of a time-series loudness response to an 85–55 dB SPL down-ramp trial. Although this calculation of indirect loudness change differs from magnitude estimation studies that calculate the ratio between static loudness judgements at the beginning and end of an intensity sweep, it was deemed most appropriate because of the decision to use a rating scale to continuously track loudness across an entire trial. Nevertheless, results from indirect loudness change measures using magnitude estimates or continuous responses are certainly comparable.

Given that the linear correlations reported in Section 3.1 were much weaker for steady-state stimuli relative to dynamic intensity stimuli, second- and third-order regression analyses were conducted to investigate the possibility of a better fitting model for the continuous loudness response to steady-state stimuli. Using Bayesian Information Criteria (BIC) as the basis for model selection, the most parsimonious model of the time-series loudness data for all steady-state conditions was a third-order cubic model. Therefore, loudness change in response to steady-state conditions in Experiment 1 was calculated by taking the difference between modeled loudness values at the beginning and end of each trial, rather than the raw loudness values that were not well represented by a linear function.

In Experiment 2, where there was no orientation tone (arguably a more ecological musical condition), loudness change was calculated by first averaging loudness ratings in the 3–4 s temporal window from stimulus onset, and the 11–12 s temporal window. This measurement procedure was chosen because we found that it provided enough time (3 s) for participants' response to settle after the initial movement from the mid-point of the scale at the beginning of a trial. The difference between the two means was defined as the magnitude of loudness change and was again calculated as a number between 0 and 100. Repeated measures analysis of variance (ANOVAs) were conducted and Bonferroni adjustments to alpha were applied when analyzing post-hoc comparisons of significant interactions. Partial eta squared (η^2_{p}) was calculated as a measure of effect size (Cohen, 1973).

3. Results

3.1. Time-series loudness responses to up-ramps and down-ramps are essentially linear

As can be seen in Table 2, mean absolute values of linear Pearson correlation coefficients were all very high (equal to or above .90) for continuous loudness in response to 15 dB SPL and 30 dB SPL intensity ramps in each of the four versions of *Mutase* in Experiment 1, and equal to or above .89 in response to 15 dB SPL intensity ramps for the

Table 2
Absolute linear Pearson correlation coefficients of continuous loudness over time.

	Version of *Mutase* melody				
	Experiment 1				Experiment 2
	Original	Retrograde	Inversion	Inv. Retrograde	Orig. Atonal
Up-ramp					
15 dB	.96 (.05)	.94 (.14)	.92 (.14)	.96 (.07)	.90 (.16)
30 dB	.95 (.07)	.96 (.06)	.94 (.13)	.95 (.08)	–
Down-ramp					
15 dB	.90 (.27)	.94 (.09)	.93 (.13)	.93 (.12)	.89 (.15)
30 dB	.95 (.06)	.96 (.06)	.96 (.06)	.95 (.05)	–
Steady-state					
55 dB	.69 (.22)	.66 (.20)	.68 (.21)	.73 (.22)	–
70 dB	.74 (.21)	.65 (.25)	.71 (.23)	.72 (.21)	–
85 dB	.70 (.20)	.71 (.22)	.70 (.20)	.74 (.20)	–

Note: All linear correlation coefficients significant at $p < .05$; Standard deviations presented in parentheses; In Experiment 1: *Original* and *Inversion Retrograde* melodies were characterized by a generally ascending melodic contour; *Retrograde* and *Inversion* melodies were characterized by a generally descending melodic contour. *Original Atonal* was presented in Experiment 2, which did not include 30 dB intensity ramps. For up-ramps and down-ramps, the range of intensity sweep is presented. For steady-state melodies, the constant intensity level is presented.

Original Atonal version in Experiment 2 ($p < .05$). From the 'hybrid' paired ramp trials in Experiment 1, the influence of ramp context on the linearity of continuous loudness data was also addressed. Results indicate that second item up-ramps and down-ramps presented in the context of a down-ramp or up-ramp, respectively, followed the same trend in results as single ramp presentations. Responses to an up-ramp when preceded by a down-ramp had a strongly linear function with Pearson correlation coefficients equal to or above .94 ($SD = <.11$) for each melody. This was also the case for responses to second-item down-ramps that were preceded by an up-ramp (Pearson correlation coefficients equal to or above .91, $SD = <.19$). Therefore, continuous loudness response to up-ramps and down-ramps presented in isolation (single ramp trials) or in the context of a preceding ramp (paired ramp 'hybrid' trials) are well represented by a linear function. Table 2 also shows the continuous loudness response to steady-state stimuli was not as well represented by a linear function, with Pearson correlation coefficients ranging from .66 to .74.

3.2. Increases and decreases of acoustic intensity

As a manipulation check, the effect of intensity range on loudness change was investigated in Experiment 1 from an intensity direction × intensity range × pitch contour within-subjects ANOVA; that is, as intensity range increases, so should perceived changes in loudness. This was the case from a significant main effect of intensity range: the 30 dB SPL range of intensity change ($M = 60.07$, $SE = 3.57$) was perceived to change significantly more in loudness than the 15 dB SPL range ($M = 44.28$, $SE = 3.14$), $F(1,28) = 83.50$, $p < .001$, $\eta^2_p = .75$. This shows that greater intensity change did elicit greater loudness change and was replicated in Experiment 2. Secondly, from a significant main effect of intensity direction, down-ramp melodies ($M = 58.52$, $SE = 4.05$) were perceived to change significantly more in loudness than up-ramp melodies ($M = 45.83$, $SE = 2.73$), $F(1,28) = 29.39$, $p < .001$, $\eta^2_p = .51$. The interaction between intensity direction and intensity range was not significant, $F(1,28) = .50$, $p > .05$, $\eta^2_p = .02$. Therefore, these results support Hypothesis 1.

Two related studies have reported potentially adaptive sex differences when investigating the perception of virtual looming/receding stimuli and complex tonal up-ramps and down-ramps (Grassi, 2010; Neuhoff, Planisek, & Seifritz, 2009). Compared to male participants, females overestimate the time of arrival of a looming relative to a receding sound source, and overestimate the subjective duration of 1050 ms–1950 ms up-ramps relative to down-ramps. We conducted equivalent analyses here from single-ramp trials using an intensity direction × intensity range × pitch contour within-subjects ANOVA with sex as the between-subjects factor, and found no significant differences between males and females. In particular, loudness change in response to both directions of intensity change was close to identical between male participants (up-ramps: $M = 46.15$, $SE = 4.99$; down-ramps: $M = 58.86$, $SE = 7.40$) and female participants (up-ramps: $M = 45.68$, $SE = 3.35$; down-ramps: $M = 58.36$, $SE = 4.97$). Consequently, the above results in Section 3.2 using the entire sample were upheld when analyses incorporated only males and only females.

To further investigate whether a decruitment-related effect on down-ramp end-level loudness can explain the greater magnitude of loudness change in response to musical down-ramps, we calculated mean loudness at the onset of the continuous response and mean loudness at stimulus offset for up-ramps and down-ramps. Fig. 2 presents these data for single ramp trials. Mean loudness in response to the relatively high-intensity onset of down-ramps ($M = 81.32$, $SE = 2.41$) and the equivalent high intensity offset of up-ramps ($M = 81.25$, $SE = 1.83$) are close to identical. It is the lower intensity portion of each stimulus that is the important factor. Specifically, loudness in response to the relatively low-intensity offset of down-ramps ($M = 19.47$, $SE = 1.96$) is significantly lower than the equivalent low-intensity onset of up-ramps ($M = 32.69$, $SE = 1.97$), $F(1,28) = 51.15$, $p < .001$, $\eta^2_p = .65$.

3.3. Ramp context effects

To investigate the effect of context on the perception of musical up-ramps and down-ramps, analyses were conducted from paired ramp (hybrid) trials comparing first- and second-item up-ramps, and first- and second-item down-ramps. Second-item up-ramps and down-ramps are presented in the context of a down-ramp or up-ramp, respectively, whereas first-item up-ramps and down-ramps do not have an intensity ramp preceding them. Loudness change in response to second-item up-ramps ($M = 61.39$, $SE = 3.61$) presented in the context of a down-ramp was significantly greater than first-item up-ramps without a preceding down-ramp ($M = 47.05$, $SE = 3.15$), $F(1,28) = 48.42$, $p < .001$, $\eta^2_p = .63$. There was no significant effect of ramp context on loudness change between first-item down-ramps ($M = 59.69$, $SE = 3.67$) and second-item down-ramps ($M = 60.90$, $SE = 4.38$), $F(1,28) = .10$, $p > .05$, $\eta^2_p = .00$. Therefore, Hypothesis 2 was supported.

3.4. Congruency effects: acoustic intensity change and melodic contour

To investigate the effects of congruent and incongruent changes of intensity and melodic contour on perceived loudness change, an ANOVA was conducted that included increases and decreases of intensity with ascending and descending changes in melodic contour. A

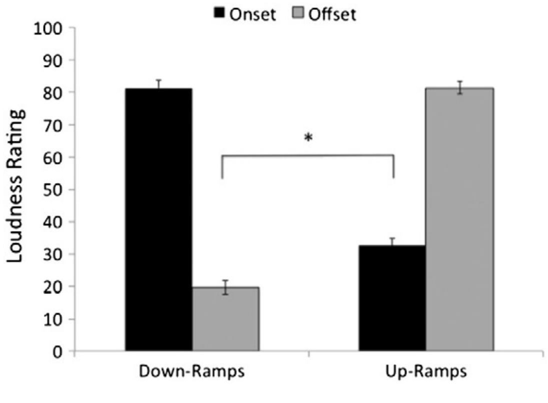

Fig. 2. Mean loudness ratings at response onset and stimulus offset for single ramp down-ramps and single ramp up-ramps in Experiment 1. On the y-axis zero represents a 'soft' loudness response and 100 represents a 'loud' loudness response. Error bars report standard error of the mean; $^*p < .001$.

significant intensity direction × melodic contour × intensity range interaction partially supported Hypothesis 3, $F(1,28) = 9.69$, $p < .01$, $\eta^2_p = .26$. As can be seen in Fig. 3, descending melodic contour down-ramps (a congruent change of melodic contour and intensity) were perceived to change significantly more in loudness than down-ramps coupled with an incongruent ascending melodic contour ($p < .01$). However, for up-ramps a congruency facilitation effect was not observed: there were no significant differences between ascending up-ramps and descending up-ramps ($p > .05$). These results were observed in both the 15 dB and 30 dB range of intensity change.

To assess participants' continuous response to steady-state stimuli comprising either ascending or descending melodic contour, a 3 × 2 repeated measures ANOVA was conducted with three levels of intensity (55 dB Low, 70 dB Mid, 85 dB High) and two levels of melodic contour (Ascending, Descending). There was a significant main effect of intensity, $F(2,56) = 5.30$, $p < .01$, $\eta^2_p = .16$, but not of melodic contour, $F(1,28) = 1.34$, $p > .05$, $\eta^2_p = .05$. There was a significant difference in loudness change between low intensity steady-state sounds and high intensity steady-state sounds. However, there were no significant differences between these variables and the mid-intensity steady-state conditions. There was a significant intensity × melodic contour interaction, $F(2,56) = 7.83$, $p < .01$, $\eta^2_p = .22$. To further investigate the steady-state results from each condition, six pairwise comparisons with an adjusted alpha of .008 (.05/6) were made against zero (a 'veridical' response of no change in loudness) for ascending and descending melodic contour conditions at steady-state intensity levels of 55 dB SPL, 70 dB SPL, and 85 dB SPL. As can been seen in Fig. 4, Hypothesis 4 was partially supported. In conditions of relatively high (85 dB SPL) and low (55 dB SPL) intensity, only ascending melodic contours were judged to significantly increase and decrease in loudness relative to a 'no-change' response of zero, respectively, with p-values <.008. In the mid intensity conditions of 70 dB SPL, there was no significant effect of ascending or descending melodic contour on loudness change (p-values >.24).

3.5. Tonality and tempo

Experiment 2 was designed to investigate whether perception of loudness change is influenced by tempo and/or unfamiliar tonality. An ANOVA was conducted on intensity direction, tonality, and tempo. Fig. 5 shows that tonal melody down-ramps ($M = 63.99$, $SE = 3.61$) were perceived to change significantly more in loudness than tonal melody up-ramps ($M = 51.46$, $SE = 2.73$), $F(1,35) = 22.28$, $p < .001$, $\eta^2_p = .39$. Furthermore, atonal melody down-ramps ($M = 60.57$, $SE = 3.94$) were also perceived to change significantly more in loudness than atonal melody up-ramps ($M = 52.89$, $SE = 2.53$), $F(1,35) = 7.10$, $p < .05$, $\eta^2_p = .17$. Thus, tonality did not influence the decruitment effect. Slow-tempo down-ramps ($M = 63.19$, $SE = 3.92$) were perceived to change significantly more in loudness than slow-tempo up-ramps ($M = 49.12$, $SE = 2.71$), $F(1,35) = 26.84$, $p < .001$, $\eta^2_p = .43$. There was no difference between up-ramps and down-ramps in the fast-tempo conditions ($p > .05$). Finally, loudness change was greater in response to fast-tempo up-ramps relative to slow-tempo up-ramps ($p < .01$).

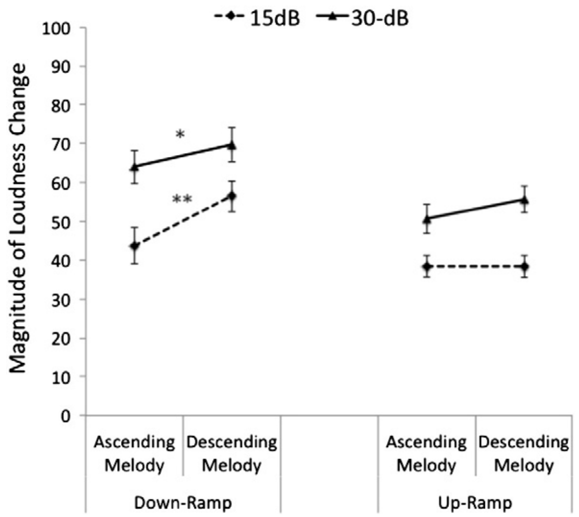

Fig. 3. Congruency effects of mean magnitude of loudness change ratings to intensity change and melodic contour as a function of each intensity range in Experiment 1. On the y-axis zero represents no perceived change in loudness and 100 represents a large perceived change in loudness. 'Ascending'/'Descending' refer to the overall direction of melodic contour. Congruent changes of intensity and melodic contour (e.g., descending melodic contour within a down-ramp) led to significantly greater perceived changes in loudness for down-ramps only. Congruent or incongruent intensity/melodic contour pairings did not result in differences in perceived loudness change for up-ramps. Error bars report standard error of the mean; *$p < .01$, **$p < .001$.

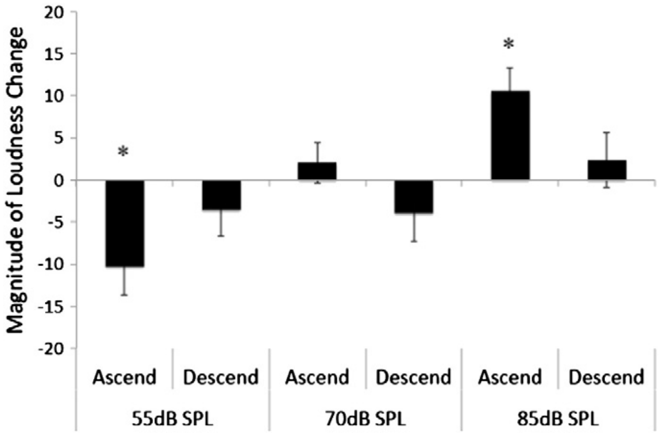

Fig. 4. Signed mean magnitude of loudness change ratings to steady-state control stimuli presented at 55 dB SPL, 70 dB SPL, or 85 dB SPL in Experiment 1. In these steady-state conditions, there was no intensity change within each trial. 'Ascend' refers to melodies characterized by an ascending melodic contour, and 'Descend' refers to melodies characterized by a descending melodic contour. Positive numbers signify an increase in perceived loudness across a trial, and negative numbers signify a decrease in loudness. Statistical comparisons are relative to zero—a 'veridical' response of no change in loudness–using an adjusted alpha of .008; Error bars report standard error of the mean; *$p < .008$.

4. Discussion

The present study reports two experiments that investigate continuous loudness change in response to acoustic intensity change in melodies. The use of a musical context in which to empirically investigate intensity and loudness change extends previous research that has used sine-waves, square-waves, and white-noise. Specifically we asked: (1) is perceived loudness change greater for increases or decreases of intensity when presented in the musical context of short melodies, and (2) are differences in perceived loudness change in response to intensity change influenced by the context in which up-ramps and down-ramps are presented, the congruency of intensity/melodic contour change, the tempo at which a melody is played, and the tonality of a melody? The results will now be considered by drawing on research into music perception and performance, auditory psychophysics, and dimensional integrality.

4.1. Perception of intensity change in melodies

Decruitment studies measuring loudness change from multiple magnitude estimates taken between the onset and offset of a stimulus have shown that down-ramps are judged to change significantly more in loudness than up-ramps (e.g., Canévet & Scharf, 1990; Canévet et al., 2003; Teghtsoonian et al., 2005). Hypothesis 1 in the present study predicted this effect using onset and offset loudness ratings extracted from continuous loudness data. In support of the hypothesis,

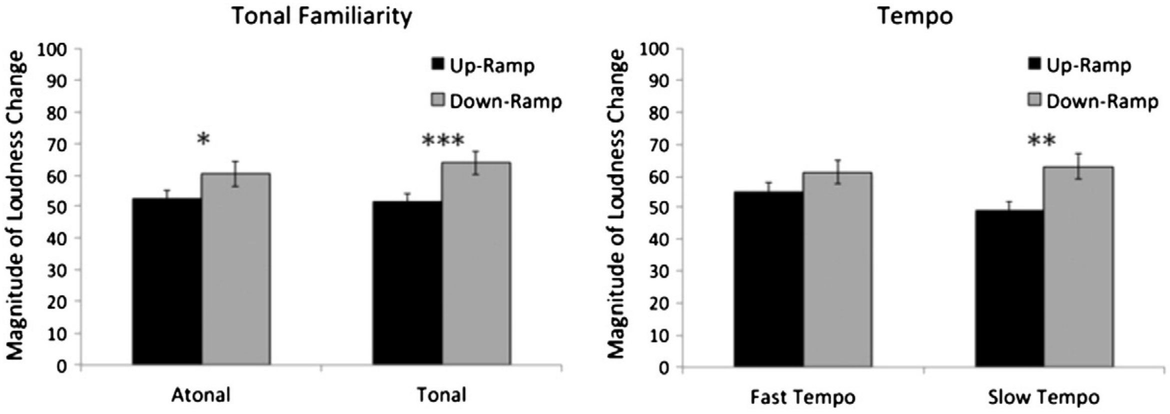

Fig. 5. Mean magnitude of loudness change ratings for tonality × intensity direction and tempo × intensity direction interactions in Experiment 2. Error bars report standard error of the mean; **p* < .05, ***p* < .01, ****p* < .001.

musical down-ramps were perceived to change significantly more in loudness than musical up-ramps. The effect of decruitment describes the instance when loudness falls to a greater extent as the continuous linear decrease of intensity of a down-ramp approaches stimulus offset. The 'softer' end-level perception of a down-ramp predicted by decruitment was evident in the present study and the response illustrated in Fig. 2. The relatively low-intensity of down-ramp end-level was perceived to be significantly softer in loudness than the equivalent low-intensity up-ramp onset. The disparity in loudness at these equivalent points of intensity could contribute to the greater perceived loudness change in response to down-ramps reported here in a more complex stimulus context than previously investigated. Of note is that the reciprocal effect of 'upcruitment' was not observed. Up-ramp offset loudness was equivalent to down-ramp onset loudness, supporting the explanation that the difference in loudness between the relatively low intensity down-ramp offset/up-ramp onset is responsible for the loudness change differences. However, one noticeable difference between the loudness response curves characteristic of decruitment and the response curves from our data is that loudness does not fall as a linear function in reports of decruitment. Indeed, in those reports, loudness continually decreases more rapidly (a gradually steepening loudness slope) as down-ramp intensity reaches 40 dB SPL and below. As noted above in Section 3.1, our loudness functions were strongly linear across the entire continuous response. This difference can be reconciled, however, by the fact that our stimuli only fall to a minimum intensity of 55 dB SPL.

Nevertheless, one mechanism that has been hypothesized in relation to greater perceived changes in loudness for down-ramps reported in decruitment studies—that of perceptual adaptation—is applicable to the present set of results. Canévet and Scharf (1990) were the first to link adaptation with down-ramp perception and argued that the previous higher intensity portion of a down-ramp at any temporal point may adapt the subsequent portion and result in a perceptually 'softer' stimulus. This would lead to down-ramp underestimation of end-level loudness. The results of the present study provide empirical support for adaptation as defined in these terms, so that it has now been shown in a temporally complex (musical) stimulus context. However, adaptation was not directly measured in the present study. Computational modeling of adaptation throughout the auditory pathway and by using simple and complex acoustic stimuli may shed light on the magnitude, location, and frequency dependency of adaptation in response to the changes of acoustic intensity within these stimuli.

The effect of dynamic intensity context on loudness change was investigated by presenting paired up-ramp/down-ramp or down-ramp/up-ramp hybrid conditions. Up-ramps presented in the immediate context of a down-ramp (down-ramp/up-ramp condition) were perceived to change significantly more in loudness than up-ramps with no immediate preceding ramp (i.e., the up-ramp in an up-ramp/down-ramp condition). Why is it that the context in which up-ramps are presented in a musical sequence has a significant effect on loudness change? Recent computational analyses of acoustic intensity change in composed, acousmatic, live-performed, and improvised works of electroacoustic music (Dean & Bailes, 2010b), improvised music (1950s to present) (Dean & Bailes, 2010a), and music from the Western Classical composers Haydn and Beethoven (Dean et al., 2013) have shown that when considered in successive pairs, decreases of intensity (decrescendi) are longer in overall duration than increases of intensity (crescendi). If a performer, at times, aims to equate the perceptual magnitude of loudness change elicited from crescendi and decrescendi, the intensity dynamics of a shorter-duration crescendo performed in the immediate context of a longer decrescendo will elicit the same perceived magnitude of loudness change as the decrescendo.

From a more psychoacoustic than music perspective, the ramp context results can also be explained by the down-ramp adaptation effect previously defined. Loudness change was greater in response to up-ramps presented in the context of (subsequent to) a down-ramp, relative to up-ramps that were not preceded by a down-ramp. Fig. 6 shows the onset and offset mean loudness ratings for up-ramps and down-ramps presented as either the first item or second item in paired ramp hybrid conditions. In single ramp conditions, down-ramps were perceived to change more in loudness because down-ramp end-level loudness is perceived to be softer than the equivalent low-intensity onset of an up-ramp. In the down-ramp/up-ramp hybrid condition shown in the left panel of Fig. 6, the mean loudness rating in response to the onset of an up-ramp ($M = 15.70$, $SE = 1.53$) was 16.19 rating values lower than the mean loudness response to the onset of an up-ramp presented as the first item in an up-ramp/down-ramp pair ($M = 31.89$, $SE = 1.97$). The difference between onset perception of first-item and second-item up-ramps is caused by a first-item down-ramp end-level loudness 'softening' effect. This results in the subsequent onset of a second-item up-ramp to be perceived softer than the onset of a first-item up-ramp that was not preceded by a continuous decrease of intensity. This, in turn, results in an overall greater perceived change in loudness for up-ramps from onset to offset when presented in the context of a down-ramp because up-ramp onset perception begins at a relatively low loudness reference point. Additionally, these context analyses show that down-ramp decruitment is evident in both hybrid combinations, but with differing effects on up-ramp loudness change within each hybrid pair. The magnitude of loudness change in response to down-ramps is almost identical when a down-ramp is presented as the first or second item in a paired ramp hybrid condition. However, in the down-ramp/up-ramp hybrid condition, down-ramp decruitment has the effect of decreasing the loudness of the subsequent up-ramp onset response and as a result, differences in loudness change

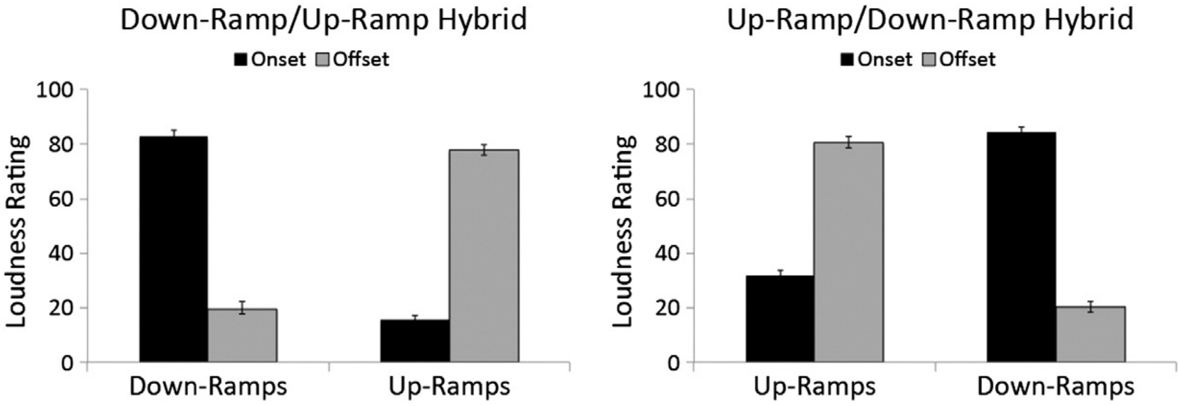

Fig. 6. Mean loudness ratings at response onset and offset for paired down-ramp/up-ramp (left panel) and up-ramp/down-ramp (right panel) 'hybrid' conditions in Experiment 1. Error bars report standard error of the mean.

between up-ramps and down-ramps originally observed in single-ramp trials are eliminated. This result is a new example of how down-ramp decruitment can significantly effect previously reported differences in perceived loudness change between up-ramps and down-ramps.

One important point from this discussion of onset/offset differences between up-ramps and down-ramps is that these are loudness measurements in arbitrary rating-scale units. It is not entirely clear, for example, whether the low-intensity offset of a down-ramp is underestimated in loudness relative to the physical offset. Future studies will quantify in physical terms (dB SPL) whether down-ramp end-level perception is indeed underestimated, as the decruitment explanation would suggest.

We have conducted an additional analysis of the contextual effects of up-ramps and down-ramps on real-time loudness perception in more complex orchestral music. Specifically, we found an asymmetric influence for changes of acoustic intensity on continuously perceived loudness in the first 65 second segment of Dvorak's *Slavonic Dance,* Opus 46, No. 1, an orchestral piece studied in depth in our previous work on relationships between intensity and perceived arousal (e.g., Dean et al., 2011). As detailed in that paper, we have 2 Hz sampled continuous loudness responses from 24 listeners to this section of music, as well as measured acoustic intensity. We used the mean perceived loudness series (averaging across the participants' data at each time point), and standardized this and the intensity series. The series then required once-differencing to obtain the required statistical stationarity, creating series we term dintensity and dloudness.[2] We modeled the dloudness series using ARX, AutoRegressive analysis with an eXternal predictor (dintensity). This gave a good model with both lag zero and lag 1 of dintensity having significant impact, and an order one autoregression of the errors was found. Its BIC was 83.22. To assess whether a rise in intensity might have an effect different in absolute quantity from a fall of the same magnitude, we made a further ARX model with the series of positive values in dintensity as one predictor (series set to zero when intensity was flat or fell), together with a series representing negative values in dintensity (with corresponding zeros) as the other. This generated a substantially improved model (BIC $= 67.53$) with lag 1 of the rise series (coefficient 0.95, $SE = 0.03$) and lag zero of the fall series (coefficient 0.63, $SE = 0.06$) as predictors. An AR1 term was again required. Thus in this particular case the effects of rises and falls are distinct, and rises of a given intensity have considerably greater impact on perceived loudness than do corresponding falls. This might be expected because the Dvorak piece contains shorter crescendi than decrescendi. Because the time-series are stationarized to have a constant mean, there is no overall net change in dintensity. The phenomenon requires broader investigation, as it might be specific to the Dvorak orchestral piece. In general, however, it is consistent with the notions of asymmetry analysed in the present study

Our analysis of intensity and tonality shows that perceived loudness change is significantly greater for down-ramps relative to up-ramps in both culturally familiar tonal conditions and the more unfamiliar atonal conditions. Greater change in loudness in response to down-ramps is therefore not specific to melodies composed in a way that either fulfills or violates culturally-bound melodic expectations, but rather, is equally strong for both. Whether these results are replicated within cross-cultural music perception awaits further investigation. Greater loudness change in response to down-ramps was also recovered for slow tempi (64.8 bpm) but not fast tempi (129.6 bpm). Perhaps the doubling of notes/discrete events in the fast tempo melodies minimized the perceptual differences between up-ramps and down-ramps observed when stimuli contained less notes/discrete events? This hypothesis would suggest that as a musical stimulus becomes more complex, for example with greater note density and tempo variations, the differential effects between up-ramps and down-ramps reported here are attenuated. The concept of an increase in complexity of one dimension minimizing the effect of another does have some empirical basis within a range of auditory contexts and acoustic dimensions (e.g., Dawe, Platt, & Racine, 1995; Melara & Mounts, 1994; Prince, Schmuckler, & Thompson, 2009). In terms of musical performance, Langner and Goebl (2003) suggest that pianists tend to play increasingly louder but not softer at faster tempi, and increasingly softer but not louder at slower tempi. Our perceptual data partly correspond to these predicted tempo/loudness performance interactions. Perceived loudness change in response to up-ramps increased as tempo increased. Fast or slow tempi did not lead to differences in down-ramp perception. The relationship between performed and perceived tempo/intensity/loudness is yet to be investigated. High levels of loudness and fast tempi are associated with perceived emotions in music such as anger (Balkwill et al., 2004), characterized by high arousal and negative valence (Russell, 1980). Coupled with emotional response to music that transcend cultural boundaries (Balkwill & Thompson, 1999), the interaction between musical tempo and intensity plays an important role in perceived and performed loudness dynamics, and is often considered in light of consumer behavior (e.g., Baker & Cameron, 1996; Kellaris & Rice, 1993). The psychological mechanisms that underpin the perception and emotional response to tempo and intensity change in music, and their relationship with other acoustic properties of music such as pitch change, timbre, and tonal complexity, is a fruitful area for continued empirical investigation (Juslin & Västfjäll, 2008).

Finally, when melodies were presented with a steady-state intensity contour, loudness change varied significantly from a veridical 'no change' response; a result that was further dependent on the intensity region of the steady-state stimulus. For the relatively low 55 dB SPL conditions, loudness change decreased across the course of the melody,

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[2] See Bailes and Dean (2012) and Dean and Bailes (2010c) for more detail on this particular method of time-series analysis applied to music perception.

whereas at the relatively high 85 dB SPL conditions, loudness change increased. Although the contours of steady-state time-series responses were relatively complex when compared to those in response to the essentially linear dynamic intensity conditions, the intensity-dependent change in loudness in response to steady-state intensity melodies could be interpreted as a 'time-order error' or 'bias edge effect' (Berliner, Durlach, & Braida, 1977; Hellström, 1985, 2003). For example, the bias edge effect shows that at relatively low intensity regions, successive tones of equal intensity presented without an interstimulus interval (akin to each tone in our steady-sate melodies) result in a sequential decrease in loudness, whereas at relatively high intensities, lead to a sequential increase in loudness. In the present study, listeners could have compared each note of the melody in a kind of 'multiple-look process' and reset their loudness percept after each note, as is the case in intensity discrimination experiments such as those reporting bias edge effects. This could explain why perceived loudness decreases over time at the lower intensity range and increase over time at the upper intensity range of the present study.

4.2. Acoustic intensity and melodic contour: interacting dimensions in music perception

The interaction between increases and decreases of acoustic intensity and ascending and descending melodic contour was investigated here in the context of short melodies. Previous studies in non-musical contexts have shown that ascending pitch intervals are perceived to be larger when coupled with increasing intensity (a congruent frequency/intensity change) relative to decreasing intensity (an incongruent change), and loudness change is greater when presented with congruent changes of frequency and intensity relative to incongruent changes. It was hypothesized that similar congruency effects are recovered using musical stimuli. Results indicate however that congruent changes of intensity and melodic contour had a significant effect on down-ramp perception only. Descending down-ramps were perceived to change significantly more in loudness than ascending down-ramps, whereas no differences in loudness change between ascending and descending up-ramps were observed. In other words, congruent changes of intensity and melodic contour have a significant effect on perceived loudness change in melodies with falling intensity (e.g., a decrescendo). When the intensity change in a melody increases (e.g., a crescendo), the melodic contour does not significantly alter perceived loudness change. Unlike experiments using basic psychoacoustic stimuli, these results suggest that rising intensity is not as susceptible to dimensional interaction in relatively complex stimuli such as melodies. For down-ramps, the magnitude of perceived change is facilitated by a congruent change in another concurrent acoustic dimension—in this case, the contour of a descending melody—and suggests that decreases of intensity are affected by dimensional interaction to a greater extent than increases of intensity. Understanding reasons for this will require further empirical investigation.

In the context of music, the present results show that the interaction between the two acoustic dimensions of intensity change and melodic contour does not simply reflect an integral, dimensionless, holistic perceptual 'blob', as the traditional model of multidimensional interaction suggests (Garner, 1974; Lockhead, 1972; Neuhoff, 2004). Rather, the key factor is the specific context created by one dimension (e.g., the 'unattended' stimulus) that influences perception of another dimension (Neuhoff, 2004). Melara and Marks have argued that multidimensional interaction is a context-dependent analytic process, and the present study lends support to this hypothesis (Melara & Marks, 1990a,b,c; Melara, Marks, & Potts, 1993). In the context of a rising intensity up-ramp/crescendo, dimensional interaction is not observed; the influence on loudness change from congruent and incongruent changes in melodic contour is minimal. In the context of a falling intensity down-ramp/decrescendo, congruency effects and thus dimensional interactions are observed, significantly influencing down-ramp perception.

The melodic contours in the set of melodies in the present study were not 100% uni-directional. That is, 67% of intervals in each melody varied in the direction compatible to its 'overall' ascending or descending contour. Such melodies represent those in musical performances across genres when compared to 100% ascending or descending patterns that are found in musical scales. Furthermore, in Experiment 1 ascending or descending melodies were presented twice in a single trial, resulting in a large interval decrease or increase, respectively, between the final note of the first melody and the first note of the second melody. However, significant effects from an 'overall' manipulation of melodic contour were still recovered, and for up-ramps and down-ramps in particular, the strong linearity of responses are evidence that the large mid-trial interval change between the first and second melody did not significantly influence the continuous loudness response. We surmise that our results pertaining to the effects of melodic contour would likely strengthen if each interval in a melody changed in the direction congruent to its overall contour at a proportion closer to 100%.

4.3. Conclusion

Continuous decreases of acoustic intensity in melodies are perceived to change more in loudness than increases of intensity; a result that is not likely to be specific to the melodies presented here. Rather, the present study provides further evidence in a new and relatively complex stimulus domain of a decruitment effect and adaptation mechanism underlying the perception of dynamic intensity sounds. Indeed, as music is a real-time listening experience rather than an event judged after the fact, it is clear from the present set of data that the perceptual phenomenon of decruitment and adaptation—rather than a 'bias for rising intensities' (Neuhoff, 1998)—is most applicable to the perception of intensity dynamics in music. This is a significant contribution of the present study. Furthermore, loudness change in response to down-ramps, but not up-ramps, was enhanced when the direction of melodic contour was congruent with the direction of intensity change. Relative to fast tempi, slow tempi resulted in greater differences in loudness change between up-ramps and down-ramps. However, the tonality of the melody did not have a significant impact on loudness change. Finally, the present study has shown that in addition to more controlled psychoacoustic stimuli, music is a useful tool to demonstrate the importance of context in perception of acoustic dynamics such as intensity and loudness change.

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Appendix A

The *atonal motive* was composed as a derivative of the tonal original, but it is necessary to note that the distinction between atonal and tonal is multidimensional. Atonality implies avoiding a single tone (or pitch class) being theoretically the 'root' or 'center' of both the motive and the pitch structure in which it resides. This is normally approached by using all twelve pitches (and hence all 12 pitch classes) in the chromatic (equal tempered) octave equivalently. One approach is to not reuse a pitch class (those notes related by octave jumps) until all other classes have been used. This was adopted, so that the 13th note of the motive is a repetition of the 3rd pitch. This pitch class is also repeated (along with others) in the tonal motive. In addition, wider intervals are used in the atonal motive, and it includes jumps of major 7th (11 semitones) and minor 9th (13 semitones). Thus the atonal motive has an average interval size between each note and the starting note of 8.66 semitones (866 cents) and the proportion of ascending intervals was .58. There are 7 rising intervals and 5 falling intervals (whereas with the tonal original there are 8 rising and 4 falling). The pitch range covered altogether is 14 semitones (1400 cents) in the tonal original, but 18 semitones (1800 cents) in the atonal.

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