Title:

Switching perception of musical meters by listening to different acoustic cues of
biphasic sound stimulus

Short title:

Switching perception of musical meters in biphasic sound stimulus

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Abstract:

Meter is one of the core features of music perception. It is the cognitive grouping of regular sound sequences, typically for every 2, 3, or 4 beats. Previous studies have suggested that one can not only passively perceive the meter from acoustic cues such as loudness, pitch, and duration of sound elements, but also actively perceive it by paying attention to isochronous sound events without any acoustic cues. Studying the interaction of top-down and bottom-up processing in meter perception leads to understanding the cognitive system's ability to perceive the entire structure of music. The present study aimed to demonstrate that meter perception requires the top-down process (which maintains and switches attention between cues) as well as the bottom-up process for discriminating acoustic cues. We created a "biphasic" sound stimulus, which consists of successive tone sequences designed to provide cues for both the triple and quadruple meters in different sound attributes, frequency, and duration, and measured how participants perceived meters from the stimulus in a five-point scale (ranged from "strongly triple" to "strongly quadruple"). Participants were asked to focus on differences in frequency and duration. We found that well-trained participants perceived different meters by switching their attention to specific cues, while untrained participants did not. This result provides evidence for the idea that meter perception involves the interaction between top-down and bottom-up processes, which training can facilitate.

Keywords: beat, musical meter, attention, acoustic cues

Introduction

Meter is one of the core features of music. Meter perception is a hierarchical grouping of beats, which regularly assigns subjective intensity to beats [1–3]. The most common meters include the duple, triple and quadruple meters. The duple meter (heard in marching music, for example) has two beats such as “s-w-s-w...” (s: strong / w: weak), while the triple meter (e.g., waltzes) has three beats “s-w-w-s-w-w...”. The quadruple meter consists of four beats with medium-strong (ms) beats “s-w-ms-w-s-w-ms-w...”. One can recognize these emphatic (strong) beats, and thus sense the meter even if the sounds do not exhibit clear differences among them in actual acoustics.

Previous studies have suggested that meter perception consists of not only bottom-up processes on acoustical cues but also of top-down attentional processes. We perceive beat strength (also called “accent”) from acoustic features of the sound event (such as pitch, duration, and loudness) and recognize the strongest beat as the first of its meter cycle [4–6]; i.e., higher, longer, or louder sound events tend to be perceived as the accented beats. Furthermore, we can perceive meter by paying attention to isochronous beats without any physical accent [7–10]. Attending to rhythms without any body movements can modulate the motor area of the brain [11,12], which suggests that the top-down process involves rhythm production.

Musical expertise appears to play an important role in the active processes of meter perception. Even non-musicians can perceive meter, but musicians can perceive it more accurately and stably [7,13–15]. Such active top-down process in meter perception has been conceptualized as the dynamic attending theory of meter perception [16–18], which places great importance on the ability to predict the timing of future events based on past sound events. This ability is especially important for extracting beat regularity, which requires an interaction between top-down and bottom-up processes. Hence, this theory posits that the perceptual strength of the beats reflects the allocation of attention.

Typical examples of the interaction between top-down and bottom-up processing can be seen in figure-ground reversals within the auditory stream segregation of sound sequences. Listeners can perceive sound series as multiple streams when their duration and frequencies are in a certain range. The number of streams can be switched according to the interplay of attention and acoustic features [19–21]. These studies on the interaction between top-down and bottom-up processes motivated us to ask whether meter perception might also switch depending on the attribute of sound events that we focus on. Studying this interaction leads to understanding the cognitive system’s capacity for perceiving the structure of music.

We assessed the effect that switching one's attentive focus between different acoustic features has on the perception of different meters, as well as its extent. To this end, we used a novel sound stimulus that consisted of successive sound sequences. We named it the 'biphasic stimulus.' By design, its purpose is to produce the perception of either a triple or a quadruple meter depending upon which acoustical cues the listeners fixed their attention, whether it was frequency or duration. We asked participants which of two meters they identified more strongly in the stimulus, in order to test whether they could perceive different meters by switching the sound attributes they focused on. Additionally, we also explored the effect of training in the perception of metric by comparing untrained participants with a group trained to enhance their top-down processing through synchronized finger tapping.

Methods

Participants

A total of 12 participants underwent the experiment. Six of them were previously trained to tap along to the sound as described in the sections below (2 females; mean age = 24.0 years, SD = 1.3 years). The other six were untrained (2 females; mean age = 24.2 years, SD = 5.6 years). No participants reported a history of hearing difficulty. All experimental procedures were approved by the Ethics Review Committee on Experimental Research with Human Subjects of the Graduate School of Arts and Sciences, The University of Tokyo, Japan (#580), and informed consent was obtained from all participants.

Stimulus

We designed two types of stimuli with sound sequences consisting of various types of band-limited noise bursts, and were designed to contain acoustical cues for two different meters, (triple and quadruple) at the same time (Fig 1). One type of stimuli had a triple-meter cycle in center frequencies of the noise bursts (high-low-low) and a quadruple cycle in their temporal durations (long-short-short-short) (Fig 1A). Another type of stimuli had the opposite property, in which triple and quadruple meters were assigned to durations and frequencies, respectively (Fig 1B). Simply put, a triple-frequency quadruple-duration stimuli and a triple-duration quadruple-frequency stimuli were designed. We fixed the inter-onset interval of noise bursts at 300 ms.

We established five conditions on the differences in center frequency between high

and low noises that deviated from the baseline frequency of 1500 Hz: 102, 128, 160, 200, and 250 Hz. Thus, the center frequency of high noise was 1580 Hz when the frequency difference condition was 160 Hz ($= 1500 + 160 / 2$), while that of low noise was 1420 Hz ($= 1500 - 160 / 2$). We named these five frequency conditions by combining “F” with the digits for frequency difference (e.g., “F102” for the condition with 102 Hz of frequency difference).

We also set five conditions on differences in the duration of long and short bursts of noise from a baseline of 100 ms. We established the five duration conditions along the following tiers: 51, 64, 80, 100, and 125 ms. Therefore, when the difference was 80 ms, the duration of a long burst was 140 ($100 + 80 / 2$) ms, and that of short burst was 60 ($100 - 80 / 2$) ms. Similar to frequency conditions, the duration condition was labeled as a combination of “D” and duration differences in milliseconds (consequently, “D51” refers to a 51-ms difference condition). The bandwidth of each noise burst was 120% of the center frequency, and the rise/decay time was 10 ms. In total, we prepared 25 different stimuli (5 frequency $\times$ 5 duration conditions) for each of the two types of the meter assignment (frequency-triple vs. duration-triple type). Each stimulus consisted of 12 noise bursts, resulting in a total duration of 3.6 s.

Procedure

The task of participants was to evaluate how well they identified the quadruple meter in a stimulus by pressing buttons corresponding to a five-point scale; 1: “strong triple”, 2: “triple rather than quadruple”, 3: “neither triple nor quadruple”, 4: “quadruple rather than triple”, and 5: “strong quadruple”. In one trial, we instructed a participant to focus on either frequency or duration by showing the phrase “height difference” or “duration difference” on a PC monitor for 0.8 s, and then we presented one stimulus twice successively. After collecting the response from the participant, we presented the next trial immediately. One whole trial was around 10 s in duration. We presented 100 trials (25 conditions $\times$ 2 types $\times$ 2 instructions) in random order as one block, and we conducted six blocks per participant. There was a break between blocks lasting at least five minutes.

The experiment was programmed and run with the use of Presentation 18.1 (Neurobehavioral Systems, Inc., USA). Visual stimuli were presented on a 21-inch LCD monitor (EIZO FlexScan L797; Eizo, Japan). The distance between the participant and the monitor was 80 cm. Auditory stimuli were generated using MATLAB R2017a (MathWorks) and presented binaurally at approximately 70 dB SPL via external soundcard (UA-22, Roland, Japan) and earphones (Earphone Insert, Compumedics

Neuroscan Inc., USA). We instructed the participants to perform the task without any synchronized body movements such as finger tapping or head nodding. Immediately before starting the experiment, untrained participants listened to stimuli of the F250 condition with no duration difference as well as of the D125 condition without any frequency differences in order to learn to identify differences of frequency and duration in stimuli.

Training

Before the experiment began, participants of the trained group practiced focusing their attention on one acoustic cue (frequency or duration) by listening to the stimulus and accompanying it with hand tapping. At first, we presented them with a simple stimulus, which only differed in one feature. Then, we presented stimuli that included an additional difference. Participants understood the difference in frequency through practice, by listening and tapping along to the F250-D0 condition first. Then, we presented them with stimuli of the F250-D51, F200-D64, and F160-D80 conditions, in that order. They tapped along to the sound while paying attention to the difference in frequency; this helped them understand the meter. When they reported that they could fully pay attention to the frequency difference of one stimulus, we presented the next stimulus. In the training of attention to the duration difference, we presented the participants with stimuli of F0-D125, F102-D125, F125-D100, and F160-D80 conditions, in that order. The training took between 30 minutes to an hour, depending on the participant. After training, the experiment began.

Analysis

To assess whether the participants perceived different meters by switching their attention between acoustic features, we categorized data as “triple-targeted” or “quadruple-targeted” trials in which participants paid attention to the acoustic feature with the regularity of triple or quadruple meter, respectively. We first averaged subjective rating scores of either the triple- or quadruple-targeted trials for each of the 25 conditions. Then, we calculated the difference between them. The difference margin was larger when the participant successfully perceived different meters by switching their attention between acoustic features.

For testing the statistical significance, we averaged the differences among 25 conditions for each participant and performed a one-sample *t*-test to check if the mean

difference was larger than zero. We also performed a two-way repeated measure analysis of variance (ANOVA) to assess the significance of factors for frequency conditions (five levels), duration conditions (five levels), and the interaction between them in each group.

To examine the effect of training, we compared the mean rating difference between the trained and untrained groups by a two-sample Welch's t test. The significance level was set at 0.05.

Results

Previous studies have suggested that meter perception involves the interaction between top-down and bottom-up processes. According to this idea, we expected that the perceived meter could switch depending on the regularity of the stimulus attribute that the listener focused on. Thus, the present study aimed to examine whether a listener could perceive meter by switching their attention across different acoustic features and, if so, to what extent.

We designed the biphasic sound stimulus to contain two different meters (triple and quadruple) for different acoustic features. The participants evaluated the subjective strength of the quadruple meter. We found relatively lower scores in triple-targeted trials (mean $\pm$ SD; 1.40 ± 0.14 in trained, 2.17 ± 0.13 in untrained) and higher in quadruple-targeted trials (4.43 ± 0.16 in trained, 3.54 ± 0.15 in untrained) (Figs 2A-D). The one-sample t -test statistic of rating differences indicated that the average rating difference was significantly larger than zero ($t = 5.49$, $df = 11$, $p < .001$). This suggests that the perceived meter changed due to a switch in the attentional focus.

In the trained group, the rating difference was between 3.44 for the F200-D100 condition and 2.51 for F250-D51 (Fig 2E). We conducted a two-way repeated measures ANOVA (5 frequency $\times$ 5 duration conditions) and obtained a significant main effect for the duration, $F(4, 20) = 5.23$, $p = .005$, partial $\eta^2 = .511$, and the interaction between two factors, $F(16, 80) = 2.31$, $p = .008$, partial $\eta^2 = .316$, but the effect for the frequency was not significant, $F(4, 20) = 1.50$, $p = .241$, partial $\eta^2 = .230$.

Training enhances top-down processing, as has been pointed out by previous studies, in which formal musical training facilitated meter perception [7,13,15]. In order to examine this, we calculated the subjective rating differences of the untrained group. The rating differences ranged from 1.63 for F160-D100 to 1.10 for F160-D64 (Fig 2F). A two-way ANOVA was performed, which showed that the effect of the duration factor was significant, $F(4, 20) = 3.49$, $p = .026$, partial $\eta^2 = .411$, but this was not the case for the frequency conditions, $F(4, 20) = 1.13$, $p = .371$, partial $\eta^2 = .184$ or the interaction

between them, $F(16, 80) = 0.65$, $p = .835$, partial $\eta^2 = .115$.

To assess the effects of training in detail, we compared the rating differences between trained and untrained participants (Figs 2E and F), and found that the inter-participant standard errors of trained participants were smaller than those of untrained participants. The data suggest that among untrained listeners there are individual differences in their ability to perceive meter (by switching their attention between acoustic cues). They also suggest that training may reduce or eliminate said differences.

We conducted a two-sample Welch's t test between the trained and untrained groups using the average rating differences (Fig 3). The average rating of the trained group was significantly higher than that of the untrained group ($t = 2.52$, $df = 5.81$, $p = .047$). The analysis revealed that training facilitated the participants' perception of different meters by switching their attention between different acoustic features.

Discussion

The present study investigated whether it was possible to perceive different meters by switching one's attention to different acoustic features in sound stimuli designed to contain triple or quadruple periodicity in frequency and temporal duration. We found that participants perceived meters differently depending on the sound attributes that they paid attention to (Figs 2A-D). Moreover, trained participants perceived the targeted meter more strongly and showed smaller individual differences than untrained participants did (Figs 2E, 2F and 3). These results suggest that meter is perceived not only through the bottom-up process (by differentiating acoustic cues) but also through interactions with the top-down process (by paying attention to them) and that training enhances the interaction between them.

Our results provided the optimal condition to perceive meters from the biphasic stimulus equally in both frequency and duration attributes. As the frequency condition increased beyond F160 and the duration condition beyond D80, the rating difference of trained participants also became larger (Fig 2E, right panel). However, the difference was smaller when either the frequency or the duration conditions were extremely large, such as in F250-D51 and F102-D125 (Fig 2E, right panel). This suggests that the listener's attention is likely to focus on cues that are more salient. Moreover, attention tends to remain fixed on salient cues and it hardly switches to those that are not. Thus, as long as two cues are equally balanced, the listener would be able to perceive both meters by switching their attention to one of them.

The trained participants had a stronger recognition of the target meters compared to

the untrained group, depending on whichever acoustic feature we instructed them to focus on (Figs 2A-D). This resulted in the higher differences in rating between quadruple- and triple-targeted trials (Figs 2E, F, and 3). These findings suggest that the training with sound-synchronized tapping enhanced top-down processes for meter perception, such as paying attention to appropriate cues. Since the motor cortex can be activated by paying attention to rhythm without actual movements [11,12], our training possibly enhanced the link between the meter-related attention and the regular motor action via finger tapping, which requires paying attention to the beat.

We trained select participants to listen for targeted meter cues, and the untrained group had more inter-participant standard errors than the trained group (Figs 2, 3). This suggests that participants originally had individual variability in top-down processing of meter perception before receiving dedicated training. Because musical expertise improves the accuracy of meter perception [7,13,15], we believe that the musical experiences of each untrained participant also contributed to the individual differences in top-down processing during the present study. The effect of musical experience on meter perception of the biphasic stimulus needs to be assessed in a future study.

We employed triple and quadruple meters for the biphasic stimuli, instead of duple meter, which is one of the most typical meters. This is because we intended to avoid the risk of participants perceiving a sextuple meter (grouping as a set of six beats) from the stimulus containing triple and duple meters. In fact, we confirmed that several volunteers reported to have heard a sextuple meter in such stimuli during our pilot study. The biphasic stimulus for triple and duple meters exhibited the most accented sound (high and long) in a six-sound cycle as the common multiple of two meters, and tends to sound as a sextuple meter at a relatively faster tempo. Even for isochronous sound sequences (with no physical accent) participants hear the grouping of six sounds when the sound-interval is 300 ms or less [22]. In contrast, the combination of triple and quadruple meters (used in this study) potentially provides the cue for a twelve-beat meter, but it is rarer in music than sextuple meter and has more elements that make up a group. Hence, it is difficult to perceive twelve-beat meter in our stimulus at the current tempo, IOI of 300 ms.

In the present study, we aimed to test whether we could perceive different meters by switching the listener's attention to different acoustic features. We did not examine whether a change in tempo altered meter perception. According to a previous review [23], the range of IOI for meter perception is between 100 ms to 6 s. As discussed above, there could be a relationship between tempo and meter perception; the listener might perceive longer meters (more beats in one cycle) with faster tempo, or shorter meters with slower tempo. Future studies are required to address how the variety of meters from the biphasic

stimuli with different tempo is perceived.

The present study demonstrated that participants controlled their attention to certain acoustic features in order to perceive meter. This provides an insight into how we perceive meter through the interaction between top-down-bottom-up processing. Furthermore, we corroborated that training has a direct impact on the perception of metric.

We developed a sound stimulus that has multiple acoustic features like actual music but is easier to control. Previous studies used short melodies and rhythmic sequences, which had similar patterns to real music pieces, in order for participants to perceive the meter [15,24]. These stimuli were not be suitable for our purpose since they contained too many cues in different acoustical features, such as pitch, duration, and timbre. Our stimulus design (with a limited variety of acoustical cues) allowed us not only to assess the interaction directly but also to finely adjust the differences in frequency and duration in order to examine the changes in meter perception.

We contributed to assessing the key feature of musical expertise because our results suggest that the training leads to the strengthening of top-down processes for meter perception. Musicians produce and perceive the meter that guides their performance, and their top-down processing of meter perception should be stronger than that of non-musicians. Though further studies will be needed to sophisticate the training procedure for promoting meter perception, we believe that enhancements of the interaction between top-down and bottom-up processes must be the key for musical expertise, particularly in meter perception and production.

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Figures

Fig 1. Schematic drawings of the biphasic meter stimuli. The stimuli consisted of various types of band-limited noise bursts. Inter-onset intervals were fixed at 300 ms. **A.** One type of stimuli had triple-meter regularity in the center frequencies of the noise bursts (high-low-low) and a quadruple cycle in their temporal durations (long-short-short-short). **B.** Another type of stimuli had the opposite property; triple and quadruple meters were assigned to durations (long-short-short) and frequencies (high-low-low-low) respectively. **C.** Schematic spectrogram of the former type of stimulus (shown in panel A) when the frequency difference is 160 Hz and the duration difference is 80 ms (F160-D80 condition). The bandwidth was 120% of the center frequency.

Fig 2. Subjective rating and rating difference for 25 conditions (Frequency × Duration condition) and each group (trained and untrained). A,B. Subjective rating of each condition when trained participants focused on the acoustic feature which had a (A) triple-meter or (B) quadruple-meter regularity. C,D. Subjective rating of each condition when untrained participants focused on the acoustic feature which had a (C) triple-meter or (D) quadruple-meter regularity. E,F. Rating difference between quadruple-targeted and triple-targeted trials in (E) trained participants and (F) untrained participants. Error bar indicates the standard error across participants ($n = 6$).

Fig 3. Mean rating difference between the trained and untrained groups for the 25 conditions. Error bar indicates interparticipant standard error ($n = 6$). A two-sample Welch's t test showed that the mean rating difference in the trained group was significantly larger than that in the untrained group.