SYNCHRONIZATION AND CONTINUATION TAPPING TO COMPLEX METERS

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THE GOAL OF THIS STUDY was to assess the ability of North American adults to synchronize and continue their tapping to complex meter patterns in the presence and absence of musical cues to meter. We asked participants to tap to drum patterns structured according to two different 7/8 meters common in Balkan music. Each meter contained three nonisochronous drumbeats per measure, forming intervals in a *short-short-long* (SSL) or a *long-short-short* (LSS) pattern. In the synchronization phase of each trial, participants were asked to tap in synchrony with a drum pattern that was accompanied by either a matching or a mismatching Balkan folk melody. In the continuation phase of the trial, the drum pattern was turned off and participants continued tapping the drum pattern accompanied by the same melody or by silence. Participants produced ratios of long to short inter-tap intervals during synchronization that were between the target ratio of 3:2 and a simple-meter ratio of 2:1. During continuation, participants maintained a similar ratio as long as the melody was present but when the melody was absent the ratios were stretched even more toward 2:1. Tapping variability and tapping position relative to the target locations during synchronization and ratio production during both synchronization and continuation showed that the temporal grouping of tones in the drum pattern was more influential on tapping performance than the particular meter (i.e., SSL vs. LSS). These findings demonstrate that people raised in North America find it difficult to produce complex metrical patterns, especially in the absence of exogenous cues and even when provided with musical stimuli to aid them in tapping accurately.

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RHYTHM PERCEPTION AND PRODUCTION are primary aspects of musical behavior (Krumhansl, 2000). These basic skills underlie our ability to produce movement in coordination with music and with other people, such as tapping, clapping, dancing, singing, and playing an instrument in time with other performers. Musical *meter* is an abstract cognitive structure that is thought to guide rhythmic behaviors. Music theorists describe meter as containing a hierarchy of two or more isochronous (evenly spaced) beat levels, which are abstracted from and not necessarily identical to rhythms in the musical surface structure (Lerdahl & Jackendoff, 1983; London, 2002, 2004; Palmer & Krumhansl, 1990). For example, a waltz in triple meter (three primary beats per measure) might have highly variable rhythmic patterns from one passage to the next. Nevertheless, throughout these passages listeners typically perceive a metrical structure with a slow beat level corresponding to the measure length, and a faster beat level that divides the measure into three isochronous units. Alternatively, a march in duple meter (two beats per measure) would invoke beat levels and subdivisions in units of two.

Several constraints are thought to apply to production of well-formed metrical structures in Western music. The primary constraint is that all beat levels should be isochronous (Large & Kolen, 1994; Lerdahl & Jackendoff, 1983). A second constraint is that the beat level at which listeners focus their attention, also called the *pulse level*,

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should fall within the temporal range that is optimal for temporal perception and production (200–1200 ms, Engström, Kelso, & Holroyd, 1996; Friberg & Sundberg, 1995; London, 2004; Mates, Müller, Radil, & Pöppel, 1994; Parncutt, 1994; Van Noorden & Moelants, 1999). A third constraint is that adjacent beat levels in the metrical hierarchy should be related by simple integer ratios, such as 3:1 in a triple meter or 2:1 in a duple meter. A final constraint is that the multiple beat levels should be in phase with each other, resulting in the different levels coinciding at the beginning of the measure (and sometimes at other points within the measure). This point of coincidence corresponds to an especially salient point called the *downbeat,* which is associated with high expectancy for musical events to occur (Jones, 1976; Jones & Boltz, 1989; Jones, Moynihan, MacKenzie, & Puente, 2002; Large & Jones, 1999). These constraints are consistent with the types of rhythmic structures and meters, such as duple and triple, which appear most commonly in Western classical and popular music.

Some musical cultures from the Balkan Peninsula, Africa, Asia, and Latin America make extensive use of rhythmic structures and meters that violate these rules (London, 1995). For example, *complex* meters from the Balkan Peninsula typically contain three beat levels: a slow isochronous level corresponding to the measure, a fast isochronous level that subdivides the measure (e.g., into 5, 7, 11, or 13 beats), and an intermediate beat level that groups the faster beats in an uneven fashion, thus creating a nonisochronous pattern that repeats once per measure. The nonisochronous pulse typically adheres to the tempo constraint (i.e., 200–1200 ms) and serves as the framework for drumming and dancing that accompanies the music. An example of a complex meter is 7/8 meter, in which the fastest beat level subdivides the measure into units of seven, which are grouped at the intermediate level into short (S) intervals of two units and long (L) intervals of three units, resulting in a pulse of nonisochronous beats having a 3:2 ratio. Two different types of 7/8 meter are typically invoked, depending on whether the long interval is the first interval or the last interval in a given measure (i.e., SSL, LSS; Figure 1A and 1B).

The use of complex meter in the folk music of non-Western cultures suggests that constraints described by Western music theorists (e.g., Lerdahl & Jackendoff, 1983) do not necessarily generalize to all musical cultures. This possibility is supported by the finding that young infants have little difficulty perceiving timing disruptions of musical patterns in both simple and complex meters, while North-American 1-year-olds and adults only perform accurately in the context of simple meters (Hannon & Trehub, 2005a, 2005b). These data suggest that North American adults' difficulty with nonisochronous meters arises from learned representations of Western meters and not from the intrinsic difficulty of complex meters.

An alternative method to perceptual tasks for studying musical rhythm and meter is to ask participants to produce finger movements in synchrony with the perceived pulse (e.g., Drake, Jones, & Baruch, 2000; Drake, Penel, & Bigand, 2000; Large, Fink, & Kelso, 2002; Repp, 1999a, 1999b; Snyder & Krumhansl, 2001; Toiviainen & Snyder, 2003; van Noorden & Moelants, 1999; Vos, Van Dijk, & Schomaker, 1994). The basic logic behind tapping tasks is that the accuracy (e.g., mean distance of taps from the beat) and precision (e.g., variability of tap position relative to the beat) of finger movements should reflect difficulty in the processing of rhythmic and metrical structures.

A number of previous studies using motor production tasks have demonstrated that people from Western cultures have a strong tendency to produce long and short intervals in rhythmic patterns with a 2:1 ratio (Collier & Wright, 1995; Fraisse, 1956; Povel, 1981; Repp, Windsor, & Desain, 2002; Semjen & Ivry, 2001). A recent study of tapping to rhythms in complex meters demonstrated that North American participants with high amounts of tapping experience and music training had difficulty accurately producing complex ratios (Repp, London, & Keller, 2005). In particular, these participants produced ratios of long-to-short inter-tap intervals that were between 1.5 (the target ratio) and 2.0 (a ratio characteristic of simple meter). Distortion toward the simple meter ratio occurred during *synchronization,* when participants tapped in time with the target events, but the distortion was slightly larger during *continuation,* when participants continued tapping the patterns without auditory pacing tones. An additional finding was that changing the metrical organization of the long and short beats (e.g., SSL vs. LSS) had little effect on the produced ratios or the tap locations relative to the target locations. This demonstrates that the temporal grouping of tones, rather than the specific metrical organization of beats (i.e., location of the downbeat), played a dominant role in how participants perceived the complex metrical patterns.

One limitation to the study by Repp et al. (2005), however, is that it deliberately focused on rapid tempi that may have prevented the nonisochronous metrical level from being perceived as the main beat. Another limitation is the use of highly simplified stimuli that outlined the complex meter pattern but provided no

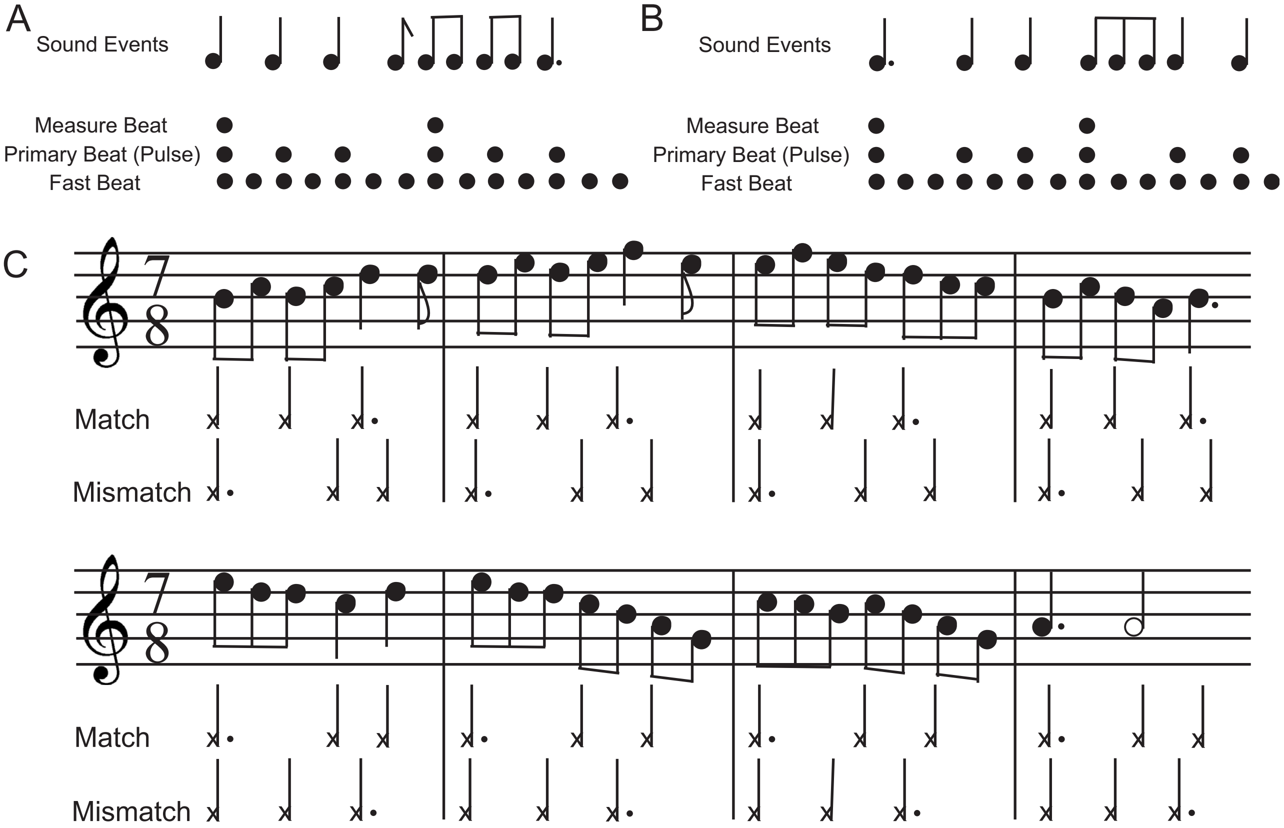

FIG. 1. Examples of complex meter patterns in short-short-long (A) and long-short-short (B) versions of 7/8 meter with theoretical beat structures at the isochronous measure level, nonisochronous pulse level, and isochronous fast level. Examples of two melodies used in the study, one in short-short-long meter (above) and one in long-short-short meter (below), with matching and mismatching drum patterns shown below the notation (C). On each trial, either the matching or mismatching drum pattern was presented along with the melody.

other musical cues to meter. In contrast to these stimuli, composed and performed music contains a large number of informational sources that can cue meter (Brown, 1993; Huron & Royal, 1996; Järvinen, 1995; Palmer & Krumhansl, 1990). Laboratory experiments have further shown that, during meter perception tasks, people are sensitive to a variety of metrical cues, including sound intensity, sound duration, inter-onset timing, and melodic patterning (e.g., Drake, Penel, & Bigand., 2000; Hannon, Snyder, Eerola, & Krumhansl, 2004; Snyder & Krumhansl, 2001; Thomassen, 1982; Toiviainen & Snyder, 2003; Vos et al., 1994), and these cues are utilized in a flexible and integrative manner (Hannon et al., 2004). The use of more musically realistic stimuli might thus enable participants to more closely reproduce complex meter ratios. For example, tapping to complex-meter patterns might be enhanced when some cues support the intended meter, but disrupted when multiple cues conflict with the intended meter.

In the current study, we asked participants to produce the nonisochronous pulse of complex-meter folk melodies in two trial phases. In the synchronization phase, participants were required to tap in time with a nonisochronous drum pattern that accompanied a melody. In the continuation phase, participants were asked to keep tapping the drum pattern after it was turned off (cf. Semjen, Schulze, & Vorberg, 2000; Wing & Kristofferson, 1973a, 1973b), with or without the melody present. The synchronization phase assessed participants' ability to produce complex metrical patterns in a stimulus-driven manner, while the continuation phase indicated the extent to which participants could represent and produce from memory a complex metrical pattern in the absence of an explicit target drum pattern.

We used two different examples of 7/8 meter that are common in Balkan music (SSL and LSS). To determine whether participants were able to abstract information directly from the melody, sometimes the melody supported the drum pattern (the "matching" condition) and sometimes it conflicted with the drum pattern (the "mismatching" condition), as shown in Figure 1C. If participants were able to pick up on information about the meter in the melodic pattern, they should exhibit disrupted tapping performance in the mismatching condition. To further test this possibility, sometimes participants performed the continuation in silence and sometimes with the melody present, with the prediction that the presence of a melody that matched the synchronization drum pattern should facilitate tapping performance. Because we used 7/8 meters that were also used by Repp et al. (2005), we were able to attempt a replication of their finding that tapping is more influenced by temporal grouping than by meter. We further asked whether the more musical stimuli in the current study would lead to stronger effects of meter than previously observed.

Method

Participants

Twenty-four undergraduate students (13 women and 11 men; age range = 18–25 years) at Cornell University participated in this study for extra course credit after giving written, informed consent. Thirteen participants had at least 5 years of music experience with a mean of 5.8 years across all participants. None of the participants were familiar with music from Balkan countries, although one with 16 years of music experience recognized the musical stimuli as being in complex meter.

Materials and Procedure

Auditory stimuli were created as musical instrument digital interface (MIDI) files in Digital Performer (*MOTU*, Cambridge, MA) and converted to digital audio files (aiff) using QuickTime MIDI instruments. The drum patterns had a woodblock timbre with a constant MIDI velocity (proportional to intensity and onset abruptness) of 127 and the melodies had a flute timbre with a constant MIDI velocity of 90. Stimuli were presented to participants using a custom PsyScope (MacWhinney, Cohen, & Provost, 1997) program running on a Macintosh G4 computer over Koss UR 20 closed-ear headphones. Participants made tapping responses on the center button of a PsyScope-compatible button box (*New Micros*, Dallas, TX) with 1 ms timing resolution, using the index finger of their dominant hand. No sensory feedback was provided other than the sound of the button mechanism (measured as <50 dB SPL at ear level) and the somatosensory feedback associated with pressing the button. Tapping responses throughout each trial were recorded in the PsyScope program with time 0 corresponding to the first drumbeat of the lead-in.

On each trial, a drum pattern in 7/8 meter (seven eighth-note durations per measure) was presented to participants with the fast beat level having a period of 250 ms. This is a moderate tempo and it is possible for participants to count the short and long beats of complex meter (i.e., one-two-one-two-one-two-three in SSL or one-two-three-one-two-one-two in LSS). It should be noted, however, that counting in this manner requires knowledge that the ratio of long to short intervals was 3:2. Counting was therefore unlikely in the group of participants, most of whom were unfamiliar with complex meters. Two different versions of 7/8 meter were used, one with a repeating pattern of intervals that outlined a SSL structure and another that outlined a LSS structure. The short intervals had durations of 500 ms and the long intervals had durations of 750 ms, intervals that are easy to perceive and produce when they are presented isochronously (Engström et al., 1996; Friberg & Sundberg, 1995; Mates et al., 1994). Each measure was 1,750 ms long and the stimuli had no expressive timing variations. Each trial consisted of three distinct phases: lead-in, synchronization, and continuation. The *lead-in* phase consisted of two measures of the target drum pattern with no other accompanying sounds and served to induce the metrical structure prior to any tapping. Immediately following the lead-in with no interruption of the beat, the *synchronization* phase consisted of the same drum pattern repeated for four measures, simultaneously with one of 24 folk melodies from Balkan countries (Geisler, 1989).

Half of the melodies had SSL structure and half had LSS structure. On each trial, the drum pattern either had the *matching* version of 7/8 meter or the *mismatching* version of 7/8 meter. For example, the matching condition consisted of both the drum pattern and the melody having SSL structure or both having LSS structure. In the mismatching condition, the drum could have a SSL structure with the melody having a LSS structure, or vice versa. During synchronization, participants were instructed to begin tapping in synchrony with the drum pattern (SSL or LSS) as soon as they felt ready. Finally, during the *continuation* phase, the drum pattern was turned off for four more measures and participants were instructed to continue tapping the same pattern. The same melody that was presented during synchronization either continued playing for the rest of the trial (*present* condition) or was turned off for the rest of the trial (*absent* condition). At the end of the trial, a high-pitched tone indicated that participants could cease tapping.

Twenty-four trials were presented in each of four separate blocks to each participant. Two of the blocks contained trials with the melody present during continuation and two of the blocks contained trials with the melody absent during continuation. The melody present blocks and the melody absent blocks alternated (i.e., present, absent, present, absent or the reverse) with half of the participants having one order of blocks and the other half having the other order of blocks. Within each block, matching trials alternated with mismatching trials, with half of the participants starting with a matching trial and the other half of participants starting with a mismatching trial. Each of the 24 melodies was presented once in each block in one of the four conditions (i.e., match/present, match/absent, mismatch/present, mismatch/absent) with the melodies presented in a pseudo-random order.

Results

We analyzed taps only during the synchronization and continuation phases. Any taps occurring during the lead-in phase were not analyzed. We first normalized taps by the length of the measure such that values of 0 and 1 corresponded to the beginning of the measure. Values between 0 and 1 corresponded to taps occurring at different points within the measure. For example in SSL, the three drumbeats occurred at 0, 0.2857, and 0.5714 (i.e., 0/1750, 500/1750, and 1000/1750); in LSS, the three drumbeats occurred at 0, 0.4286, and 0.7143 (i.e., 0/1750, 750/1750, and 1250/1750). These values corresponded to the time of targets to which participants attempted to tap during the synchronization phase. Taps in the continuation phase were similarly normalized to values between 0 and 1 based on the duration between taps corresponding to the first beats of adjacent measures (rather than 1,750 ms), and the first tap was assumed to be perfectly synchronized with the target beat (i.e., fixed at time 0). Each tap was matched to the closest target value in the appropriate meter, and any taps that were more than 200 ms from the target (0.1143 in normalized units) were excluded from further analysis. For synchronization, ~5% of possible tap positions were excluded. For continuation, ~20% of possible tap positions were excluded. Most excluded tap positions were too far from the target, although there was also a smaller number of missing taps (e.g., failure to tap at the beginning of synchronization) or extra taps (e.g., the button box registering multiple taps).

For each participant, taps were analyzed separately for synchronization and continuation. The taps were further divided into eight conditions, corresponding to the two meters (SSL and LSS), whether the melody matched or mismatched the meter, and whether continuation was performed with the melody present or absent. Finally, for synchronization (but not for continuation) the tap times were sorted according to the interval that preceded them: the first short interval (S1), the second short interval (S2), or the long interval (L). Note that these intervals occurred at different positions in SSL and LSS. Music experience was also considered as a between-subjects variable, by dividing the participants into two groups, those with less than 5 years of music training and those with 5 or more years of music training. Only main effects of music experience will be reported.

Figure 2 shows the mean tap positions during synchronization and continuation phases. We derived three measures of tapping performance from the tap times, including ratio of long to short intervals, variability of tap position, and mean tap position relative to the target beat (cf. Snyder & Krumhansl, 2001; Toiviainen & Snyder, 2003). *Ratios* of long to short intervals were calculated as the mean long interval (L) divided by the short intervals (S1 and S2), resulting in two ratios, *L:S1* and *L:S2*. *Variability* was calculated as the standard deviation of the normalized tap position. For synchronization, variability was analyzed separately for the three intervals (S1, S2, L); for continuation, variability was calculated across the two non-downbeat positions because the downbeat was fixed at 0. *Tap position* was the mean difference between the target position and the tap position (tap minus target) with sign preserved. Thus, negative values indicated taps that preceded the target whereas positive values indicated taps that followed the target. Tap position was only analyzed for synchronization because in continuation there were no drumbeats present to objectively define the timing of tap positions relative to target positions.

Production of Complex Meter Ratios

The ratio of long to short intervals provides the most direct information about how accurately participants were able to produce complex metrical patterns. Note that producing a ratio of 2.0 (i.e., 2:1) would indicate complete assimilation to simple meter, while a ratio of 1.5 (i.e., 3:2) would indicate veridical complex meter production. As a group, participants produced ratios between complex and simple meter ratios for both synchronization (1.679) and continuation (1.732) tapping,

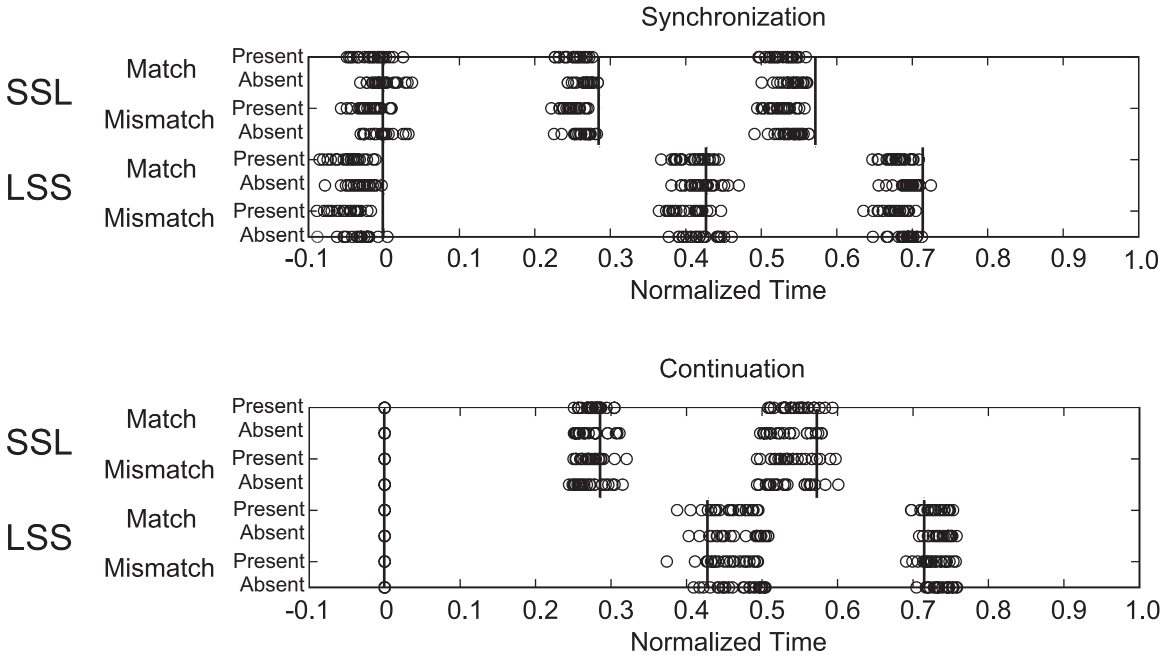

FIG. 2. Mean tap positions normalized to the measure duration for each of the eight conditions in synchronization (top) and continuation (bottom) at tap positions following the two short intervals and the long interval. Each circle represents one of the 24 participants' mean tap position. For synchronization, vertical lines indicate temporal positions of the drumbeats. For continuation, all taps on the first beat of the measure were fixed to time 0 and target positions and taps at the other beats were calculated with reference to the first beat. The measure length was defined as the time between consecutive taps on the first beat.

with both these values being closer to complex than to simple meter. The range of participants' mean ratios for synchronization was 1.46 to 1.98 and for continuation the range was 1.37 to 1.97. To evaluate ratio production during synchronization, we performed a three-way repeated-measures analysis of variance (ANOVA) on the average ratio with meter (SSL and LSS), match/mismatch, and whether the long to short ratio was formed with S1 or S2 (L:S1/L:S2) as variables. As shown in Figure 3A, during synchronization, participants produced the complex meter ratio more accurately when tapping to the LSS meter than when tapping to the SSL meter, $F(1, 23) = 4.80$, $p < .05$. Participants produced the complex ratio more accurately for the L:S2 ratio than for the L:S1 ratio, $F(1, 23) = 5.97$, $p < .025$, and this effect was larger for SSL meter than for LSS meter as indicated by an interaction between meter and L:S1/L:S2, $F(1, 23) = 9.92$, $p < .005$ (Figure 3A). Ratios during synchronization did not vary with music experience, $F(1, 22) = 0.32$, ns.

To evaluate accuracy during continuation, we performed a four-way repeated-measures ANOVA with meter, match/mismatch, L:S1/L:S2, and melody present/absent as variables. Participants produced ratios that were closer to the target ratio when the melody was present than when it was absent during continuation, $F(1, 23) = 9.75$, $p < .005$. This suggests that the mere presence of a melody provided cues to 7/8 meter, regardless of whether the melody and drum pattern matched or mismatched. There was also a significant meter by match/mismatch interaction, $F(1, 23) = 6.93$, $p < .025$. This was due to lower accuracy when the melody mismatched the SSL meter, but higher accuracy when the melody mismatched the LSS meter. Opposite of the result from synchronization, complex ratio production during continuation was more accurate for the L:S1 ratio than for the L:S2 ratio, $F(1, 23) = 10.43$, $p < .005$, and this effect was larger for the SSL meter than for the LSS meter as indicated by an interaction between meter and L:S1/L:S2, $F(1, 23) = 11.88$, $p < .005$ (Figure 3B). This interaction was mainly due to a smaller difference between L:S1 and L:S2 for the matching condition in LSS meter as indicated by a three-way interaction between meter, L:S1/L:S2, and match/mismatch, $F(1, 23) = 7.37$, $p < .025$. Ratios during continuation did not vary with music experience, $F(1, 22) = 1.61$, ns.

Tap Timing Variability

Variability provides information about the precision of tapping and thus can indicate the overall difficulty of the various conditions, independent of accuracy. The

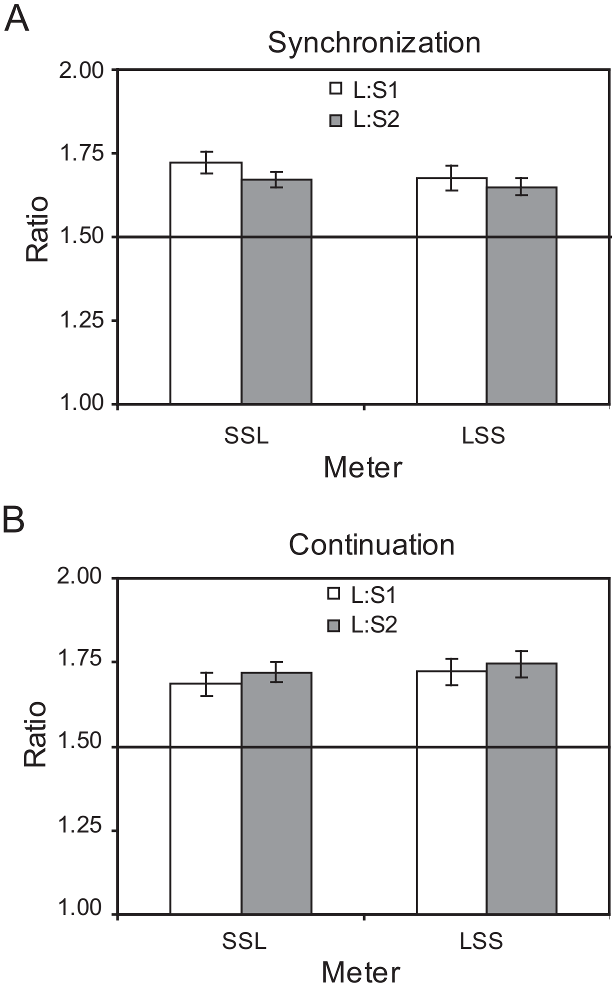

FIG. 3. Ratios of long to short inter-tap intervals. Horizontal lines indicate the target ratio of 1.5 (i.e., 3:2). Note that tapping a simple meter would yield a ratio of 2.0 (i.e., 2:1). (A) Ratios for synchronization showing performance closer to the target ratio for LSS meter compared to SSL meter, and performance closer to the target ratio for the L:S2 ratio than the L:S1 ratio. (B) Ratios for continuation showing performance closer to the target ratio for the L:S1 ratio than the L:S2 ratio.

range of participants' mean variability values for synchronization was 0.0217 to 0.0458 and for continuation the range was 0.0163 to 0.0475. For variability during synchronization, we performed a three-way repeated-measures ANOVA with meter, match/mismatch, and interval preceding the tap (S1, S2, L) as variables. For synchronization, variability was higher for the LSS meter than for the SSL meter, $F(1, 23) = 34.37$, $p < .001$, despite the fact that participants more accurately produced the target ratios for LSS. This could suggest a trade-off between production of complex ratios and tapping variability, with lower variability when producing a ratio closer to simple meter. As with the ratio production, there was no main effect of whether the melody matched or mismatched the meter of the drum pattern, $F(1, 23) = 1.96$, ns. However, as shown in Figure 4A there was a significant meter by match/mismatch interaction, $F(1, 23) = 6.28$, $p < .025$, due to the fact that variability was higher when the melody mismatched the meter in LSS, $F(1, 23) = 4.56$, $p < .05$, but not SSL, $F(1, 23) = 0.58$, ns. This suggests that the presence of a reinforcing melody helped stabilize the complex metrical tapping, but only in LSS meter. There was also a main effect of interval, $F(2, 46) = 100.93$, $p < .001$, with variability highest for the tap following L and smallest for the tap following S2 (Figure 4B). This pattern appeared for both meters with no interaction between interval and meter, $F(1, 23) = 2.69$, ns, indicating that drumbeat grouping had a larger effect on synchronization than did the particular meter (cf. Repp et al., 2005). Variability during synchronization was lower in participants with more music experience, $F(1, 22) = 5.54$, $p < .05$.

Variability during continuation was substantially higher than during synchronization. This is likely an artifact of fixing the first beat of the measure to be 0, which artificially transfers the variability associated with tapping on the downbeat to the other beats. For variability during continuation, we performed a three-way repeated-measures ANOVA with meter, match/mismatch, and present/absent as variables. For variability during continuation, interval was not included as a variable because the first beat of the measure was fixed at 0. There was no main effect of meter, $F(1, 23) = 0.22$, ns, or match/mismatch, $F(1, 23) = 0.51$, ns. As with variability during synchronization, however, a significant meter by match/mismatch interaction occurred, $F(1, 23) = 10.03$, $p < .005$, due to an increase in variability when the melody mismatched the LSS meter, $F(1, 23) = 6.17$, $p < .025$, but no change in variability when the melody mismatched the SSL meter, $F(1, 23) = 2.63$, ns (Figure 4C). When the melody was absent, variability was decreased relative to when the melody was present, $F(1, 23) = 5.83$, $p < .025$ (Figure 4D). It is possible that participants' tapping variability became smaller as they produced patterns that were closer to simple meter during continuation, again suggesting a trade-off between ratio production and variability. Specifically, when the melody was present during continuation, the events in the melody may have caused phase-resetting away from a stable pattern of tapping that did not exactly match the prescribed pattern with intervals in a 3:2 ratio, resulting in more variable tapping compared to continuation tapping with the melody absent. Variability during continuation did not vary with music experience, $F(1, 22) = 0.49$, ns.

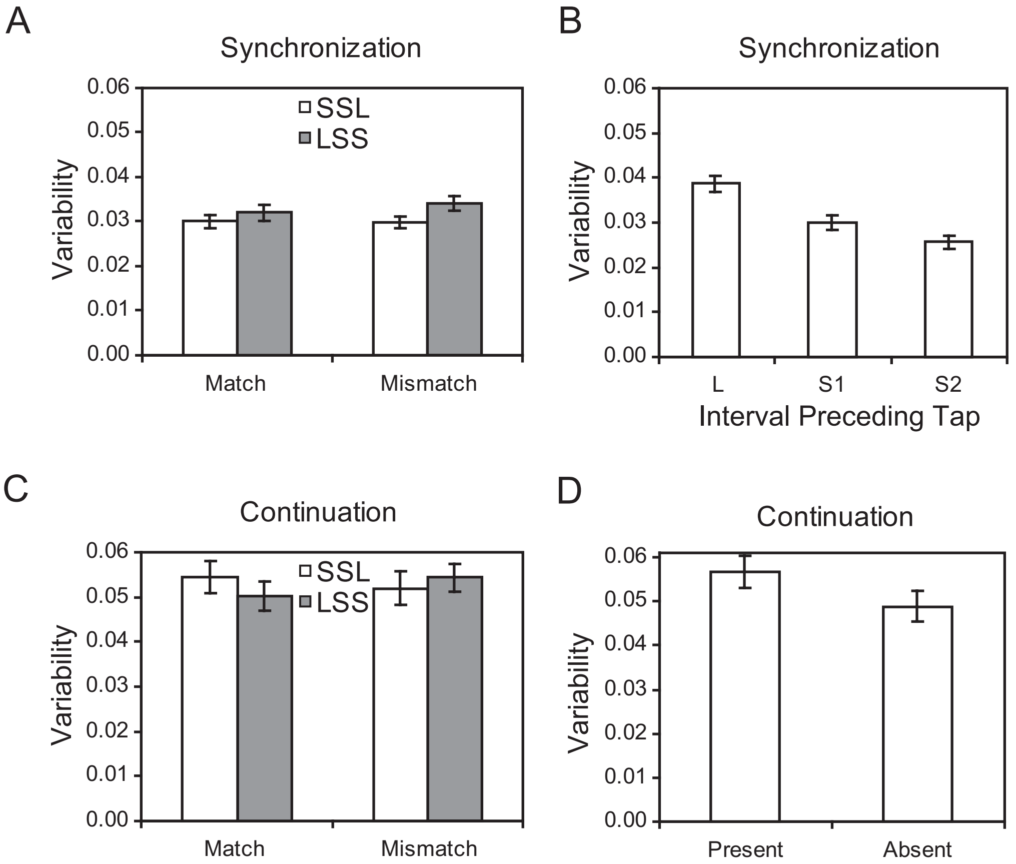

FIG. 4. Variability. (A) During synchronization, variability was higher for LSS than SSL meter, and was higher when the melody mismatched the meter for LSS but not for SSL. (B) During synchronization, variability was highest for the tap following L and lowest for the tap following S2. (C) During continuation, variability was higher when the melody mismatched the meter for LSS but not for SSL. (D) During continuation, variability was lower when the melody was absent.

Delay of Tapping Relative to the Beat

Tap position, which is a measure of the absolute deviation of each tap from the target position, provides information about the mean tap position relative to the three target locations. The pattern of tap position across the three beats can thus provide information about how participants perceptually organized the complex metrical patterns. For example, if participants were strongly influenced by the meter, they should have responded to the location of short and long intervals relative to the downbeat of the measure, and their taps should have varied as a function of downbeat location. This would predict an interaction between meter (SSL and LSS) and interval size (S1, S2, and L). If, on the other hand, participants were influenced only by the grouping of the three intervals, as suggested by Repp et al. (2005), participants should have showed only a main effect of interval with no interaction between meter and interval.

The range of participants' mean tap position values for synchronization was −0.0550 to −0.0071. For tap position during synchronization, we performed a three-way repeated-measures ANOVA with meter, match/mismatch, and interval as variables. As shown in Figure 5, tap position was negative, indicating that participants anticipated the target locations, a phenomenon known as *negative asynchrony* (Aschersleben & Prinz, 1995; Vos, Mates, & Van Kruysbergen, 1995; Wohlschläger & Koch, 2000). Negative asynchrony was smallest for the taps following L and largest for S2, as reflected by a significant main effect of interval, $F(2, 46) = 43.81$, $p < .001$. In addition, there was a significant main effect of meter on tap position, $F(1, 23) = 7.19$, $p < .025$ (Figure 5A). There was a significant interaction, however, between meter and interval, $F(2, 46) = 5.31$, $p < .025$, indicating that the meter modulated this basic pattern of negative asynchrony across the three target locations (Figure 5A). The interaction was due to earlier taps following L in LSS meter compared to SSL meter,

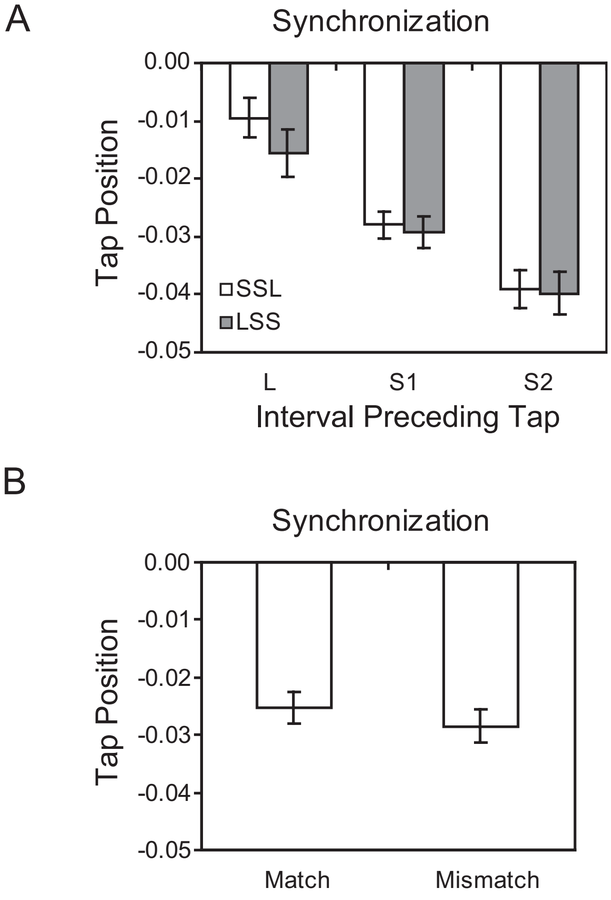

FIG. 5. Tap position. (A) During synchronization, the tap following L showed the smallest negative asynchrony (i.e., tapping ahead of the target beat) and the tap following S2 showed the largest negative asynchrony. For the tap following L, SSL meter had a smaller negative asynchrony than LSS meter. (B) During synchronization, negative asynchrony was smaller when the melody matched the meter.

$F(1, 23) = 12.24$, $p < .005$, but no such effect for the taps following S1 and S2, Fs $(1, 23) < 1.50$, ns. This is consistent with the previous finding that less negative asynchrony is found for downbeat positions (Keller & Repp, 2005) because in SSL the tap following L is the downbeat. We observed a significant main effect of match/mismatch, $F(1, 23) = 46.64$, $p < .001$, due to larger negative asynchronies when the meter of the melody mismatched the meter of the drum pattern (Figure 5B). Finally, negative asynchrony did not vary with music experience, $F(1, 22) = 2.04$, ns.

Discussion

While attempting to synchronize with and continue tapping to complex metrical patterns with long and short intervals in a 3:2 ratio, North American participants systematically produced a ratio falling between 3:2 and a simple meter ratio of 2:1, consistent with previous findings (Collier & Wright, 1995; Fraisse, 1956; Povel, 1981; Repp et al., 2005; Repp et al., 2002; Semjen & Ivry, 2001). Although the participants in the current study showed systematic bias toward a 2:1 ratio, they were on average closer to the complex ratio of 3:2 even in the continuation phase with no melody present. This contrasts with recent perceptual evidence showing that North American adults were largely unable to detect a change from complex to simple meter (Hannon & Trehub, 2005a, 2005b). The participants in the current study had varying amounts of music training, although previous studies have shown that even highly trained participants have difficulty producing complex ratio rhythms (Collier & Wright, 1995; Repp et al., 2005). Comparisons of North American infants of different ages and adults from North American and Balkan countries suggest that difficulty with complex meters could be due to culture-specific experience with simple meters (Hannon & Trehub, 2005a, 2005b).

All three measures of tapping behavior revealed differences between LSS and SSL meters. Although participants produced the 3:2 ratio more accurately for LSS meter, they also exhibited higher variability and greater negative asynchrony for LSS meter than for SSL meter. This set of results could arise from a trade-off between accuracy of producing a complex ratio and the precision of tapping. Participants may have produced the two meters differently because of their contrasting downbeat locations. For example, a previous finding indicated that pianists more accurately produced a 3:2 ratio in an LS rhythmic pattern than in an SL rhythmic pattern (Repp et al., 2002). An important difference between patterns that contain an initial long interval compared to patterns containing an initial short interval is that the former type splits the series of tones into two groups, whereas the latter type contains a single group of tones. It is thus possible that the splitting of a series of tones into more than one group could facilitate accurate production of ratios. Despite this possibility the current study and the study by Repp et al. (2005) found limited evidence that the two 7/8 meters (SSL vs. LSS) differentially influenced the perceived grouping.

Instead, the current study found similar patterns of variability (S1>S2>L) and tap position (S1>S2>L) for the two meters, consistent with Repp et al. (2005). During synchronization, the L:S2 ratio was produced more accurately than the L:S1 ratio and vice versa for continuation, but again with only small differences in this pattern of results across the two meters. These results suggest that the presentation of different metrical organizations (i.e., position of the downbeat) did not strongly influence how participants grouped the drum patterns. This is consistent with previous work on perceptual organization of repeating sequential patterns. For example, participants prefer to hear long series of events rather than splitting the events into smaller groups (Garner & Gottwald, 1968; Preusser, Garner, & Gottwald, 1970a, 1970b), which would predict participants to be biased to hear the pattern as SSL, regardless of downbeat position. On the other hand, the presence of a metrically consistent melody lowered variability for LSS meter during synchronization and continuation, suggesting that North American adults were able to pick up on some aspects of complex meter (e.g., measure length) from the duration and pitch patterns of the melody.

Future research should test participants who were raised listening to complex-meter music. Testing such participants using a sensory-motor task like the one used in the current study might reveal subtle biases for simple metrical structures even in individuals with a lifetime of exposure to complex-meter music. Given the large number of cultures using 3:2 ratios but the lack of cultures using more complex ratios, it is also possible that more complex ratios (e.g., 7:4) are intrinsically difficult to produce. Future research should also compare production of simple and complex meters in adults raised listening only to simple meter music in order to better define the difficulties in production of complex meters. Finally, an important aim for future research should be to analyze ratio production in expert performances of complex-meter music to compare with ratio production in laboratory tasks such as the one used in the current study. This would clarify how to define a "good" performance in sensory-motor tasks using complex meter stimuli.

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