Attention, Perception, & Psychophysics
2010, 72 (5), 1390-1403
doi:10.3758/APP.72.5.1390

Do metrical accents create illusory phenomenal accents?

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In music that is perceived as metrically structured, events coinciding with the main beat are called *metrically accented*. Are these accents purely cognitive, or do they perhaps represent illusory increases in perceived loudness or duration, caused by heightened attention to main beats? In four separate tasks, musicians tried to detect a small actual increase or decrease in the loudness or duration of a single note in melodies comprising 12 notes. Musical notation prescribed a meter (6/8) implying a main beat coinciding with every third note. Effects of metrical accentuation on detection performance were found in all four tasks. However, they reflected primarily an increase in sensitivity to physical changes in main beat positions, likely to be due to enhanced attention. There was no evidence of biases indicating illusory phenomenal accents in those positions. By contrast, and independent of metrical structure, pitch accents due to pitch contour pivots were often mistaken for increases in loudness.

In their seminal book on tonal music, Lerdahl and Jackendoff (1983) distinguished three kinds of accent: phenomenal, metrical, and structural. *Phenomenal accents* are conveyed by aspects of the physical sound structure, such as differences in loudness or duration, leaps in pitch, and temporal separation.[1] *Metrical accents*, by contrast, are "a mental construct, inferred from but not identical to the patterns of accentuation at the musical surface" (p. 18). Structural accents are less relevant to the present study and can be left aside.

The perception of metrical structure in a musical rhythm rests largely on temporal regularity and the perception of phenomenal accents. For example, Povel (1984) and Povel and Essens (1985) developed a well-known theory of how perception of a beat is induced by a rhythmic pattern containing only temporal (grouping) accents created by the durations of intervals between events. More recently, Hannon, Snyder, Eerola, and Krumhansl (2004) and Ellis and Jones (2009), among others, have conducted detailed investigations of the relative importance of temporal and melodic (pitch) accents in the perceptual induction of meter. Meter consists of at least two hierarchically nested levels of beats, one of which (the main beat, or *tactus*) is most salient. After a metrical structure has been induced by a pattern of phenomenal accents, it tends to persist, making possible the perception of phenomena such as syncopation, offbeat accents, and hemiola. Musical sounds are considered to be metrically accented if they coincide with the main beat. London (2004, p. 23) puts it thus: "A metrical accent occurs when the metrically entrained listener projects a sense of both temporal location and relatively greater salience onto a musical event."

Phenomenal accents, although important, are not the only determinants of perceived meter. There are endogenous determinants as well, as is already suggested by the fact that an induced metrical structure can persist in the face of conflicting input. If the pattern of phenomenal accents is impoverished or ambiguous, the same musical passage can give rise to different perceived metrical structures. A classic example is the metrical perception of metronomic sequences that do not contain any phenomenal accents (apart from the temporally privileged first event, which tends to be perceived as metrically accented; see Brochard, Abecasis, Potter, Ragot, & Drake, 2003; Toiviainen & Snyder, 2003). Such sequences are often perceived as being in duple, triple, or quadruple meter, depending on their tempo and on the listener (Bolton, 1894). This form of metrical perception is entirely endogenous and reflects the listener's sensorimotor resonance to preferred beat periods in a broad region around 600 msec (Parncutt, 1994; Todd, Lee, & O'Boyle, 2002; Todd, O'Boyle, & Lee, 1999; Van Noorden & Moelants, 1999). Perception of different meters can also be induced deliberately, without changing the musical passage that is the object of perception. One such way is to accompany or precede the passage with a metronome or with another passage that unambiguously instantiates a beat or meter (Desain & Honing, 2003; Repp, Iversen, & Patel, 2008). Another way, for musically literate persons, is to present the music in notation that has a time signature, bar lines, and beaming of short notes (Repp, 2007; Sloboda, 1985). These notational devices tell performers or listeners what meter the music is intended to be in, thereby encouraging them to impose the corresponding mental construct on the

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music when they play it or listen to it. Also, musicians can simply decide or be instructed verbally to think of music as being in one or another meter, as long as the passage is sufficiently ambiguous (Repp, 2005). Like meter induction (e.g., Grahn & Brett, 2007), such *imposition* of meter most likely involves internal motor processes (Iversen, Repp, & Patel, 2009). A more unusual method of manipulating metrical perception was devised by Phillips-Silver and Trainor (2005, 2007, 2008), who bounced infants or adults (or asked adults to bounce) at a particular beat period while an ambiguous rhythm was played. Later recognition tests showed that the rhythm had been encoded in the meter induced by the movement.

Even in cases in which the meter of a musical passage is unambiguous, it is still a mental construct, as Lerdahl and Jackendoff (1983) emphasized, not an objective property of the sound pattern. The mental construct (the term subsumes motor cognition) has apparent perceptual consequences, however. A musical passage heard in one meter can seem quite different from the same passage when it is heard in a different meter; the passages "sound" different and often are not recognized as being related (Repp et al., 2008; Sloboda, 1985). How literally should the verb "sound" in such informal reports be interpreted? Does it refer merely to a different cognitive organization (grouping, hierarchical structuring) of the same sequence of elementary auditory percepts, or are the individual tones in the music actually heard differently? Are metrical accents merely privileged points in an abstract cognitive/motor schema, or are they illusory phenomenal accents induced by that schema—actual top-down modifications of the auditory percepts associated with the individual notes? In other words, does the mental construct of meter feed back to and interact with the perception of phenomenal accents? If there were such an interaction, metrical structure would not be purely cognitive and abstract but, rather, it would be a dynamic phenomenon that alters the sensory input so as to increase its own stability.

In theory, there are (at least) three forms in which such an interaction might occur. First, according to dynamic attention theory (Jones & Boltz, 1989; Large, 2001; Large & Jones, 1999; see also London, 2004), metrical accents may represent moments of heightened attention. A metrical structure is assumed to rest on entrained internal oscillators whose frequencies exhibit simple ratios, and metrical accents represent the moments when the oscillators come into phase with each other (Large & Palmer, 2002). The oscillators are assumed to control attentional energy, which is highest when a main beat is expected. Increased attention may have two consequences: It may lead to heightened sensitivity to physical properties of the sound that is the focus of attention, and/or it may increase the perceptual salience of the attended event, which may be reflected in judgments that the sound seems louder or longer than neighboring sounds with similar physical properties (i.e., it may confer illusory phenomenal accents). A third, perhaps less plausible, theoretical possibility is that metrically accented events are only *expected* to be louder or longer than other events but, if they do not fulfill these expectations, are actually perceived as less loud or less long than other events. These three hypotheses will be referred to here as *increased sensitivity*, *positive bias*, and *negative bias*, respectively.

Previous Relevant Research

Several recent studies have provided intriguing hints that metrical cognition may indeed interact with auditory perception. When Phillips-Silver and Trainor (2007) entitled their article "Hearing What the Body Feels," they seemed to mean "hearing" rather literally. Their participants (as well as those in their 2005 and 2008 studies), after having bounced (or having been bounced) in one of two ways while listening to an ambiguous rhythm, were presented with disambiguated versions of the rhythm in which the sounds coinciding with one or the other previously induced beat were played louder than the other sounds. By identifying one of these rhythms as matching the one they had heard previously, participants seemed to indicate that they had perceived and remembered the ambiguous rhythm (in which all sounds were equally loud) as containing phenomenal intensity accents on the tones coinciding with bounces. The plausibility of this interpretation is enhanced by a recent demonstration that not only actual movement involving the head but also rhythmic electrical stimulation of the vestibulum (which induces apparent head movement) has a comparable effect on rhythm perception and recognition (Trainor, Gao, Lei, Lehtovaara, & Harris, 2009). Trainor et al. explicitly hypothesized that auditory signals are enhanced through multisensory integration with vestibular signals in the posterior parietal cortex (see also Trainor & Unrau, 2009). It should be noted, however, that the recognition choices in these studies never included the original ambiguous rhythm. The results would be even more convincing if participants were found to consistently prefer one of the disambiguated rhythms to the rhythm that had actually been presented during their bouncing.

Clearly, meter induction does not require overt movement or vestibular stimulation. Metrical structure in music is readily perceived while the listener is sitting still. Brochard et al. (2003) investigated spontaneous metrical perception by measuring event-related potentials (ERPs) to deviant notes in a metronomic sequence. A deviant note was less loud than the surrounding tones and occurred in an odd or even sequence position early in the sequence. Musicians, but not nonmusicians, showed a larger ERP response to deviants in odd than to deviants in even positions, which suggested that musicians perceived the sequence as being in duple meter, with the first event and all subsequent odd events being perceived as metrically accented. The result is consistent with increased sensitivity to a physical change in metrically accented positions, but it seems inconsistent with metrically accented notes being perceived as being louder than other notes, because, in that case, the response to metrically accented deviants (which, too, would have been perceived as being louder and, thus, would have differed less from neighboring notes) should have been weaker than the response to deviants in other metrical positions. However, such a tendency could have been overridden by increased sensitivity to change and surely also depended on the magnitude of the deviation. (Inclusion of deviants that are louder than neighboring notes might have been informative.) In a follow-up study, Abecasis, Brochard, Granot, and Drake (2005) tested nonmusicians with sequences in which duple or triple meter was cued explicitly by durational accents and found similar differences in the ERP responses to soft deviants in metrically strong and weak positions. Recently, Potter, Fenwick, Abecasis, and Brochard (2009) replicated the original study of Brochard et al., with a small methodological improvement that allowed them to detect early ERP differences, suggesting the presence of top-down influences on early auditory perception, which they attributed to dynamic attending.[2]

Consistent with a possible influence of dynamic attending on auditory perception, several other ERP studies have found enhanced brain responses to auditory stimuli when they occurred at attended moments (Lange, Krämer, & Röder, 2006; Lange, Rösler, & Röder, 2003; Sanders & Astheimer, 2008). An advantage in pitch processing of temporally expected tones has also been reported (Bausenhart, Rolke, & Ulrich, 2007; Jones, Moynihan, MacKenzie, & Puente, 2002), and attended events often seem longer in duration than do unattended events (K.-M. Chen & Yeh, 2009; Mattes & Ulrich, 1998; Tse, Intriligator, Rivest, & Cavanagh, 2004; Ulrich, Nitschke, & Rammsayer, 2006). Although these studies compared expected with unexpected events, rather than metrically accented and unaccented events, within the dynamic attending framework the former can be considered to be more strongly expected than the latter (Large & Palmer, 2002).

Two recent magnetoencephalographic (MEG) studies provide evidence suggestive of illusory phenomenal accents in metrically accented positions, although other interpretations are possible. Abecasis, Brochard, del Rio, Dufour, and Ortiz (2009) found larger left-hemisphere responses to metrically accented than to metrically unaccented, physically identical tones in a rhythm. At the same time, however, they found that deviants, which were louder than other notes in that study, elicited an increased left-hemisphere response in metrically unaccented positions but elicited a decreased response in metrically accented positions, which suggests that metrically accented notes were expected to be louder, but were not heard as louder. In a study by Iversen et al. (2009), musically trained participants listened to a simple rhythm composed of a repeating group of two notes and were instructed to "hear" the rhythm such that the main beat fell on either one or the other note (cf. Repp, 2005). In a control condition, one or the other note was played louder. The analysis focused on early high-frequency oscillatory responses to the notes in the beta (20–30 Hz) and gamma (30–50 Hz) ranges of the MEG signal. Louder notes clearly elicited larger responses in both ranges. Remarkably, subjective metrical accentuation in the absence of any loudness difference generated an equally large increase in the MEG response in the beta range, but not in the gamma range. The similarity of the beta response in the two conditions could be interpreted as suggesting that metrical accentuation bestows an illusory phenomenal (loudness) accent on the target events.

However, brain signals in response to auditory stimuli cannot be interpreted simply as reflecting auditory percepts; they may reflect other processes that accompany, but do not interact with, auditory processing. Iversen et al. (2009) favored the hypothesis that neural activity in the beta range reflects activation of an auditory–motor link (see also J. L. Chen, Penhune, & Zatorre, 2009; Fujioka, Trainor, Large, & Ross, 2009). Indeed, a plausible way of generating and maintaining a metrical structure for an auditory rhythm is to "move inwardly with the main beat" (i.e., to use motor imagery to mark metrically strong events). This internal activity is felt most clearly when it coincides with the absence of an external event, as in the case of syncopation. It has also been shown that listening to rhythms that strongly induce a beat engages motor areas in the brain (J. L. Chen, Penhune, & Zatorre, 2008; Grahn & Brett, 2007), as does internal generation of a beat (Grahn & Rowe, 2009). Motor imagery could affect auditory perception indirectly via multimodal integration, or it could be accompanied by auditory imagery that merges with the auditory input. Alternatively, however, motor imagery could merely accompany auditory perception without affecting it.

If metrical cognition interacted with auditory perception, it should be possible to demonstrate this in psychophysical tasks requiring judgments based on the perceived relative loudness or duration of tones. A previous study by the author (Repp, 1995) attempted to do just that. Metrical structure was manipulated by presenting two very similar isochronous melodies that, according to their musical notation and pitch structure, differed in the locations of their main beats. In two perceptual experiments, participants were required to detect increases in the duration or intensity of single notes that either did or did not coincide with the main beat. The results showed no clear effects of metrical structure. The detection of intensity changes depended strongly on the pitch structure of the melodies, but not on metrical structure. A negative correlation was found between the detection of duration changes and the typical expressive timing patterns in pianists' performances of the two melodies, which suggested a role of temporal expectations (negative bias), but did not seem to reflect metrical structure as such.

One reason for the negative findings with regard to effects of metrical structure in that study may have been the relatively long intervals between note onsets (600 msec), which were optimal for a main beat but suboptimal for a differentiated metrical structure. To achieve a better differentiation of metrical accents, a faster event rate may be necessary, so that notes coinciding with the main beat can be contrasted with subdivision notes falling between these beats. Arguably, differences in metrical strength are greatest between the main beat and its subdivisions, especially when the main beat is near the most preferred beat frequency and thus evokes the strongest internal resonance (Large & Kolen, 1994; Van Noorden & Moelants, 1999).

The Present Study

The present study used isochronous melodic sequences (used previously in Repp, 2007) whose notes formed triple subdivisions of a main beat that had a period of 600 msec, so that every third note was metrically accented (i.e., the 1st, 4th, 7th, and 10th notes). The sequences are shown in Figure 1. The meter (6/8) was prescribed by musical notation and thus, in large part, was subjectively imposed. Three melodies were formed from a single pitch sequence by shifting the phase of the main beat, thereby dissociating metrical structure from pitch structure. The participants' task was to detect intensity or duration increments or decrements that could occur in any serial position, thus either coinciding with the main beat or not. Because of the way the materials were constructed, any effects of metrical structure were independent of any effects that pitch or melodic contour might have on task performance. Relative intensity (loudness) was the parameter of primary interest in connection with possible top-down effects of meter on auditory perception. However, it was considered possible that secondary effects of meter on duration perception would also occur, because intensity and duration have been shown to provide integral cues to phenomenal accent (Tekman, 2002).

Independent of metrical structure, aspects of pitch structure—particularly, pitch accents due to pivot points in the melodic contour—were also expected to affect perception of intensity changes (Repp, 1995; Tekman, 1995, 1997, 1998; Thomassen, 1982). Furthermore, perception of duration changes was expected to be difficult near the end of a melody (Repp, 1992, 1995, 1998), and effects of serial order (position in the melody) were considered to be possible. These effects were of secondary interest in the present study, but they are discussed.

METHOD

Participants

All participants had extensive musical training, and comprised 9 graduate students from the Yale School of Music (6 women and 3 men, ages 22–28), who were paid for their services, and the author (age 64), a lifelong amateur pianist. Because of time constraints, 1 participant could complete only the duration-change conditions.

Materials and Equipment

The basic materials were three 12-note melodies (referred to as *Cmel*, *Dmel*, and *Emel*) in 6/8 meter. These are shown in Figure 1. The melodies represent the same (iterated) pitch sequence with three different starting points: C, D, and E. Dmel was created from Cmel by moving the C to the end; similarly, Emel was created from Dmel by moving the D to the end. The identical pitches are approximately aligned vertically in Figure 1.

Each trial consisted of one of the three melodies played twice in succession without pause, plus a final long note (the same pitch that began the pattern), all played legato (i.e., without silences between notes) with a 200-msec baseline interonset interval (IOI). The purpose of the final 600-msec note was to define the duration of the last IOI and to provide closure. The first presentation of the melody was always strictly isochronous and isodynamic; that is, all notes were played with the same MIDI (musical instrument digital interface) velocity (50). The purpose of the first presentation was to provide a metrical context for the second presentation, in which the duration or intensity (MIDI velocity) of a single note was changed. Note and IOI duration were always changed simultaneously, so as to maintain legato articulation. The changed note could occur in any of the 12 serial positions.

Stimulus generation and data collection were controlled by a program written in MAX 4.3.6, running on an Apple iMac with an Intel processor. The notes (piano timbre) were produced by a Roland RD-250s digital piano according to MIDI instructions sent by the MAX program and were presented at a comfortable intensity over Sennheiser HD540 Reference II headphones.

Design and Procedure

The experiment comprised four separate sessions on different days, each lasting close to 1 h and usually separated from the next session by at least 1 week. The four sessions involved, respectively, the detection of increments and decrements of intensity (*Int+ task* and *Int− task*, respectively) and of duration (*Dur+ task* and *Dur− task*, respectively). The order of these four conditions was approximately counterbalanced across participants. Each session consisted of eight blocks of trials, with 36 trials in each block. In each block, the melody changed from trial to trial in the fixed repeating order Cmel–Dmel–Emel. In each of the 12 presentations of each melody in a block, the changed note (the *detection target*) was in a different serial position. The order of target positions was freshly randomized by the MAX program for each melody in each block.

Before starting, participants were shown the notation of the three melodies. The similarity of their pitch structure was pointed out, and the importance of always "hearing" the melodies as notated (i.e., of subjectively imposing the prescribed phase of the meter) was emphasized. Participants sat in front of the computer and started the first trial of a block by clicking a virtual button with the mouse. This made the notation of the appropriate melody (without the repeat signs and the final long note) appear on top of the screen, and 1 sec later, playback of the melody started. Below the musical notation were displayed 12 small boxes, aligned with the notes, and the question "Which note was louder (softer, longer, shorter)?" To discour-

Figure 1. The three test melodies: Cmel, Dmel, and Emel.

age random guessing, another box, labeled "no clue," was displayed to the right. The participants clicked either the box below what they believed to be the changed note or the "no clue" box. In the former case, the participants then rated their confidence by clicking one of three boxes, labeled "very sure," "not so sure," and "just a hunch." Participants then clicked another button to start the next trial. At the end of a block, the number of correct responses (out of 36) was shown on the screen as well as information about any change of settings for the next trial that affected the difficulty of the task. Because earlier studies (Repp, 1992, 1998) had shown that participants often assign perceived duration changes to the subsequent serial position, such responses were counted as correct. However, participants were alerted to this tendency and were told to click the box below the lengthened or shortened note, not the box indicating the delayed or advanced note.

To avoid ceiling and floor effects, a simple adaptive procedure was used to set the difficulty levels (amounts of change of note duration or intensity) of successive blocks. The settings for the initial blocks were chosen on the basis of pilot runs by the author. They were 20 msec for duration increments, 16 msec for duration decrements, 5 MIDI velocity units for intensity increments, and 8 MIDI velocity units for intensity decrements.[3] For each subsequent block, the setting either was kept the same or was changed, depending on the number of correct responses (out of 36) in the preceding block. If that number was between 18 and 23, the setting was maintained. If the score was between 12 and 17 or between 24 and 29, a change of ± 2 msec or ± 1 MIDI velocity unit was made to the setting; if the score was between 6 and 11 or between 30 and 35, the change made was twice as large; and if the score was between 0 and 5 or was 36, the change made was three times as large. The change was always such that the task became easier when the score was low and more difficult when the score was high.

RESULTS

Analysis

The results were analyzed in terms of the percentages of correct and incorrect responses given to each serial position in each melody. In duration-change tasks, but not in intensity-change tasks, a response to the note immediately following the changed note was considered to be correct. Mean confidence ratings (coded as 3, 2, 1, 0, with 0 representing "no clue" responses) correlated almost perfectly with mean percent correct scores across the 12 melody positions in all four tasks ($r > .994$), so that no additional information was to be gained from analyzing confidence ratings. Signal detection theory indices of sensitivity and bias (d' and c) could not be calculated for several reasons: (1) Incorrect responses (false alarms) were contingent on missing a target in the same trial, which violates assumptions of signal detection theory; (2) incorrect responses were too infrequent in many melody positions; and (3) it was unclear how to calculate their proportions so as to be comparable to hit proportions. Percentages of incorrect responses to each position of a melody were computed by tallying the number of times the position was chosen when it did not contain a target and expressing that number as a percentage of the combined numbers of all incorrect and "no clue" responses to the melody.[4]

Separate $3 \times 4 \times 3$ repeated measures ANOVAs were conducted on the percentages of correct and incorrect responses in each task. The independent variables were melody (Cmel, Dmel, and Emel), note group (four groups of three eighth notes each, as is indicated by the beaming in the notation; see Figure 1), and metrical position within each group (1, 2, and 3, with 1 bearing the metrical accent). A significant main effect of metrical position (with 1 being different from 2 and 3) would indicate an effect of metrical accentuation, whereas a main effect of note group, and any interactions, would indicate effects of melodic pitch structure or serial position. No main effects of melody were expected. The Greenhouse–Geisser correction was applied to all p values. It is important to understand that, because the pitch structure shifted relative to the metrical structure across the three melodies (see Figure 1), a main effect of pitch structure (not a variable in the ANOVA) would show up as an interaction between metrical position and melody and/or note group. Such interactions thus do not imply an interaction between metrical structure and pitch structure, which—if it existed—could not be assessed in the present design.[5]

Hypotheses and Predictions

The predictions of three hypotheses regarding effects of metrical structure are illustrated schematically in Figure 2. The increased sensitivity hypothesis predicts better detection of any physical change in metrically accented positions (Position 1 in the metrical group) than in metrically unaccented positions (Positions 2 and 3). At the same time, it predicts no response bias in favor of Position 1. Response bias would be reflected in an increase of incorrect responses. If such a bias were observed, a parallel increase in correct responses could not be interpreted unambiguously as reflecting increased sensitivity, because it could be due to bias as well. The positive-bias hypothesis, according to which illusory phenomenal accents arise from metrical accentuation, predicts increases in both correct and incorrect responses in Metrical Position 1 when intensity or duration increments are to be detected but predicts decreases when decrements are to be detected, because the decrements would tend to cancel the illusory phenomenal accents and, therefore, would be hard to detect. The negative-bias hypothesis, according to which listeners compensate in perception for expected, but absent, phenomenal accents, makes the opposite predictions. The two bias hypotheses (see also Tekman, 2001, who calls them "pattern completion" and "compensation," respectively) are mutually exclusive, but either bias could coexist with a change in sensitivity. No predictions were made regarding any differences between Metrical Positions 2 and 3.

Int+ Task

Across the eight trial blocks, the adaptive procedure decreased the intensity increments from an initial setting of 5 MIDI velocity units to a final mean setting of 3.4 units ($SD = 1.1$). The overall mean percent correct score was 63.0%. The remaining responses consisted of 18.9% incorrect and 18.1% "no clue" responses.

The detailed pattern of correct responses is shown in Figure 3A. The ANOVA revealed the main effect of note group and all four interactions to be highly significant ($p < .001$). However, the main effect of metrical position also reached significance [$F(2,16) = 7.12, p = .020$].

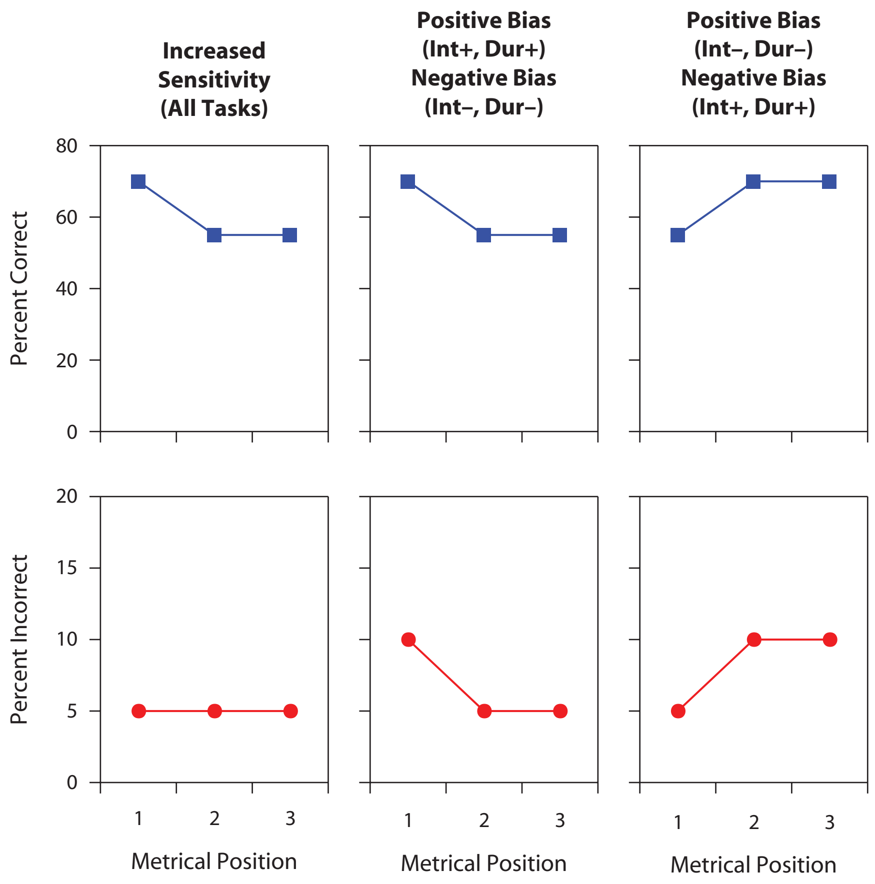

Figure 2. Schematic illustration of results predicted by three hypotheses concerning effects of metrical structure.

Figure 3B illustrates this effect, showing that detection was slightly better in Metrical Position 1 than in Positions 2 and 3. The interactions indicate large effects of pitch structure, which had been expected. Indeed, the response functions for the three melodies were found to be almost identical when aligned according to pitch contour (like the notation in Figure 1). The peak scores in Serial Positions 4–6 and 10–12 represent the pitches F and B, respectively, which were the highest and lowest pitches in the range and thus corresponded to contour pivot points. The immediately following pitches (E and C, respectively) correspond to the low scores in Serial Positions 5–7 and 11 and 12, respectively.

The pattern of incorrect responses (Figure 3C) shows similar peaks that shift between the melodies. The pitches F (Serial Positions 4–6) and B (Serial Positions 10–12) attracted the large majority of responses. The correlation of correct and incorrect response percentages was .55, significant ($p < .001$) but relatively low because of a floor effect for incorrect responses. The ANOVA on incorrect responses showed a significant main effect of note group [$F(3,24) = 12.20, p = .003$] as well as significant interactions between melody and metrical position [$F(4,32) = 13.26, p < .001$], between note group and metrical position [$F(6,48) = 3.89, p = .024$], and between all three variables [$F(12,96) = 5.89, p = .009$]. The main effect of metrical position (Figure 3D) was not significant. All significant effects reflect the magnitude and shifts of the pitch-related peaks in the response functions.

Int− Task

Across the eight trial blocks, intensity decrements decreased from an initial mean setting of 7.8 MIDI velocity units to a final mean setting of 6.3 units ($SD = 1.5$). Intensity decrements were clearly more difficult to detect than were intensity increments, which had a final setting of 3.4 units. The overall mean percent correct score was 68.5%. The remaining responses consisted of 16.3% incorrect and 15.2% "no clue" responses.

Percent correct responses are shown in Figure 4A. Interestingly, their pattern is quite unrelated to that of the responses in the Int+ task (Figure 3A); the correlation between the two data sets is −.09 (n.s.). The ANOVA revealed highly reliable main effects of note group [$F(3,24) = 20.09, p < .001$] and metrical position [$F(2,16) = 23.24, p < .001$]. Also significant were the interaction between note group and metrical position [$F(6,48) = 4.41, p = .011$] and the three-way interaction [$F(12,96) = 3.01, p = .028$]. The note-group main effect was due to a decline in scores from the beginning to the end of the melodies, with

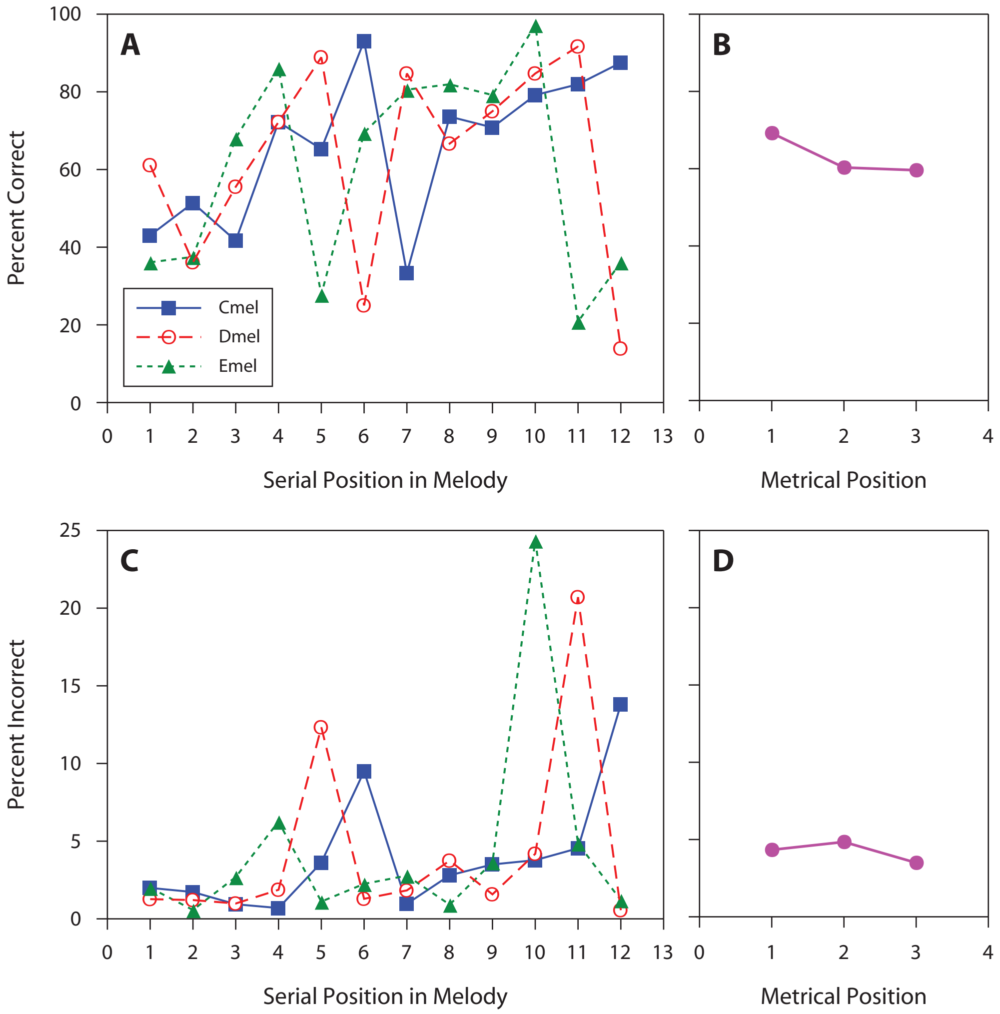

Figure 3. Int+ task: Mean percentages of correct and incorrect responses as a function of serial position and metrical position. For further explanation, see text.

a precipitous decline at the end. The main effect of metrical position is shown in Figure 4B: Scores declined linearly from Position 1 to Position 3. Because the melody-final decline in scores made a major contribution to both main effects, the ANOVA was repeated without the data for the last group of notes (Positions 10–12). The main effect of metrical position remained significant [$F(2,16) = 6.79$, $p = .010$], as did the main effect of note group [$F(2,16) = 7.29$, $p = .006$], whereas the interactions were no longer significant and thus had been due to the last group of notes.

The pattern of incorrect responses is shown in Figure 4C. It, too, bore no relation to the pattern of incorrect responses in the Int+ task ($r = -.12$, n.s.). Its correlation with the pattern of correct responses in the present task was .46 ($p < .01$), mainly due to a common downward trend across serial positions. However, the main effect of note group did not reach significance in the ANOVA. Indeed, there was only one significant effect: the main effect of metrical position [$F(2,16) = 5.04$, $p = .028$], shown in Figure 4D. It reflects an unexpected tendency to incorrectly perceive the notes in the second metrical position as being softer than adjacent notes.

Dur+ Task

Across the eight trial blocks, the duration increment decreased from the starting value of 20 msec to a final mean setting of 7.8 msec ($SD = 2.6$ msec). The overall mean percent correct score was 68.5% (47.9% on target and 20.6% in the subsequent position). The remaining responses consisted of 18.3% incorrect and 13.3% "no clue" responses.

Figure 5A shows the percent correct scores. The ANOVA revealed significant main effects of note group [$F(3,27) = 14.63$, $p < .001$] and metrical position [$F(2,18) = 62.64$, $p < .001$], as well as significant interactions between melody and note group [$F(6,54) = 4.13$, $p = .009$], note group and metrical position [$F(6,54) = 20.14$, $p < .001$], and all three variables [$F(12,108) = 2.57$, $p = .038$]. Figure 5B shows the main effect of metrical position, which shows that scores in Position 3 were lower than those in Positions 1 and 2.

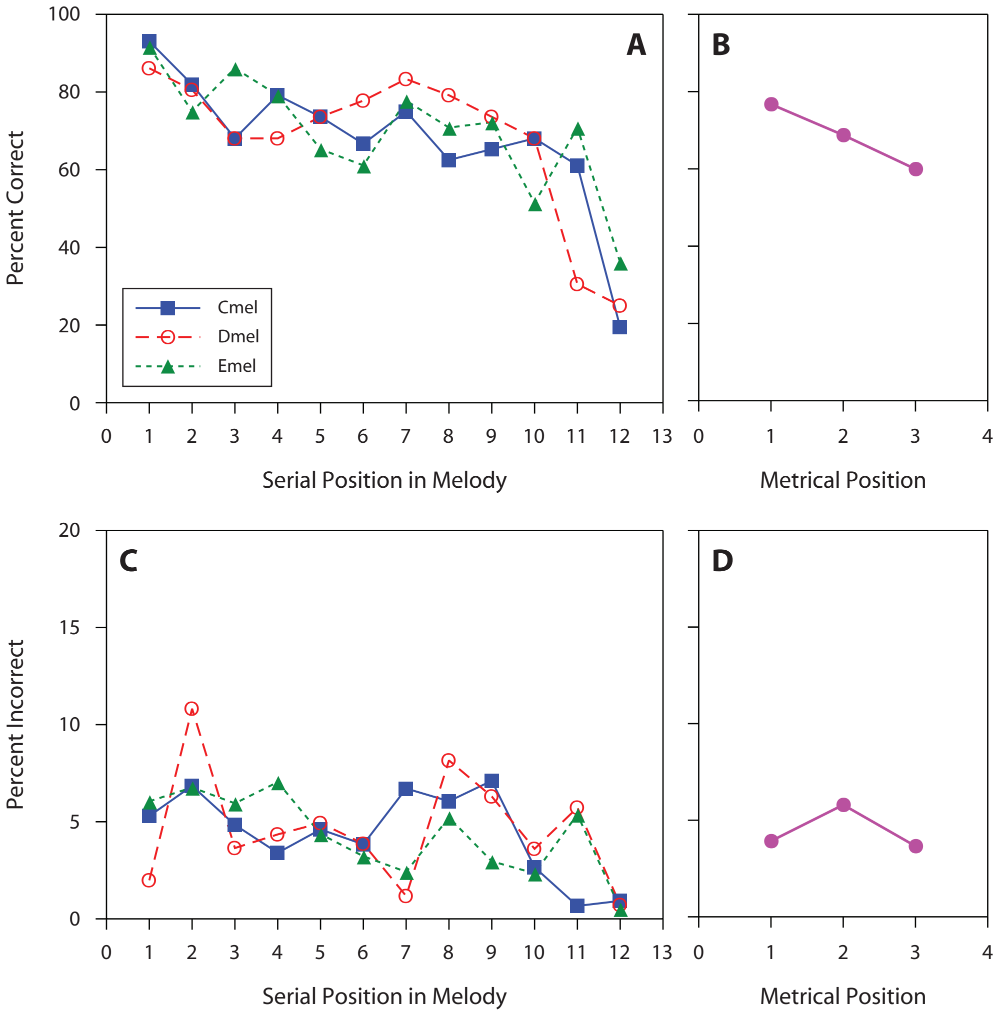

Figure 4. Int− task: Mean percentages of correct and incorrect responses as a function of serial position and metrical position. For further explanation, see text.

It is evident from Figure 5A that a major contributor to the significant effects was a precipitous decline in detection accuracy at the end of each melody, which had been expected on the basis of previous results (Repp, 1992, 1995, 1998). Therefore, the ANOVA was repeated without the final group of notes. That analysis still yielded significant main effects of note group [$F(2,18) = 17.41$, $p < .001$] and metrical position [$F(2,18) = 9.22$, $p = .006$], as well as a three-way interaction [$F(8,72) = 2.92$, $p = .034$]. The note-group effect was due to higher scores for the third group of notes than for the first two. The effect of metrical position remained similar to that shown in Figure 5B, only it was less pronounced. The three-way interaction is difficult to describe.

Figure 5C shows the distribution of incorrect responses across melody positions. It is fairly different from the pattern of correct responses; the correlation of the two sets of data is only .45, which is nonetheless significant ($p < .01$). The ANOVA yielded a significant main effect of metrical position [$F(2,18) = 7.07$, $p = .018$], as well as interactions between melody and note group [$F(6,54) = 3.71$, $p = .030$] and between note group and metrical position [$F(6,54) = 4.40$, $p = .007$]. The metrical position effect, shown in Figure 5D, indicates a tendency to perceive the second note in a group as being lengthened. This tendency was evident mainly in the last two note groups (i.e., in Serial Positions 8 and 11), but with substantial differences among the three melodies.

Dur− Task

Across the eight blocks, the duration decrement decreased from the mean starting value of 15.8 msec to a final mean setting of 9.2 msec ($SD = 4.5$). The large *SD* reflects large individual differences in perceptual sensitivity to duration decrements. The overall mean percent correct score was 62.4% (46.6% on target and 15.8% in the subsequent position). The remaining responses consisted of 24.7% incorrect and 12.9% “no clue” responses.

Figure 6A shows the pattern of correct responses. It was unrelated to the pattern of correct responses in the Dur+ task ($r = -.05$, n.s.). The ANOVA revealed reliable main effects of note group [$F(3,27) = 8.22$,

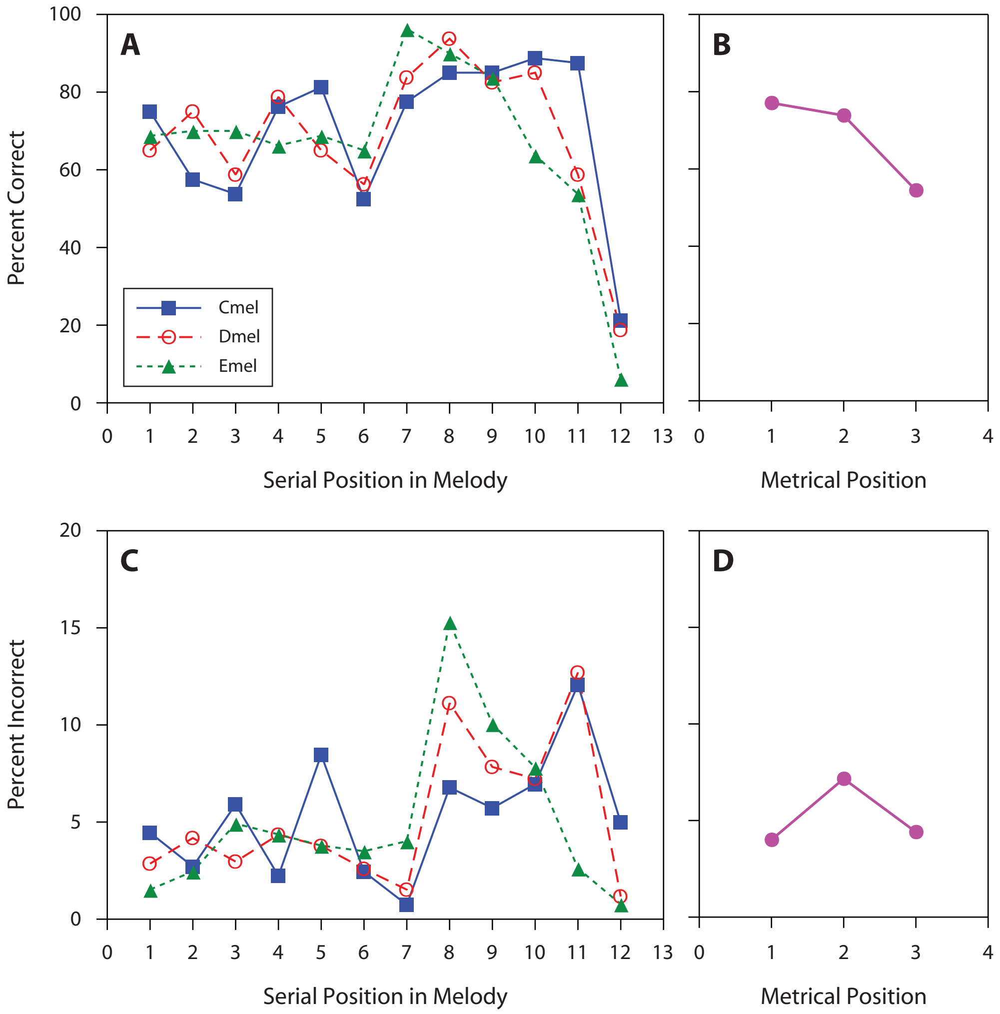

Figure 5. Dur+ task: Mean percentages of correct and incorrect responses as a function of serial position and metrical position. For further explanation, see text.

p = .007] and metrical position [$F(2,18) = 8.16$, p = .004], as well as a significant three-way interaction [$F(12,108) = 3.07$, p = .020]. The interactions between melody and note group [$F(6,54) = 2.48$, p = .068] and between melody and metrical position [$F(4,36) = 3.18$, p = .063] merely approached significance. The main effect of note group reflects better performance early in each melody than later. The metrical position effect is shown in Figure 6B. Detection of duration decrements was poorer in Position 2 than it was in Positions 1 and 3. This effect was shown most clearly by Dmel, but was present in the other two melodies as well. Unlike Dur+ scores, Dur− scores did not decline near the end of a melody; in fact, they increased in Cmel. This increase contributed to the three-way interaction, which otherwise is difficult to describe.

The distribution of incorrect responses is shown in Figure 6C. It is not significantly (inversely) related to the pattern of incorrect responses in the Dur+ task ($r = -.24$, n.s.) but bears a great resemblance to the pattern of correct responses in the present task; the correlation between the two response types is .75 ($p < .001$). The ANOVA showed the following effects to be significant: the main effects of note group [$F(3,27) = 6.04$, p = .008] and metrical position [$F(2,18) = 5.56$, p = .017] and the interaction between melody and metrical position [$F(4,36) = 5.97$, p = .003]. The note-group effect, similar to that for correct responses, reflects a decrease in incorrect responses across serial positions. The mean metrical effect, shown in Figure 6D, is remarkably similar to that for the correct responses, showing a tendency for Position 2 to be chosen incorrectly less often than Positions 1 and 3. The interaction, however, indicates additional effects of pitch structure. The patterns for Dmel and Emel (Figure 6C) show periodic peaks that are shifted by one position relative to each other, which indicates that the same pitches in the two melodies (E, D, and C; see Figure 1) tended to attract incorrect responses. However, Cmel shows quite a different pattern. In Figure 6A, too, a similar shift between Dmel and Emel can be discerned, with Cmel showing a different pattern.

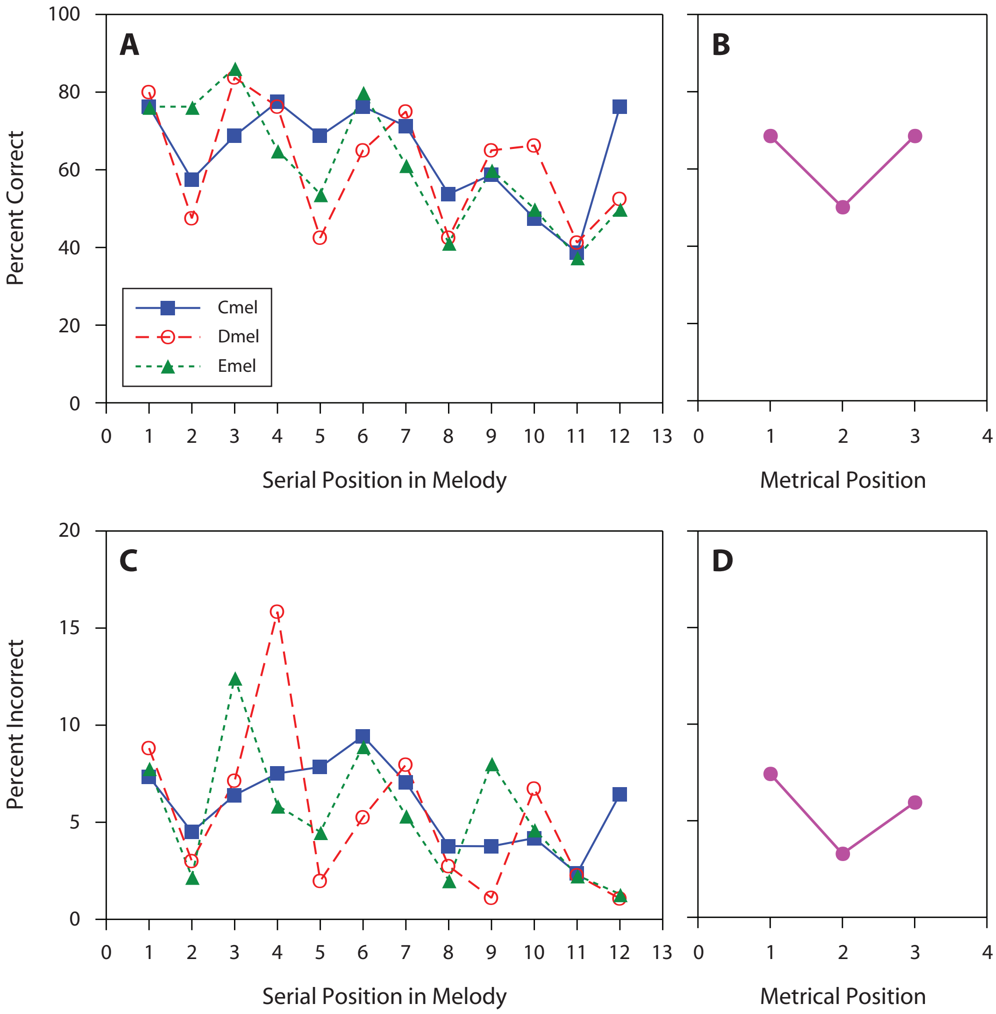

Figure 6. Dur− task: Mean percentages of correct and incorrect responses as a function of serial position and metrical position. For further explanation, see text.

DISCUSSION

Metrical Structure and Auditory Perception

The present study was an investigation into whether metrical structure, an essentially subjective organization of rhythmic input, interacts with perception of intensity and duration differences in music. There was no reason to doubt that participants indeed perceived the melodies with the intended metrical structure. The metrical induction procedure relied on (1) musical notation that was in view throughout, (2) a well-known tendency to perceive the first tone as a downbeat (Brochard et al., 2003; Repp et al., 2008; Toiviainen & Snyder, 2003), (3) repetition of each melody (i.e., parallelism; Temperley & Bartlette, 2002), and (4) careful instruction of musically trained participants. Although the melodic pitch structure common to the three melodies might favor a particular metrical structure over others (in particular, Cmel or Emel over Dmel; see Repp, 2007), these melodic cues to meter were almost certainly too weak to override the induction cues provided. None of the participants, all of whom had been told that it was important always to "hear" each of the three melodies as notated, reported any problems in doing so, nor did the author experience any as a participant. (Subjectively, the three melodies are quite different, even though they are carved from the same pitch sequence and "mishearings" are easy to detect.) Each melody thus was heard as consisting of four three-note groups, with the first note of each group representing the main beat, as is indicated in the notation.

Significant effects of metrical position were found in all four detection tasks. This finding provides strong support for the general hypothesis that meter is not just an abstract mental construct but interacts with low-level auditory perception. The pattern of results was not simple, however. Three hypotheses were set forth: Metrical accents might increase sensitivity and/or might introduce either a positive or a negative bias.

Increased Sensitivity Hypothesis

The hypothesis that metrical accent enhances sensitivity to physical change was derived from dynamic attention theory, which claims that metrically strong positions receive more attention than do metrically weak ones (Large & Palmer, 2002). The hypothesis predicts a higher percentage of correct responses in Metrical Position 1 than in Positions 2 and 3 in all detection tasks. However, because correct responses can reflect bias as well as sensitivity, the pattern of incorrect responses needs to be considered in interpreting the pattern of correct responses. In particular, if the patterns are similar, correct responses may represent variation in bias rather than in sensitivity.

Intensity increments were detected best in Position 1, and there was no significant bias favoring Position 1. This supports the increased sensitivity hypothesis, although this metrical effect occurred in the context of very large pitch-based effects (discussed later). Intensity decrements, too, were detected best in Position 1, and there was no bias favoring that position. This also supports the increased sensitivity hypothesis. Intensity decrements also tended to be detected better in Position 2 than in Position 3, which may have been due to a bias, in that there was a corresponding difference in incorrect response percentages. However, such a bias is not inconsistent with increased sensitivity in Position 1.

Duration increments were detected more often in Positions 1 and 2 than in Position 3. The pattern of incorrect responses suggested a bias favoring Position 2, but not Position 1. Thus, the increased sensitivity hypothesis is again supported. Finally, duration decrements were detected more often in Positions 1 and 3 than in Position 2, but there was a corresponding pattern of incorrect responses, suggesting a bias favoring Positions 1 and 3 over Position 2. Therefore, the data from the Dur− condition do not clearly support the increased sensitivity hypothesis, but they also do not contradict it, because increased sensitivity may coexist with bias.

On the whole, then, the results of the present study are quite consistent with the idea that metrically accented positions receive more attention (Large & Palmer, 2002), which, in turn, leads to more accurate detection of loudness or duration deviants in those positions. The deviants presumably were detected relative to a memory standard built up during exposure to the preceding melody tones and/or relative to the immediately surrounding tones.

Positive- and Negative-Bias Hypotheses

The positive-bias hypothesis was inspired—with appropriate caveats—by the findings of Phillips-Silver and Trainor (2005, 2007, 2008), Abecasis et al. (2009), and Iversen et al. (2009). It predicts that metrically accented tones might be perceived as being louder, and perhaps also as being longer, than are metrically unaccented tones. It is the hypothesis referred to in the title of the present article. The hypothesis predicts that incorrect response percentages should be highest in Metrical Position 1 in the increment-detection tasks, whereas they should be lowest in Position 1 in the decrement-detection tasks. If such a pattern exists, correct responses may show a similar pattern, although independent variation of sensitivity could obscure it in the decrement-detection tasks. The negative-bias hypothesis was derived primarily from earlier research on timing, results of which suggested that listeners perceive the timing of musical events relative to internally generated expectations (Repp, 1992, 1998; Tekman, 2001). Its predictions are exactly contrary to those of the positive-bias hypothesis.

There was no significant effect of metrical position on incorrect responses in the Int+ task, hence offering no evidence of bias. In the Int− task, incorrect responses unexpectedly were most frequent in Position 2. Correct responses, too, were higher in Position 2 than in Position 3, which is consistent with a bias favoring Position 2. It is possible that, in a triple meter, notes in Position 2 (which follow the main beat) are less salient than those in Position 3 (which precedes the main beat, and, thus, notes in this position can function as upbeats) and, therefore, tend to be perceived as being softer. This would be a form of positive bias, albeit in terms of deaccentuation. (The alternative, a negative bias arising from an expectation to hear louder notes in Position 2, makes less sense.) Of course, it could also be interpreted as a positive bias in terms of subjective accentuation of notes in Positions 1 and 3. However, there was no corresponding opposite bias in the Int+ task, and it is unclear why notes in Position 3 should be perceived as being accented.

Results of the Dur+ task also suggested a bias favoring Position 2, whereas, in the Dur− task, the pattern was reversed, suggesting a bias against Position 2. This symmetric bias pattern indicates that notes in Position 2 tended to be perceived as being longer than are notes in Positions 1 and 3. Here, a negative bias interpretation (notes in Position 2 being perceived as relatively long because they are expected to be relatively short, thus being metrically less salient) makes more sense than does a positive bias interpretation (notes in Position 2 being perceived as relatively long because they are most salient). The expectation may have a basis in music performance, where there may be a tendency to shorten the second interval in triple meter (Repp, 1990).

On the whole, it can be concluded that the present data provide little support for the positive-bias hypothesis and only tentative support for negative bias in the perception of duration (for which there is previous evidence; Repp, 1992, 1998). In particular, there is no evidence that metrically accented notes are perceived as being louder or longer than are unaccented notes. Thus, it seems that metrical accents do not create illusory phenomenal accents, which answers the question posed in the title. The intriguing MEG results of Abecasis et al. (2009) and Iversen et al. (2009) may represent some internal process concomitant with metrical accents (most likely motor imagery), a process that does not interact directly with auditory perception. The results of Phillips-Silver and Trainor (2005, 2007, 2008), too, need not (and probably should not) be interpreted as implying that rhythms accompanied by head movement or vestibular stimulation are perceived as containing illusory phenomenal accents. However, the possibility that vestibular stimulation does interact directly with auditory perception (Trainor et al., 2009) remains an interesting hypothesis. It could be tested in a paradigm such as the present one, by reinforcing metrical accents with overt head movements or electrical stimulation of the vestibulum.

Pitch-Related Effects

Although the present study was concerned primarily with effects of metrical structure, the most striking effect found, specifically in the Int+ task, derived from the pitch structure of the melodies. The effect was by no means unexpected, because it is well known that changes in melodic pitch contour or pitch jumps are associated with the perception of accents (e.g., Hannon et al., 2004; Huron & Royal, 1996; Tekman, 2001; Thomassen, 1982). The extreme pitches in the range of the present melodies, B and F, which necessarily constituted pivot points in the melodic contour, were associated with pronounced increases in correct and, especially, incorrect responses in the Int+ task, whereas the pitches immediately following showed response decreases. These results indicate a strong positive bias, suggesting that notes with extreme pitches, even those within a rather narrow pitch range, are perceived as louder than other notes.[6]

However, it is not clear how a change in pitch actually might affect perception of loudness. In that connection, it is worth noting that the results of the Int− task gave no indication whatsoever that the pivot notes were perceived as louder than other notes. If they had been so perceived, an intensity decrement of these notes should have been difficult to detect and they should rarely have been chosen as incorrect responses. Neither tendency was observed. Thus, the effect of pitch accent was strongly asymmetrical, being restricted to judgments about increases in loudness. This suggests that pitch accents do not really affect perceived loudness, but affect only relative salience in a more abstract sense. Although the increased salience they confer is confusable with intensity increases, it cannot compensate for an intensity decrease.

Pitch-related effects were also observed in the Dur− task. Curiously, however, they seemed to be restricted to two of the melodies, Dmel and Emel, with Cmel showing quite a different pattern of responses. In Dmel, the notes in Serial Positions 1 (D), 4 (E), 7 (D), and 10 (C), and in Emel, the tones in Positions 3 (E), 6 (D), and 9 (C), attracted both correct and incorrect responses and thus seemed to be perceived as being shorter than other notes. These notes were at the center of three-note ascending or descending pitch-contour segments; thus, the local pitch contour seemed to be the cause of the response tendencies. Again, however, an interpretation in terms of a perceptual bias is called into question by the fact that the results for the Dur+ task showed no corresponding pattern at all. The apparent deaccentuation associated with the medial position in a three-note ascending or descending segment did not seem to affect perceived note duration, but seemed merely to introduce a response bias contingent on duration-decrement judgments. Why this bias was not observed in Cmel is anyone's guess, but it does suggest that metrical structure interacted in some way with pitch-based effects. Some such interactions were also present in the Dur+ task. These interactions between pitch accents and metrical structure require further study.

Serial Position Effects

In addition to effects of metrical structure and pitch structure, there were also main effects of the note-group variable, which divided the melodies into four three-note segments. These segments were not independent of the pitch structure, which shifted by only one or two positions between melodies. (To make note groups independent of pitch structure, 12 different melodies would have had to have been used.) As can be seen in Figure 1, the highest pitch (F) was always in Group 2, whereas the lowest pitch (B) was always in Group 4. Thus, the note-group variable can be viewed as a rough coding of the pitch contour. Nevertheless, some of the observed effects of note group probably reflect serial position rather than pitch contour.

Significant main effects of note group were present in all four tasks. The most striking differences occurred at the ends of melodies, particularly in the Dur+ and Int− tasks. Percent correct scores in those tasks were much reduced in the final position (the penultimate note of the trial, which was followed by a long final note), and, in some melodies, scores were also lowered in the preceding position. Incorrect responses were also infrequent in those positions, which suggests a perceptual bias: The final and near-final notes tended to be perceived as being relatively short and loud. This is likely to be a negative bias based on expectations derived from experience with music performance or from more general principles of rhythmic action that music performance is subject to, since it is common for a musical passage to end with a ritardando and a decrescendo. Indeed, the difficulty of detecting lengthening of a penultimate tone is familiar from earlier research, in which performance of the musical test passages was also measured (Repp, 1992, 1995, 1998). Also in agreement with previous findings (Repp, 1998), however, there was no such final decline of scores in the Dur− task. In that task, Cmel showed an increase in both correct and incorrect responses at the end of the melody, which is consistent with a negative perceptual bias, but the other two melodies did not. The fact that only Cmel ended on the tonic (the final long note) may have played a role here. Similarly, the final decline of responses in the Int− condition was matched by a corresponding increase in the Int+ condition only in the case of Cmel. That increase, however, has been attributed to a pitch-based bias (see above). Thus, these results suggest an asymmetric bias that hurt detection of changes in the expected direction more than it helped detection of changes in the unexpected direction.

Some pitch-related effects clearly contributed to detection score differences between groups of notes. However, there were some quite consistent global trends: In the Int+ and Dur+ tasks, both correct and incorrect scores tended to increase with serial position, whereas in the Int− and Dur− tasks, they tended to decrease, notwithstanding some large local deviations from these trends.[7] In other words, increments seemed to become easier to detect as more notes were heard, whereas decrements became harder to detect. However, because each test melody was preceded by itself, the number of tones heard hardly could have been the decisive factor. A position-based response bias also seems unlikely in view of the different directions of the trends for increments and decrements. If the trends are negative perceptual biases, they are probably not performance based, because it is not common to play a melody with a steady accelerando and crescendo until shortly before the end. So, these global trends remain somewhat mysterious, although they seem quite consistent.

CONCLUSIONS

The present study was motivated by the hypothesis that metrical accents might confer illusory phenomenal accents on notes with which they coincide. No support for this hypothesis (positive bias) was found. This does not exclude the possibility that such effects might yet be found in other situations—for example, when head movements accompany metrical accents. The data do offer support for another hypothesis—namely, that metrical accents are associated with an increase in temporally focused attention that enhances perceptual sensitivity to intensive and temporal properties of the target events. Some support was also found for a third hypothesis (negative bias)—namely, that perceptual compensation occurs for temporal expectations derived from music performance or from more general principles of perception or action. Furthermore, the study revealed some expected and some unexpected effects of pitch structure and of serial position on the detection of local intensity and duration changes in melodies. Even though the musical materials were simple, the results were quite complex and surely do not exhaust the phenomena that can be observed in connection with the perception of musical accents. Replication with different and more varied materials will be necessary to ensure the generality of the results.

AUTHOR NOTE

This research was supported by National Science Foundation Grant BCS-0642506. I am grateful to John Iversen and Edward Large for helpful comments on an earlier draft of the manuscript. Address correspondence to B. H. Repp, Haskins Laboratories, 300 George Street, New Haven, CT 06511-6624 (e-mail: repp@haskins.yale.edu).

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NOTES

1. *Phenomenal* means "known through the senses rather than through thought or intuition" (www.merriam-webster.com/dictionary/phenomenal).

2. For related findings, see also Snyder and Large (2005), who presented alternating loud and soft tones, thus confounding metrical structure with auditory expectations based on the physical signal.

3. According to earlier acoustic measurements of the digital piano notes (Repp, 1997, Figure 1), a change of 3 MIDI velocity units is approximately equivalent to a change of 1 dB in peak sound level. For the author, who ran himself first, the initial settings for duration decrements and intensity decrements were 14 msec and 6 MIDI velocity units, respectively; they were changed later to make the tasks easier initially.

4. It was assumed that incorrect responses in the duration-change tasks were always on target and were never assigned to the subsequent position.

5. An alternative way of analyzing the data would have been to align them the way the melodies are aligned in Figure 1 and to conduct ANOVAs on the 10 pitches that they have in common (or even on all 12 pitches, after moving the initial pitches of Cmel and Dmel to the end). These analyses would have just two independent variables, melody and pitch contour. A main effect of pitch contour would indicate pitch-related effects, whereas an interaction would indicate effects of metrical structure. Such analyses are not reported here, however, because they are redundant with the ANOVAs presented and show effects of metrical structure less directly.

6. One possible concern with regard to this particular finding was that the tones B and F, each of which occurred only once in the test melody, may actually have been louder than the other tones, due to imperfect calibration of the proprietary synthesis algorithm of the digital piano. Although no perceptual loudness matching of the tones in isolation was performed, measurements of peak sound pressure levels revealed that B was actually about 3 dB *softer* than D, E, and F, which were of similar amplitude, with C in between. Thus, acoustic amplitude differences cannot account for the observed biases and even run counter to them in the case of B. In fact, these differences are probably due to the phase relationships of the harmonics of the complex tones and do not predict differences in perceived loudness; if they did, B would have attracted huge numbers of incorrect responses in the Int− task, which it did not (see Figure 4C, Positions 10–12).

7. The linear component of the note-group main effect was significant in all tasks and for both types of response except for correct Dur+ responses, for which the final decline in scores offset the preceding increase. With the final note group omitted, that increase was significant as well.

(Manuscript received September 25, 2009;
revision accepted for publication March 11, 2010.)