The Impact of Specialized Musical Training on Rhythm Abilities:

Comparing Drummers, Pianists, Singers and String Players

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ABSTRACT

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Tomas Matthews

The current study assessed the importance of specialized musical experience in rhythm perception and production by comparing the rhythm abilities of four groups of musicians. Drummers, singers, pianists and string players performed four different rhythm tasks: the Rhythm Synchronization task, the Beat Synchronization task, the Tap-Continuation task and the Beat Alignment Perception Test. This battery of rhythm and beat-based tasks were used to assess the effects of specific musical experience on both higher level rhythm processing and basic sensorimotor synchronization. Within-group differences in performance showed that factors such as meter, metrical complexity, tempo and beat phase significantly affected the ability to perceive and synchronize taps to rhythm or beat. Interestingly, there were no between-group differences in performance for any of the tasks except the basic Tap-Continuation task which tested the ability to maintain a target tapping tempo without the aid of a metronome. When un-paced tapping variability was split into motor and timing variability using the Wing-Kristofferson model (1973), drummers were shown to have the lowest timer variability while pianists had the lowest motor variability. These results suggest that general musical experience is more important than specialized musical experience with regards to higher cognitive processing of rhythms, whereas low-level cognitive processes and bottom-up motor processes are affected uniquely by specialized experience.

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Introduction

Perceptually grouping a series of auditory events into a coherent rhythmic pattern within the context of music is a universal skill that is likely innate, at least in humans (Honing, 2012; Iversen, Patel & Ohgushi, 2008). Production of a musical rhythm involves the temporally precise coordination of auditory and motor processes at a level not seen in other domains. The integration of the perceptual and productive processes necessary for rhythm processing makes rhythm a useful tool in studying sensorimotor interactions. An important step in processing a musical rhythm is to find the underlying beat, which is an isochronous pulse that defines the tempo of a rhythm, and is generally what we synchronize our movements to. The beat also provides a framework around which elements of the rhythm are organized into hierarchical structures which define a rhythm's meter (Fitch, 2013). The ability to extract and synchronize to the beat and/or metrical structure of a rhythm is crucial to musical performance, and is likely developed over a musician's career.

Various studies have shown that musical training can improve rhythmic perception and production (Chen, Zatorre & Penhune, 2008; Drake, 1993; Smith 1983), fine-grained temporal processing (Drake & Botte, 1993; Farrugia, Benoit, Harding, Kotz, & Dalla Bella, 2012; Rammsayer & Altenmuller, 2006; Repp, 2010; van Vugt & Tillman, 2014) and precise motor synchronization (Collier & Ogden, 2004; Franěk, Mates, Radil, Beck, & Pöppel, 1991; Repp, 2010; Repp & Doggett, 2007). These improvements are driven by reinforced connections between sensory, proprioceptive, cognitive, and motor systems resulting from years of instrumental practice (Zatorre, Chen, & Penhune, 2007).

As playing an instrument provides rhythm processing advantages, it follows that the specialized experience of practicing a particular instrument would lead to training-related effects unique to that experience. There are many studies showing differences between musicians and non-musicians, however few studies have looked at the effects of specialized training among different groups of musicians. The current study used a battery of rhythm tasks, both perceptual and productive, to determine whether the unique experience of specialized musicians leads to differences in rhythm abilities. Four groups of musicians (drummers, singers, pianists, and string players) were compared on four rhythm tasks, each testing different aspects of rhythm processing. We predicted that the unique experience of these specialized musicians would lead to differences in performance. Specifically, it was expected that drummers, whose primary focus is rhythm, would perform best on all the tasks and that singers, whose primary focus is pitch and melody, would have the most difficulty with these tasks. In addition to providing information regarding how instrument-specific training impacts rhythm and timing abilities, this study may also affect how researchers recruit musicians for future studies testing rhythm and timing.

Background

Many researchers have tested the effects of musical training on rhythm processing by comparing musicians and non-musicians. Most of this research can be categorized into two groups based on which aspect of rhythm processing is emphasized. In one category are studies that focus on the higher level or top-down cognitive processes related to organizing rhythms into hierarchical structures (e.g. Chen et al., 2008; Drake, 1993; Grahn & Rowe, 2009; Smith, 1983). In the other category are studies that are concerned with bottom-up motor and timing processes (e.g. Collier & Ogden, 2004; Baer et al., 2013, 2014; Franěk et al., 1991; Repp, 1999). Together these studies show that the advantage in rhythm processing provided by musical training is two-fold. On one hand, training improves fined grained timing perception and sensorimotor synchronization (i.e. synchronizing movements to auditory or visual stimuli). On the other hand, musical experience improves the ability to use a rhythmic framework to find the underlying pulse and parse the metrical structure. In the next section, several studies are reviewed which highlight the effects of musical training on rhythm processing.

Musicians vs. Non-musicians

In a functional magnetic resonance imaging (fMRI) study focusing on the top-down effects of musical training, Chen and colleagues (2008) tested the effects of metrical complexity and musical training on tapping synchrony. While in the fMRI scanner, musicians and non-musicians were asked to listen to a rhythm then synchronize their taps with each note of that rhythm during a second presentation. The authors found that musicians were less variable and more accurate than non-musicians in synchronizing their taps with event onsets. They also found that tapping variability increased with metrical complexity. In addition, while performing the task musicians recruited ventral and dorsal prefrontal areas to a greater extent than non-musicians. This increased prefrontal activity, as well as self-reports regarding the strategy that the participants employed during the task, indicated that musicians used a top down strategy allowing them to rely on their superior musical knowledge to perceptually group individual intervals into rhythmic patterns. In this way musicians are able to encode and reproduce intervals in relation to a higher order structure. This 'beat-based' processing reduces the cognitive load necessary to process the temporal patterns, thus leading to improved synchronization performance.

Using the same task as that created by Chen and colleagues (2008), Bailey and Penhune compared early- and late-trained musician groups (2010), as well as a non-musician control group (2012). The authors found that early-trained musicians showed superior synchronization abilities to the late-trained musicians and that both groups outperformed non-musicians.

Together these studies show the effects of musical training and metrical complexity on rhythm synchronization while also providing evidence for an early sensitive period with regards to rhythm abilities.

Other studies have focused on improvements in bottom-up timing and motor functions due to musical training. For example, Repp (2010) found that musicians showed lower tapping variability, smaller asynchronies, and were more sensitive to phase shifts than non-musicians during basic synchronization tasks. Furthermore, previous work has shown that musical expertise leads to improvements in tempo sensitivity (Drake & Botte, 1993), anisochrony detection (Friberg & Sundberg, 1995) and duration replication (Franěk, et al., 1991). In another study from this lab, Baer, Thibodeau, Gralnick, Li and Penhune (2013) used a Tap-Continuation task and a circle drawing task to test whether dissociable timing processes are engaged in musicians and non-musicians. In the Tap-Continuation task, participants synchronized taps to a metronome and then continued tapping at the same tempo after the metronome had stopped. The authors found that musicians were significantly less variable in their un-paced tapping compared to non-musicians and that tapping variability increased as tempo decreased for both groups.

Recently two separate groups have developed two batteries of rhythm and timing tasks in order to assess rhythm perception and production. The Battery for the Assessment of Auditory Sensorimotor and Timing Abilities (BAASTA), developed by Farrugia, Benoit, Harding, Kotz and Dalla Bella (2012), includes four timing and rhythm perception tasks and four tapping tasks. The authors found that musicians were better than non-musicians on all four perceptual tasks. Only non-musicians were tested on the tapping tasks. Fujii and Schlaug (2013) developed the Harvard Beat Assessment Test (H-BAT) which includes four beat-based tasks, three of which had both perceptual and productive components. Musicians and non-musicians were not compared explicitly however they found that musical training was significantly correlated with measures of synchronization consistency.

Together these results indicate that musical training improves performance on rhythm tasks, either through top down effects relating to musical expertise and/or through basic timing function and motor implementation leading to more accurate and precise tapping. However, these studies do not tell us about the effects of specialized musical experience on rhythm processing. Does the instrument that one plays make a difference?

Comparing Musician Groups

Aside from a few studies showing improved rhythm perception and production in drummers (Fujii & Oda, 2006; Fujii, Kudo, Ohtsuki & Oda, 2009; Petrini, Dahl, Rocchesso, Waadeland, Avanzini, Puce & Pollock, 2009), few studies have examined the effects of specialized musical training. Those that do exist have generally focused on functional and structural changes in auditory and motor regions related to playing a particular instrument (e.g. Bangert & Schlaug, 2006; Halwani, Loui, Ruber, & Schlaug, 2011; Gebel, Braun, Kaza, Altenmüller & Lotz, 2013; Jäncke, Shah & Peters, 2000; Kajihara, Verdonschot, Sparks & Stewart 2013; Münte, Nager, Beiss, Schroeder & Altenmüller, 2003). Even fewer studies have actively compared different musician groups, particularly with regards to rhythm and timing abilities. The following section reviews the few studies that do exist.

An early study comparing different musician groups employed a forced choice discrimination task, where participants responded as to whether the second of two isochronous sequences contained a timing deviation (Ehrlé & Samson, 2005). The authors found that percussionists were capable of detecting smaller timing deviations compared to classical musicians and non-musicians, who did not differ. They reasoned that percussionists, as rhythm experts, were able to perceptually subdivide the intervals, allowing for finer temporal deviation detection.

In a study just published, pianists, brass players and non-musicians were compared on two timing detection tasks and a variant of the Tap-Continuation task (van Vugt & Tillman, 2014). Results showed that both musician groups performed better on all three tasks compared to non-musicians, however the pianists and the brass players did not differ on any of the tasks. The authors also determined that synchronization ability was a better predictor of detection ability, over and above musical experience. These results suggest that musical training improves synchronization abilities which generalize to better timing perception, regardless of the instrument-specific experience.

Kraus, Pollok and Schnitzler (2010) tested drummers, professional pianists, amateur pianists, singers, and non-musicians on a visual and auditory synchronization task as well as a cross-modal discrimination task. During auditory synchronization, drummers had significantly smaller asynchronies than the amateur pianists, and were less variable in their tapping compared to singers, amateur pianists and non-musicians. Similarly, Repp, London, and Keller (2013) found that rhythm experts (four percussionists and one violinist) were less variable than another group of well-trained musicians in synchronizing with non-isochronous rhythms, however this was only true for faster rhythms.

Together these results show that synchronization abilities as well as timing discrimination and deviation detection abilities are affected by musical experience. In particular, drummers, as timing experts, showed a performance advantage over other types of musicians in most cases.

Sensorimotor synchronization has been theorized to involve two distinct processes: an internal timekeeper that entrains to a regular stimulus and a motor implementation process which uses input from the time-keeper to accurately time movements (Wing & Kristofferson, 1973). It is not clear whether the superior performance of drummers is driven by a more accurate and precise internal clock, or if it is due to reduced delay or variability in the motor system. It is important to note that not all of the studies reviewed above showed between-musician differences in performance. In the study by van Vugt and Tillman (2013), pianists and brass players did not perform differently on the perception or synchronization tasks. Kraus and colleagues, (2010) showed that drummers performed better than amateur pianists, singers and non-musicians in the synchronization tasks and singers and non-musicians in the discrimination task. However, no differences were found between drummers and professional pianists on any of the tasks. This suggests that musicians that started at an early age and practice at the level of a professional, perform as well as drummers on timing and synchronization tasks. Based on these studies, it is not clear whether differences in rhythm abilities are primarily driven by general musical experience, or instrument-specific training. Furthermore, it cannot be determined as to whether it is a more accurate and precise internal timekeeper that drives these differences or a well-trained motor system, or an interaction of the two.

The current study

The current study used four tasks to test various aspects of rhythm processing and production in four groups of musicians. As stated above, there are known to be two key processes involved in perceiving and producing a musical rhythm. The underlying beat or pulse must be extracted by finding the most stable and/or salient isochronous structure within a rhythm. Secondly, elements of the rhythm must be grouped into hierarchical structures based on explicit and subjective accents as well as one's knowledge of musical patterns (Fitch, 2013). In the present study, the Rhythm Synchronization task was used to test the latter process, while the Beat Synchronization task was used to test the former.

In the Rhythm Synchronization task, participants were asked to listen to rhythms, then synchronize finger taps with each note of the rhythm upon the second presentation (Chen et al., 2008). In the Beat Synchronization task participants were asked to synchronize finger taps with the underlying beat of a rhythm during the second and third presentation of that rhythm (Kung, Chen, Zatorre, & Penhune, 2013). As both of these tasks require precisely timed finger taps, a variant of the Tap-Continuation task was used to test the ability to accurately maintain a target tapping tempo without the aid of a metronome. In this task participants synchronized their taps to a metronome, then continued tapping at the same rate as accurately as possible after the metronome had stopped. Beat perception, the ability to extract the pulse of a rhythm without moving synchronously with it, is crucial to the Beat Synchronization task. In light of this, we included the perceptual version of the beat alignment test (BAPT; Iversen & Patel, 2008), in which participants were asked to find the underlying beat of musical excerpts and judge whether a metronome was synchronized with that beat, without tapping along. Bailey and Penhune (2012) found that auditory working memory correlated with performance on the Rhythm Synchronization task. Therefore, we included the Digit Span and Letter Number Sequencing tasks from the Wechsler Adult Intelligence Scale IV (Wechsler, 2008) in order to test whether differences on the rhythm tasks might be related to differences in auditory working memory.

Together, we believe that these four tasks have the breadth and sensitivity to detect any difference in rhythm processing that may exist in musicians. Both the Rhythm Synchronization and Beat Synchronization tasks have been previously shown to be effective in testing the ability to process and produce various aspects of rhythm (Chen et al., 2008; Kung et al., 2012).

Additionally, the Tap-Continuation task is well established as a measure for sensorimotor synchronization (Wing & Kristofferson, 1973) and the BAPT has been shown to be successful in assessing beat perception abilities across populations (Iversen & Patel, 2008).

As previous work has shown, the particular training of musicians is related to superior performance on timing and rhythm tasks. By extension, it is logical that the specialized, instrument-specific experience of musicians would lead to differences in rhythm abilities. The four rhythm tasks used in the current study test different aspects of rhythm that rely on distinct processes which are expected to be differentially affected by specialized musical experience. For example, performance on the Rhythm Synchronization task may depend more on the ability to use a top-down, rhythmic grouping strategy. This ability may be improved through general musical experience, as the ability to extract a pulse or meter and use these structures to inform motor responses is crucial for most types of musical performance, regardless of instrument. On the other hand, the Tap-Continuation task relies more on basic, bottom-up, motor timing processes which may be more or less improved based on the specialized experience of the musicians.

Drummers are specifically trained to become timing experts whereas singers are specifically trained to become pitch and melody experts. Pianists have intensive practice in terms of timing and sequencing discrete finger movements, whereas right-handed string players are highly trained at making continuous bowing movements with their right hands. Differences in training with regards to which effectors are used (i.e. fingers vs. arms) and the type of movements made (i.e. discrete vs. continuous) may affect how these musicians perform on these tasks. Based on these differences, as well as previous literature (e.g. Kraus et al., 2013; Repp et al., 2013), we predicted that drummers would outperform singers, pianists and string players.

Pianists were also expected to outperform the singers and string players and string players were expected to outperform singers.

It is important to note that, as there is very little research comparing the rhythm and timing abilities of different type of musicians, these predictions were at least partially based on the experience of the authors as well as anecdotal experience of other musicians. It should also be noted that, as this is a quasi-experiment, it cannot be definitively shown that playing a particular instrument improves rhythm abilities differentially. It is possible that rhythm abilities demonstrated at a young age determine which instrument an individual ends up playing. However, based on previous research, we are working under the assumption that if differences in rhythm abilities are found, they are due to specialized musical training and not due to inherent abilities.

Method

Experimental Design

All participants performed the Beat Synchronization task, the Rhythm Synchronization task, the Tap-Continuation task, the beat alignment perception task (BAPT) and two working memory tasks (Digit Span and Letter Number Sequencing). As discussed above, the four rhythm tasks were included to test four different aspects of rhythm processing, including basic abilities such as un-paced tapping and higher level abilities such as beat and meter perception and production. The tasks were administered in a counter-balanced order, except that the Rhythm Synchronization and Beat Synchronization tasks were never administered consecutively. Digit Span (DS) and Letter Number Sequencing (LNS) were administered during the break between the two blocks of the Rhythm Synchronization and Beat Synchronization tasks with the DS always administered first. The whole battery of tasks took approximately two hours.

Participants

The main purpose of this study was to compare rhythm abilities of singers, pianists, drummers and string-players. To achieve this, every effort was made to recruit participants with exclusive experience in their chosen instrument and with as close to eight years of exclusive experience as possible. However, as it is common for musicians at higher levels to have at least some experience with one or more additional instruments, complete exclusivity was not generally possible. Participants completed an extensive musical experience questionnaire (MEQ) (Bailey & Penhune, 2010). From this questionnaire we extracted five variables that we thought were most important in characterizing the groups: age of start, number of years playing primary instrument, number of years playing any instrument, current hours of practice per week and years of lessons (see Table 1 for results of the MEQ and see the results section for a detailed description and statistical analysis of these measures).

Forty-four right-handed musicians (10 drummers, 12 pianists, 10 string players, and 12 singers), aged 18 to 35 (M = 22.7, SD = 3.9), were recruited via advertisements placed online and around the McGill and Concordia University campuses. Overall the sample was 55% female, however eight of the ten string players were female and only one of the drummers was female. Participants were free of any neurological disorders and reported no motor or hearing problems. Informed consent was obtained and participants were compensated for their time. The study was approved by the Concordia University Human Research Ethics Committee.

Test Battery

Rhythm Synchronization

Stimuli and materials. This task was developed by Chen and colleagues (2008). Participants were asked to listen to a rhythm made up of a woodblock sound and then tap along to every note of that rhythm, synchronizing each tap to each onset as accurately as possible. The stimuli for this task consisted of six non-isochronous rhythms. Each rhythm consisted of 11 woodblock notes (100 ms) and lasted six seconds. The rhythms contained five inter-onset intervals (IOI) of 250 ms, three intervals of 500 ms, one interval of 750 ms, one interval of 1000 ms and one interval of 1500 ms. Each rhythm was unique in terms of how the IOIs were organized to create temporal structures of differing complexity or metrical strength according to the model of Essens and Povel (1985) and Essens (1995). There were three levels of metrical complexity: metric simple (MS), metric complex (MC), and non-metric (NM). Two rhythms at each level were presented. Rhythms were presented through Sony MDR 7506 headphones and tapping responses were made using the left button of a USB computer mouse. Stimuli were presented and responses were recorded using Presentation software (Presentation, v0.8, Neurobehavioral Systems; for a more detailed description of the stimuli see Chen et al., 2008) on an IBM-compatible laptop.

Procedure. Each trial began with a warning sound followed by the presentation of one of six rhythms during which the participants simply listened. This was followed by a second warning sound after which the same rhythm was presented a second time, and the participants were asked to tap along with their right index finger as accurately as possible. During each block, each rhythm was presented six times in a counterbalanced fashion for a total of 36 trials per block. There were two blocks, 11 minutes each with a short break in between, during which either the Digit Span or Letter Number Sequencing task was administered.

Measures. Tapping performance was measured using two dependent variables: the inter-tap interval (ITI) deviation and the percentage of correct taps. The percentage of correct taps (henceforth referred to as percent correct) was considered a measure of global accuracy, whereas

ITI deviation has been shown to be more sensitive measures of synchronization ability. A tap was considered correct if it was made within half of the onset-to-onset interval before or after a woodblock note. The ITI deviation measures the extent of the discrepancy between the ITI and the corresponding IOI. It was calculated by dividing the ITI by the IOI, subtracting the ratio from one and then taking the absolute value. This measure is indicative of how well participants have reproduced the temporal structure of the rhythms. ITI deviation was calculated only for taps that were considered correct, that is, taps that occurred within the 50% window. Both measures were then averaged across each trial for each rhythm type.

Beat Synchronization

Stimuli and materials. The Beat Synchronization task was developed by Kung and colleagues (2013) as part of an fMRI study looking at activation of the sensorimotor network during beat extraction. Participants were asked to listen to a rhythm during the first presentation and then tap along to the underlying beat of the rhythm during the second and third presentations. The stimuli consisted of rhythms made up of eleven 100 ms woodblock sounds. Duple and triple rhythms were created each with four levels of metrical complexity. In duple rhythms, beats alternate between strong and weak consecutively (e.g., a march). In triple rhythms, a strong beat is followed by two weak beats (e.g., a waltz).

The levels of metrical complexity were established according to the work of Povel and Essens (1985), which shows that as the number of sounds that fall on predicted beat points increases, the metrical strength and thus the ease of finding a beat increases. For the strongly metric rhythms, there were stimulus onsets at all predicted beat points (i.e., five and seven onsets on the beat for duple and triple rhythms respectively). The weakly metric rhythms had stimulus onsets at only a subset of the predicted beat points (i.e., two and four onsets on the beat for duple and triple rhythms respectively). In addition, there were two rhythm tempi, where the smallest IOIs were 195 ms for the fast tempo and 260 ms for the slow tempo. Each of the duple rhythms contained five eighth notes (195 and 260 ms in fast and slow tempi, respectively), three quarter notes (390 and 520 ms), one dotted quarter note (585 and 780 ms), and one half note (780 and 1040 ms). Rhythms at the fast and slow tempi lasted 3.51 and 4.68 sec respectively (see Kung et al., (2013) for more detail on how the stimuli were created).

In order to minimize the number of trials, the current study used a subset of the rhythms created by Kung et al., (2013). In that study the authors found that participants had a harder time finding and synchronizing to the beat in the triple rhythms. For this reason 20 of the duple rhythms and 12 of the triple rhythms were used in the current study. The task was split into two 11 minute blocks, each consisting of 32 trials, where each rhythm was used once per block. The rhythms in the two blocks were alternated such that the slow rhythms in the first block were the fast rhythms in the second. During the task, trials were pseudo-randomized between triple and duple meter and fast and slow tempi in order to prevent participants from using the beat from the previous trial to tap in the current trial.

Rhythms were presented through Sony MDR 7506 headphones and tapping responses were made using the left button of a USB computer mouse. Stimuli were presented and responses were recorded using Presentation, v0.8 (Neurobehavioral Systems), on an IBM-compatible laptop.

Procedure. In each trial of the Beat Synchronization task, a rhythm was presented three times with each presentation preceded by a warning sound. In the first presentation, the participants were asked to listen and find the underlying beat of the rhythm. During the second and third presentation, participants were asked to tap out the underlying beat or pulse of the rhythm on a mouse, as accurately as possible. The warning sound preceding the second and third presentation of the rhythms was different compared to the first warning sound in order to differentiate listen and tapping portions of the trial. The intervals preceding and following the second and third warning sounds were multiples of the smallest IOI so as not to interfere with the pulse of the rhythms. This way participants could continue tapping through the second and third presentation of the rhythms without stopping between the two. Participants were free to tap at the duple or quadruple rate for the duple rhythms and the triple or sextuple rate for the triple rhythms. Before completing the task participants completed a familiarization block which consisted of eight trials familiarizing the participant with every possible meter (triple, duple) and tempo (fast, slow). If it was clear, based on observation, that the participant was not finding the beat, an experimenter would demonstrate by tapping along to the beat (for a more thorough description see Kung et al., (2013)).

Measures. Unlike in the Rhythm Synchronization task, participants were asked to tap isochronously, matching the inter-beat interval (IBI). For this reason, a stricter window of 20% of the IBI, before or after each onset was used and percent correct was the proportion of taps falling in that window. Participants were not instructed as to what metric level they were to tap, therefore the first step in the analysis was to determine whether they tapped at the duple or quadruple level, thus determining the target IBI. Therefore, the ITI deviation was calculated as the variability of the ITI with reference to the target IBI, not an absolute interval. The dependent measures were calculated for correct taps only and were averaged over each trial for meter, tempo and metrical complexity.

Tap-Continuation

Stimuli and materials. This task is a variant on the well-used synchronization and continuation task and uses the same experimental setup as used by Baer and colleagues (2013). In this task, participants were asked to synchronize taps to a metronome and then keep tapping at the same rate after the metronome stopped. The stimuli consisted of a metronome made up of a computer-generated tone (1 KHz pure tone, 20 ms in duration) presented at three tempos with IOIs of 200 ms, 500 ms, and 750 ms. Finger movements were recorded using an active, three dimensional motion capture system (Visualeyez VZ3000, Phoenix Technologies, Burnaby, BC, Canada). Two infrared-sensitive cameras tracked the motion of an infrared light emitting diode (LED) that was attached to participants' right index fingernail using Velcro. The trajectory of the LED was tracked at a sampling rate of 200 Hz and to a spatial resolution of 0.015 mm. The infrared-sensitive cameras were synchronized to the metronome with a National Instruments 6221 Data Acquisition board. Stimuli were presented through Sony MDR-7506 headphones.

Procedure. At the beginning of each trial, participants tapped their right index finger on the surface of a table, synchronizing their taps to the metronome (paced phase). The metronome lasted for 35 cycles and then stopped. Participants were asked to continue tapping, matching their tempo of tapping to the tempo of the metronome as accurately as possible for another 35 cycles until they heard a final tone indicating the end of a trial (un-paced phase). Participants performed six trials per tempo. The order that the tempi were performed in was counterbalanced across participants (see Baer et al., 2013 for more details).

Measures. As we are interested in un-paced tapping ability, only taps generated after the metronome had stopped were analyzed. Mean ITIs were compared to ensure that participants were able to tap out the target interval successfully. In order to characterize long-term drift away from the target interval, the tapping data was linearly detrended. The absolute slope of the detrending line was used as a measure of the magnitude of drift. The variance of the ITIs that remained in the data after detrending was used as a more accurate representation of the cycle-to-cycle tapping variability. Using the Wing-Kristofferson model (1973), tapping variability was then split into that related to the internal timekeeper and that related to motor implementation. Each measure was analyzed separately. In addition to these variability measures, use of the motion capture system allowed for analysis of kinematic measures. Smoothness of tapping movement was measured using mean squared jerk (see Baer et al., 2013). All measures were averaged over each tempo and compared between groups.

The Beat Alignment Perception Test (BAPT)

Stimuli and materials. This task was used to measure the ability of musicians to perceive the underlying pulse of a rhythm without synchronizing their motor output. Stimuli for the BAPT were created and made available by Iversen and Patel (2008). Stimuli consisted of 17 clips of recorded music 15.9 seconds on average. A computer generated metronome made up of a digital tone (1 KHz pure tone, 100 ms duration) was superimposed on the musical clips such that the metronome was either in sync or out of sync with the underlying beat of each music clip. The metronome could be out of sync in one of two ways: stretched (at a slower tempo than the music clip) or shifted (out of phase with the music clip). Stimuli were presented and responses were recorded with software written in Python (v2.7), and played through Sony MDR 7506 headphones at a comfortable volume.

Procedure. During each trial participants heard the stimuli (excerpt plus metronome) and then were asked to indicate whether the metronome was in sync with the beat or not. Participants also rated their confidence in their response on three-point scale, where 0 = just guessing, 1 = pretty sure and 2 = 100% sure.

Measures. Measures of interest for the BAPT were the proportion of correct yes or no responses as well as the confidence ratings. Percent correct was averaged for each condition (On, stretch and shift). To analyze the confidence ratings, the proportion of responses corresponding to '100% sure' were averaged over all trials.

Working memory tasks

In order to test the involvement of auditory working memory in rhythm abilities participants completed the Digit Span and Letter Number Sequencing tasks from the fourth edition of the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 2008). These are standard tests of working memory and were scored according to the WAIS manual. Scaled scores were derived based on age-standardized scores.

Data Analysis

Mixed factor analyses of variance (ANOVA) were applied using SPSS, v22 (PASW inc.), to compare performances on each task. Dependent measures relevant for each task (e.g. meter, tempo and metrical complexity) were included as within-subject variables and musician type was included as the between-subjects variable. The Greenhouse-Geisser correction was applied in cases where the assumption of sphericity was violated according to Mauchly's test. All pairwise and simple comparisons reported below have been corrected for multiple comparisons using the Bonferroni correction.

In order to examine whether individual experience impacts performance, correlations were performed between the performance measures and five musical experience measures (years of lessons, age of start, current hours of practice, years playing primary instrument and years playing total). Additionally, we checked for correlations between the combined DS and LNS score and all task measures. Finally, we analyzed correlations between overall score on the BAPT and performance measures on the other tasks.

Scores on individual measures on individual tasks were removed as outliers if they were three or more standard deviations away from the group mean.

Results

Musical Training and Experience

To assess possible differences in training and experience between the groups, we used separate ANOVAs for each measure from the Musical Experience Questionnaire (MEQ). Only significant or marginally significant differences between groups are reported here (see Table 1 for all measures). There was a near-significant main effect of age of start, $F(3,43) = 2.585$, $p = .067$, $\eta^2 = .166$. Follow-up comparisons indicate that the drummer group started later on average ($M = 12.4$, $SD = 2.8$) compared to all groups. The largest difference was between drummers and pianists ($M = 8$, $SD = 2.1$), however this comparison was not significant after correction for multiple comparisons ($p = .119$). There was a significant main effect of years of lessons $F(3,43) = 3.493$, $p = .024$, $\eta^2 = .212$, showing that pianists ($M = 13$, $SD = 3.0$) had taken lessons on their primary instrument for significantly longer than drummers ($M = 5.5$, $SD = 3.7$).

Rhythm Synchronization

A mixed factor ANOVA was used to compare performance across all three levels of metrical complexity and between groups (see Figure 1). There was a main effect of metrical complexity for the percent correct measure $F(2,80) = 31.591$, $p < .001$, *partial* $\eta^2 = .441$, such that participants had a significantly lower proportion of correct taps for the non-metric (NM) rhythms compared to both the metric simple (MS) ($p < .001$) and the metric complex rhythms (MC) ($p < .001$). Percent correct did not differ significantly between musician groups $F(3,40)$

= .652, p = .586, η^2 = .047, nor was there a complexity by group interaction $F(6,80)$ = 1.235, p = .297, *partial* η^2 = .085.

Consistent with previous studies using this task (Bailey et al., 2013; Chen et al., 2008), metrical complexity had a significant effect on ITI deviation, $F(2,80)$ = 10.855, p < .001, *partial* η^2 = .213, such that ITI deviation was significantly lower for the MS rhythms compared to both the MC and NM rhythms (p = .007 and p < .001, respectively). However, MC and NM rhythms did not differ significantly (p = .633). In contrast to our predictions, there was no main effect of group, $F(3,40)$, = 1.082, p = .368, η^2 = .075, and no interaction effect, $F(6,80)$ = 1.514, p = .184, *partial* η^2 = .102.

Beat Synchronization

A mixed factor ANOVA was used to compare the ability to find and synchronize to the underlying beat, with independent variables tempo, metrical complexity, meter, and group membership (see Figure 2).

The first step was to use a mixed factor ANOVA to test the effect of metrical complexity collapsed over both meter and both tempi. For percent correct, there was a main effect of metrical complexity, $F(3,120)$ = 28.204, p < .001, *partial* η^2 = .414, such that percent correct was lower for more complex rhythms. There was no main effect of group, $F(1,40)$ = .490, p = .691, η^2 = .035, nor was there a significant interaction, $F(9,120)$ = .775, p = .612, *partial* η^2 = .055.

For ITI deviation there was a main effect of metrical complexity, $F(3,120)$ = 13.232, p < .001, *partial* η^2 = .249, such that the most complex rhythms had the highest ITI deviation (p < .001 for all comparisons) but the other complexities did not significantly differ. There was no main effect of group, $F(3,40) = .580$, $p = .631$, $\eta^2 = .042$, and no interaction effect, $F(9,120) = .630$, $p = .735$, *partial* $\eta^2 = .045$.

The next step was to analyze the effects of meter (duple vs. triple) and tempo (fast vs. slow) and to see if performance differed across groups in these conditions.

There was a main effect of meter on percent correct, $F(1,40) = 83.797$, $p < .001$, *partial* $\eta^2 = .677$, such that participants had a larger proportion of correct taps for the duple meter compared to the triple meter. There was a main effect of tempo, $F(1,40) = 35.671$, $p < .001$, *partial* $\eta^2 = .472$, such that participants had a larger proportion of correct taps for the slow tempo compared to the fast tempo. There was no interaction between these factors, $F(1,40) =.454$, $p = .504$, *partial* $\eta^2 = .011$. Again, there was no main effect of group, $F(3,40) = .524$, $p = .669$, $\eta^2 = .038$, and no two- or three-way interactions between tempo, meter and group.

For the ITI deviation, there was a main effect of meter, $F(1,40) = 43.625$, $p = .001$, *partial* $\eta^2 = .522$, showing that participants were more variable in their tapping for the triple meter compared to the duple meter. There was a main effect of tempo, $F(1,40) = 3.979$, $p = .053$, *partial* $\eta^2 = .091$, such that participants were slightly more variable at the fast tempo compared to the slow tempo. Here we saw a significant interaction between meter and tempo, $F(1,40) = 10.652$, $p = .002$, *partial* $\eta^2 = .210$, such that participants were significantly more variable for the fast tempo than for the slow tempo for the triple meter ($p = .004$), but not the duple meter ($p = .082$). There was no main effect of group, $F(3,40) = .894$, $p = .453$, $\eta^2 = .063$, and no two- or three-way interactions between group and the other two factors.

Tap-Continuation

A mixed factor ANOVA was used to compare un-paced tapping performance across the three tempi (IOIs of 250 ms, 500 ms and 750 ms) and across groups.

First, mean ITIs were compared across tempi and groups to ensure that participants were able to tap accurately at the three tempi without the aid of a metronome. As expected, there was a highly significant main effect of tempo, with faster rates producing shorter ITIs, $F(2,74) = 15611.38$, $p < .001$, *partial* $\eta^2 = .998$. Additionally, there was no significant tempo by group interaction, $F(6,74) = 1.22$, $p = .313$, *partial* $\eta^2 = .090$, and no main effect of group, $F(3,37) = 1.28$, $p = .296$, $\eta^2 = .094$. Together these results show that all groups were able to tap out the target intervals successfully, even without the metronome.

For detrended variance there was a significant main effect of tempo, $F(2,74) = 47.612$, $p < .001$, *partial* $\eta^2 = .563$, a significant interaction, $F(6, 74) = 2.930$, $p = .025$, *partial* $\eta^2 = .192$, and no significant main effect of group, $F(3,37) = 1.188$, $p = .328$, $\eta^2 = .088$. Pairwise comparisons showed that for the pianists and string players, detrended variance increased significantly from fast to medium and from medium to slow. For the drummers and singers, detrended variance increased as tempo decreased but only the comparison between fast and slow tempi reached significance (see Figure 3).

The magnitude of long-term drift, as measured by the absolute slope of the detrending line, was compared across groups and tempi. Consistent with Collier and Ogden (2004), there was a significant effect of tempo, $F(2,70) = 17.672$, $p < .001$, *partial* $\eta^2 = .336$, such that the magnitude of the slope increased as tempo decreased. Contrary to predictions, there was no main effect of group, $F(3,35) = 1.667$, $p = .192$, $\eta^2 = .125$, and no significant interaction, $F(6,70) = .941$, $p = .451$, *partial* $\eta^2 = .075$ (see Figure 3).

As discussed above, mean squared jerk (MSJerk) is a measure of the smoothness of movement, such that smooth movements have low MSJerk. For this measure, there was a main effect of tempo, $F(2, 76) = 617.112$, $p < .001$, *partial* $\eta^2 = .942$, showing that MSJerk increased significantly as the tempo decreased. There was no significant interaction, $F(6,76) = 1.332$, $p = .274$, *partial* $\eta^2 = .095$, and no main effect of group, $F(3,38) = .848$, $p = .476$, $\eta^2 = .063$ (see Figure 4).

Tapping variability was split into timer variability and motor variability using the Wing-Kristofferson model. For the timer variability, there was a significant main effect of tempo, $F(2,70) = 65.121$, $p < .001$, *partial* $\eta^2 = .650$, such that timer variability increased as tempo decreased. There was no significant tempo by group interaction, $F(6,70) = 1.025$, $p = .403$, *partial* $\eta^2 = .081$. There was a marginally significant main effect of group, $F(3,35) = 2.630$, $p = .065$, $\eta^2 = .184$, however pairwise comparisons did not reach significance (see Figure 5).

For motor variability, there was a significant main effect of tempo, $F(2,74) = 10.298$, $p < .001$, *partial* $\eta^2 = .218$, such that variability was significantly greater for the slow tempo compared to the fast tempo ($p < .001$), but not compared to the medium condition ($p = .494$). There was no significant interaction, $F(6,74) = 1.345$, $p = .251$, *partial* $\eta^2 = .098$. There was a main effect of group, $F(3,37) = 4.039$, $p = .014$, $\eta^2 = .247$, such that pianists showed the lowest motor variability. Pairwise comparisons showed that pianists were significantly less variable than the string players ($p = .014$). No other between-group comparisons were significant (see Figure 5).

BAPT

One singer and one pianist did not complete the BAPT task. A mixed factors ANOVA was used to test the accuracy of "on" and "off" beat judgements across groups and across the two "off" conditions (stretch and shift) (see Figure 6). There was a main effect of the on/off variable, $F(3,114) = 19.888$, $p < .001$, *partial* $\eta^2 = .344$, showing that participants were significantly more accurate when the metronome was synchronized to the beat compared to when it was off the beat

(p = .004). After splitting the off trials into stretch and shift, pairwise comparisons showed that participants were equally accurate for the on condition (95.9%) and the stretch condition (p = 1.00), whereas accuracy for the shift condition was significantly lower compared to the on condition ($p < .001$) and the stretch condition ($p < .001$). There was no main effect of group, $F(3,38)]$ = .378, p = .770, η^2 = .029, and no interaction effect, $F(3,38)$ = .333, p = .844, *partial* η^2 = .026.

These results indicate that perceiving a phase shift relative to the underlying beat of musical excerpt is more difficult than perceiving a tempo shift for all groups of musicians. In order to test for differences in confidence ratings between groups, proportion of ratings with a value of 2 (100% sure) averaged over all trials were compared between groups. No significant differences were found.

Working Memory Tasks

Using two between-subject ANOVAs, scaled scores on the Digit Span and Letter Number Sequencing tasks were compared across musician groups separately. For the Digit Span task there was no main effect of group, $F(3,40)$ = .255, p = .857, η^2 = .019, however there was a trend towards a significant main effect of group for the Letter Number Sequencing task, $F(3,40)$ = 2.705, p = .058, *partial* η^2 = .169. Follow-up comparisons showed that string players (13.8) had higher scores than pianists (10.25) and that this result approached significance (p = .069). There were no significant or near significant differences for any of the other between-group comparisons.

Correlations

Correlation analyses were performed to examine the relationship between measures of musical experience to performance measures on the various tasks collapsed over all four musician groups. All significant and marginally significant correlations are shown in Table 2. Current hours of practice per week was positively correct with percent correct on the BAPT, $r(41) = .303$, $p = .024$, and Beat Synchronization task, $r(41) = .512$, $p < .001$, and negatively correlated with ITI deviation on the Rhythm Synchronization task, $r(41) = -.380$, $p = .006$. Years of lessons was negatively correlated with ITI deviation on the Rhythms Synchronization task, $r(41) = -.253$, $p = .051$, and motor variance on the Tap-Continuation task, $r(41) = -.300$, $p = .025$, and was positively correlated with percent correct on the Rhythm Synchronization task, $r(41) = .397$, $p = .004$. The number of years playing the primary instrument was positively correlated with percent correct on the Rhythm Synchronization, $r(41) = .285$, $p = .032$, and Beat Synchronization tasks, $r(41) = .229$, $p = .070$, as well as MSJerk on the Tap-Continuation task, $r(41) = .221$, $p = .077$. Age at which musicians started playing an instrument was negatively correlated with percent correct on the Rhythm Synchronization task, $r(41) = -.248$, $p = .054$. The number of years playing any instrument was positively correlated with percent correct on both the Rhythm Synchronization, $r(41) = .268$, $p = .041$, and Beat Synchronization tasks, $r(41) = .261$, $p = .046$. The combined working memory scaled score was negatively correlated with ITI deviation on the Rhythm Synchronization task, $r(41) = -.263$, $p = .042$, and positively correlated with percent correct on the Beat Synchronization task, $r(41) = .262$, $p = .043$. Performance on the BAPT was negatively correlated with ITI deviation on the Rhythm Synchronization task, $r(41) = -.579$, $p < .001$, and positively correlated with percent correct on both the Rhythm Synchronization, $r(41) = .316$, $p = .018$, and Beat Synchronization tasks, $r(41) = .405$, $p = .003$.

Discussion

The purpose of this study was to compare rhythm abilities of drummers, singers, pianists and string players. A battery of four rhythm and beat-based tasks were used to assess the effects of specific musical experience on both higher level rhythm processing and basic un-paced tapping. Various measures were compared in an attempt to tease apart the unique contributions of top-down and bottom-up processes that are thought to be involved in rhythm perception and production.

Based on a small amount of existing research showing that drummers outperform other musicians on basic rhythm tasks (Kraus et al., 2010; Repp et al., 2013), the musician groups were expected to differ on the tasks used in the current study. However, no significant differences between musician groups were found on the Rhythm Synchronization task, the Beat Synchronization task, the BAPT, or on the basic variability and kinematic measures of the Tap-Continuation task. These results indicate that a high level of training on any musical instrument or voice, results in good performance on a range of rhythm, beat and basic tapping tasks. A main effect of group was shown on the Wing-Kristofferson measures in the Tap-Continuation task. Pianists were shown to have significantly lower motor variability than the other groups. This suggests that for pianists, experience with making precisely timed finger movements, results in lower motor variability. There was a main effect of group for the timer variability measure, however follow-up comparisons did not reach significance.

These findings cannot be explained by floor or ceiling effects, as all musician groups performed in the range of other musician groups tested on these tasks and within-task comparisons showed the expected differences. Finally, these results cannot be attributed to differences in auditory working memory, as no significant differences were found between groups on these tasks. Based on the current results we conclude that general musical experience improves higher level beat and meter processing abilities, while specialized musical experience has a stronger influence on lower level time-keeping and motor timing processes.

The lack of group differences in the current study raises the question as to whether there might be performance issues for this sample of participants. However, comparing the current results to those of other studies using the same tasks (Baer et al., 2013, 2014; Bailey et al., 2010, 2012; Chen et al., 2008; Kung et al., 2012), shows that participants in the current study performed at a comparable level.

Similar performance between the musicians in the current study and musicians in previous studies using the same tasks reinforces the idea that general music experience improves rhythm abilities. Through extensive training in reading, listening to, and performing music, musicians gain a cognitive framework that allows them to parse rhythmic structures and leads to strong expectations regarding how rhythms are organized. This framework also exists in non-musicians, particularly in avid listeners, but it is developed to a higher level in musicians (Fitch, 2013; Grahn, 2012). In addition, all four groups performed equally well on the basic Tap-Continuation task, which may indicate that having a highly developed rhythm framework transfers to low-level tapping abilities. Another possibility is that experience in moving to music in a variety of ways improves the ability to tap accurately, regardless of the specific movement that one is trained in. These two possibilities cannot be dissociated in the current study however we would propose that it is a combination of both processes.

Within-Group Differences

In addition to showing comparable results to previous studies, we found that the manipulations of metrical complexity, meter and tempo affected performance in predictable ways. In both the Rhythm Synchronization and Beat Synchronization tasks, increased metrical complexity led to increased tapping variability and decreased accuracy. Similarly, manipulation of tempo in the Beat Synchronization and Tap-Continuation tasks generally showed the expected within-group results. Participants were more variable in the Beat Synchronization task at a faster tempo, indicating that it is more difficult to find and synchronize to a beat at a faster rate. In the Tap-Continuation task, mean ITIs were close to the target intervals showing that participants were able to perform the task successfully. Additionally, tapping variability, long-term drift, jerkiness, as well as motor and timing variability increased as tempo decreased, which is consistent with previous research showing that the ability to tap out intervals breaks down as the size of the interval increases (Repp & Doggett, 2007). In the Beat Synchronization task, participants had more difficulty finding and tapping to the beat when the rhythms were in triple meter compared to duple meter. This is consistent with Kung and colleagues (2013) and was expected as the majority of western music is in duple or quadruple meter. Therefore, musicians in the current study would likely have more experience playing and listening to music with duple or quadruple meters. Together these results confirm that metrical complexity and tempo affect the ability to find and synchronize to a beat as well as the ability synchronize taps to each note of a rhythm.

Likewise, results for the BAPT were consistent with previous research (i.e. Iversen & Patel, 2008). Percent correct was higher for the “on” judgements compared to the “off” judgements and participants had more difficulty when the metronome was shifted compared to when it was stretched relative to the beat. As the within-group differences were consistent with previous research for all groups on all tasks, the lack of between-group differences cannot be attributed to a failure of the task manipulations to alter performance.

Musical Experience and Sample Size

It is also possible that group differences in the current study were obscured by differences in musical experience. Comparing groups on measures of musical experience, we see that the number of years of experience with the primary instrument and amount of current practice did not differ across groups. However, drummers were lower in their number of years of lessons and higher in their age of start compared to the other groups. Age of start was only correlated with percent correct on the Rhythm Synchronization task, indicating that it was not an important predictor of rhythm abilities in this sample. The number of years of lessons was correlated with percent correct and ITI deviation on the Rhythm Synchronization task as well as motor variance on the Tap-Continuation task. This may suggest that years of lessons is a better predictor of rhythm abilities than age of start or the other MEQ measures and that drummers, although similar in terms of years of experience, had less formal training leading to reduced performance.

Finally, it is possible that the finding of no group differences results from low statistical power due to small sample sizes. However, when examining effect sizes related to the groups differences, one can see that these measures are quite low indicating that a logistically reasonable increase in sample size would not lead to significant group differences.

Between-Group differences

In the Tap-Continuation task, no group differences were found for the basic tapping variability and kinematic measures (mean ITI, detrended variance, long-term drift and MSJerk). However, using the Wing-Kristofferson model (1973) to split tapping variability into timer and motor variability resulted in significant between-group differences. Under this model, a central clock or internal timekeeper provides timing information to the peripheral motor system which implements the tapping movement. These two processes have been shown to be serial and independent and are therefore affected differently depending on the task demands and the particular experience of the participant (Baer et al., 2013, 2014; Collier & Odgen, 2004; Wing & Kristofferson, 1973). Piano players were shown to have the lowest motor variability. Out of the four groups of musicians in the current study, pianists have the most experience in making the precisely timed, discrete finger movements required in this task. It is likely that this highly task-relevant motor training has led to increased motor efficiency, thus reducing motor variability. A trend showing that timer variability was lowest for drummers may indicate that drummers, whose training focuses on producing the correct intervals and maintaining a steady beat, have developed a highly precise internal timekeeper. This highly developed internal clock may account for the differences between drummers and other musicians seen in previous studies (i.e. Kraus et al., 2010; Repp et al., 2013).

Future directions

In comparison with previous studies (Kraus et al., 2010; Repp et al., 2013), it may be surprising that the drummers did not perform better than other musician on these tasks. One possible reason for this is that the drummers, although similar to the other musicians in terms of years of experience, had less formal training overall. Although many studies have found differences in synchronization abilities between musicians and non-musicians, several studies failed to find these differences (e.g. Essens & Povel, 1985; Hove, Spivey & Krumhansl, 2010; van Vugt & Tillman, 2014). This indicates that only musicians with an exceptionally high level of rhythmic expertise show superior synchronization abilities compared to other musicians (Repp & Su, 2013). In the study by Kraus et al., (2010), drummers had more years of experience than those in the current study although they still had less experience than the other musician groups to whom they were compared.

Secondly, the beat alignment perception test (BAPT) was the only task in the current study that uniquely tested top-down rhythm processing without a motor component that could potentially obscure top-down effects. Although there was individual variability, 14 of the 44 participants (five drummers, four pianists, three singers, and two string players) responded correctly on all trials, in all conditions. This indicates that the task was too easy for these musicians which may have reduced the task's sensitivity in differentiating beat perception abilities among musician groups. Furthermore, performance on the BAPT was correlated with both measures of performance on the Rhythm Synchronization task and only one measure for the Beat Synchronization task (see Table 2). This relative lack of correlations between the BAPT and Beat Synchronization task further suggests that the BAPT is not the ideal measure for beat perception. Perhaps with a more sensitive measure of beat perception, differences between musician groups would be revealed.

Finally, a non-musician control group was not included in this study. As discussed above, researchers have shown that musicians perform better than non-musicians on rhythm and timing tasks. Specifically, studies from this lab showed superior performance of musicians compared to non-musicians on the Rhythm Synchronization and Tap-Continuation tasks used in the current study. Furthermore, the focus of this study was to look at the effect of specialized musical training on rhythm abilities by comparing different groups of musicians. However, future work may benefit from including a non-musician control group in order to confirm the superior performance of musicians compared to non-musicians on all four tasks used here.

Summary and Conclusions

To summarize, we tested drummers, pianists, singers and string players on four rhythm tasks. No differences between groups were found on the majority of these tasks indicating that general musical experience is more important than specialized, instrument-specific experience with regards to rhythm processing. As other studies have shown, extensive training in reading, listening to, and performing music leads to general improvements in rhythm processing. We did find differences between groups in central timer and peripheral motor variability on the Tap-Continuation task. This suggests that specialized training may affect specific aspects of bottom-up timing processes, but this effect only appears in the context of a basic un-paced tapping task. Together these results suggest that general musical experience is more important than specialized musical experience with regards to higher cognitive processing of rhythms, whereas low-level cognitive processes and bottom-up motor processes are affected uniquely by specialized experience.

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Table 1
Descriptive Measures and Musical Experience

	Overall (N = 44)	Drummers (N = 10)	Pianists (N = 12)	Singers (N = 12)	Strings (N = 10)
Age	22.7 (3.9)	22.1 (2.8)	23.5 (4.5)	23.3 (4.7)	21.5 (2.8)
Sex (% female)	55%	10%**	58%	67%	80%
Age of start	9.8 (4.4)	12.4 (2.8)*	8 (2.1)	10.6 (6.6)	8.3 (3.0)
Years of Lessons (primary)	9.7 (5.8)	5.5 (3.7)**	13 (3.0)	10.3 (7.9)	9.5 (4.9)
Years Playing					
Primary	12.7 (5.4)	9.8 (4.2)	15.5 (3.4)	12.4 (7.4)	13.1 (4.3)
Secondary	3.3 (3.5)	3.9 (3.8)	2.8 (2.8)	4.5 (4.4)	1.7 (2.7)
Current practice (Hours per week)					
Primary	9.9 (12.0)	15.2 (12.1)	11.1 (14.6)	5.4 (4.9)	8.1 (12.0)
Secondary	1.7 (3.1)	1.7 (2.7)	2.9 (5.14)	0.4 (0.70)	2 (2.07)

**p* = .067, ***p* < .05.

Table 2

Results of Correlation Analysis

Musical experience	**Task (measure)**	**Pearson r**	**p-value**
Age of start	RS (% correct)	-.248	.054
Years playing primary instrument	RS (% correct)	.285	.032
	BS (% correct)	.229	.070
	T-C (MSJerk)	.221	.077
Years playing total	RS (% correct)	.268	.041
	BS (% correct)	.261	.046
Years of lessons	RS (ITI deviation)	-.253	.051
	RS (% correct)	.397	.004
	T-C (motor variability)	-.300	.025
Current hours per week	RS (ITI deviation)	-.380	.006
	BS (%correct)	.512	.000
	BAPT	.303	.024
DSLNS	RS (ITI deviation)	-.263	.042
	BS (% correct)	.262	.043
BAPT	RS (ITI deviation)	-.579	.000
	RS (% correct)	.316	.018
	BS (% correct)	.405	.003

Note. DSLNS = Digit Span and Letter Number Sequencing combined scaled scores. BAPT = Beat Alignment Perception Test. RS = Rhythm Synchronization. BS = Beat Synchronization. T-C = Tap-Continuation. MSJERK = Mean Squared Jerk.

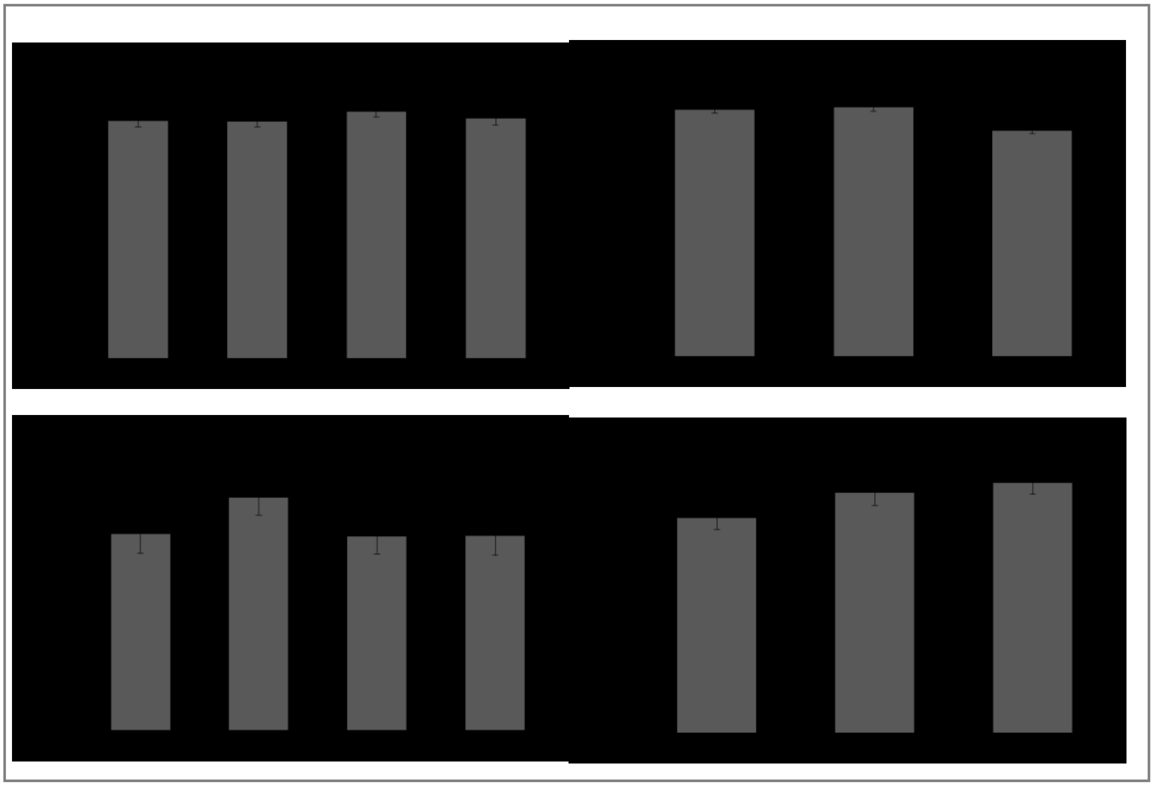

Figure 1. Performance on the Rhythm Synchronization task. A) Percentage of correct taps of the four musician groups averaged over the three levels of metrical complexity. B) Percentage of correct taps for each metrical complexity averaged over the four musician groups. C) ITI deviations (ms) of the four musician groups averaged over levels of metrical complexity. D) ITI deviations (ms) for each metrical complexity averaged over the four musician groups. * $p < .05$, ** $p < .01$.

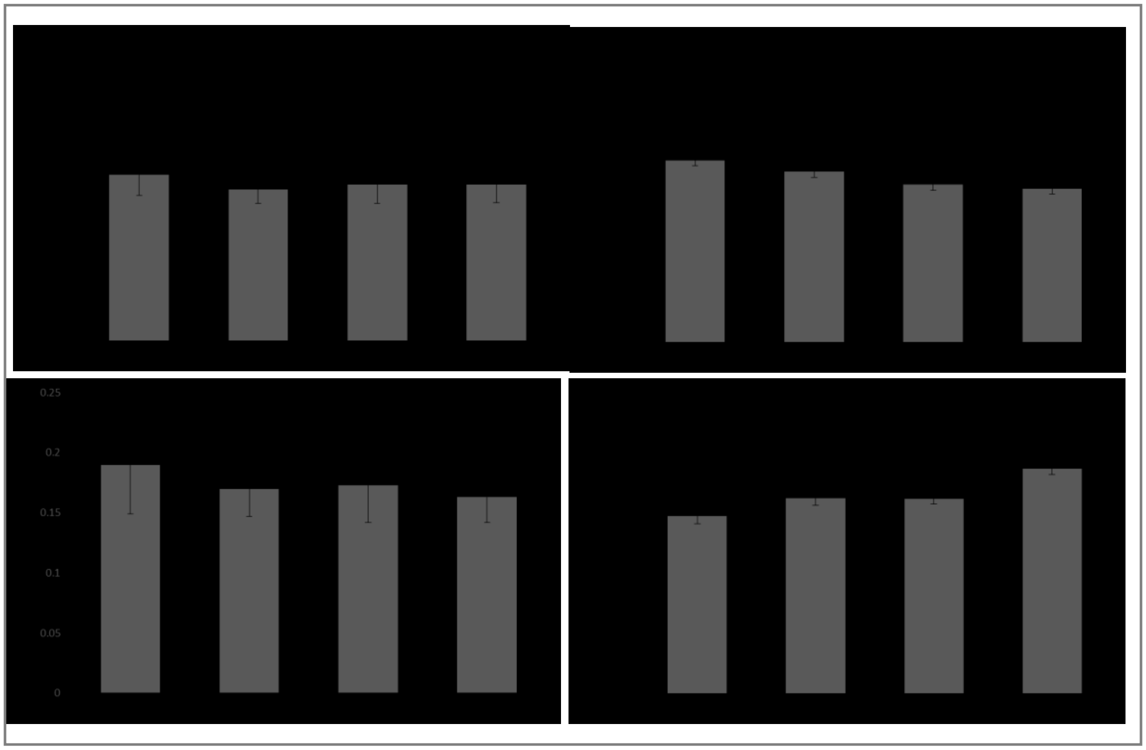

Figure 2. Performance on the Beat Synchronization task. A) Percentage of correct taps of the four musician groups averaged over the four levels of metrical complexity. B) Percent of correct taps for each metrical complexity averaged over the four musician groups. C) ITI deviations (ms) of the four musician groups averaged over the four levels of metrical complexity. D) ITI deviations (ms) for each metrical complexity averaged over the four musician groups. * $p < .05$, ** $p < .01$.

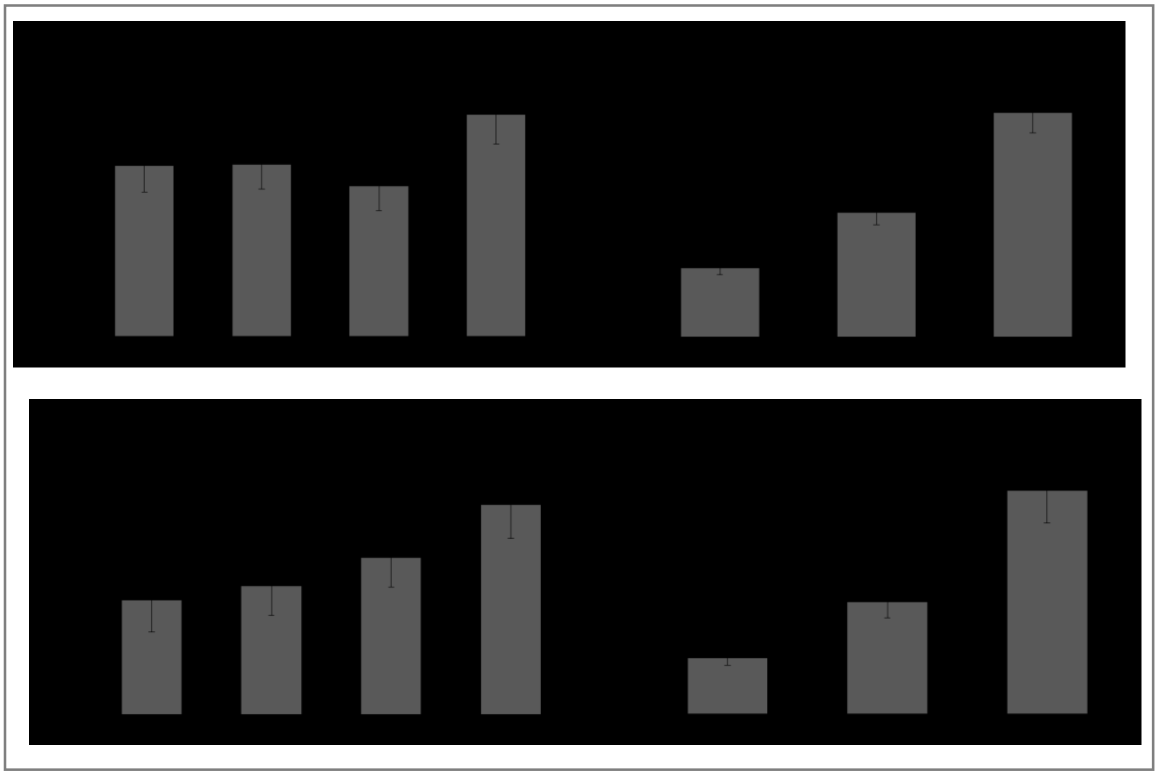

Figure 3. Variability measures for the Tap-Continuation task. A) Detrended variance of the four musician groups averaged over the four levels of metrical complexity. B) Detrended variance for each metrical complexity averaged over the four musician groups. C) Slope of the detrending line of the four musician groups averaged over the four levels of metrical complexity. D) Slope of the detrending line for each metrical complexity averaged over the four musician groups. * $p < .05$, ** $p < .01$.

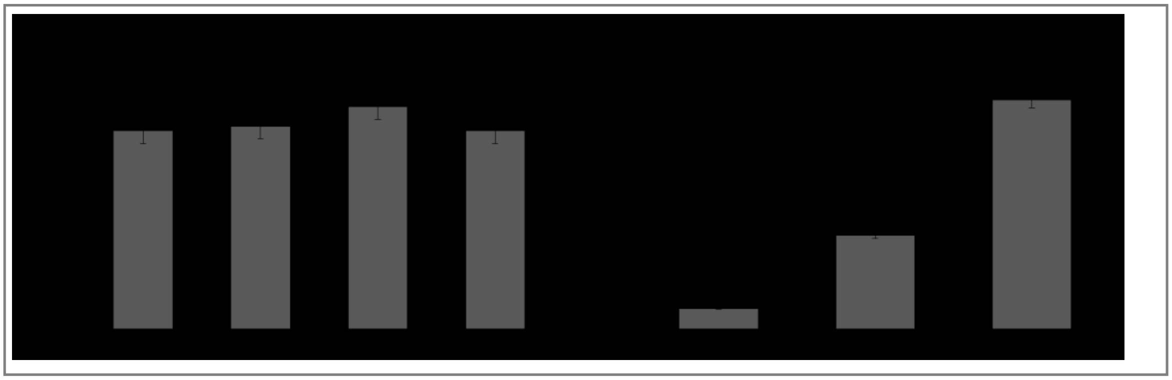

Figure 4. Kinematic measure for the Tap-Continuation task. A) Mean squared jerk of the four musician groups averaged over the four levels of metrical complexity. B) Mean squared jerk for each metrical complexity averaged over the four musician groups. * $p < .05$, ** $p < .01$

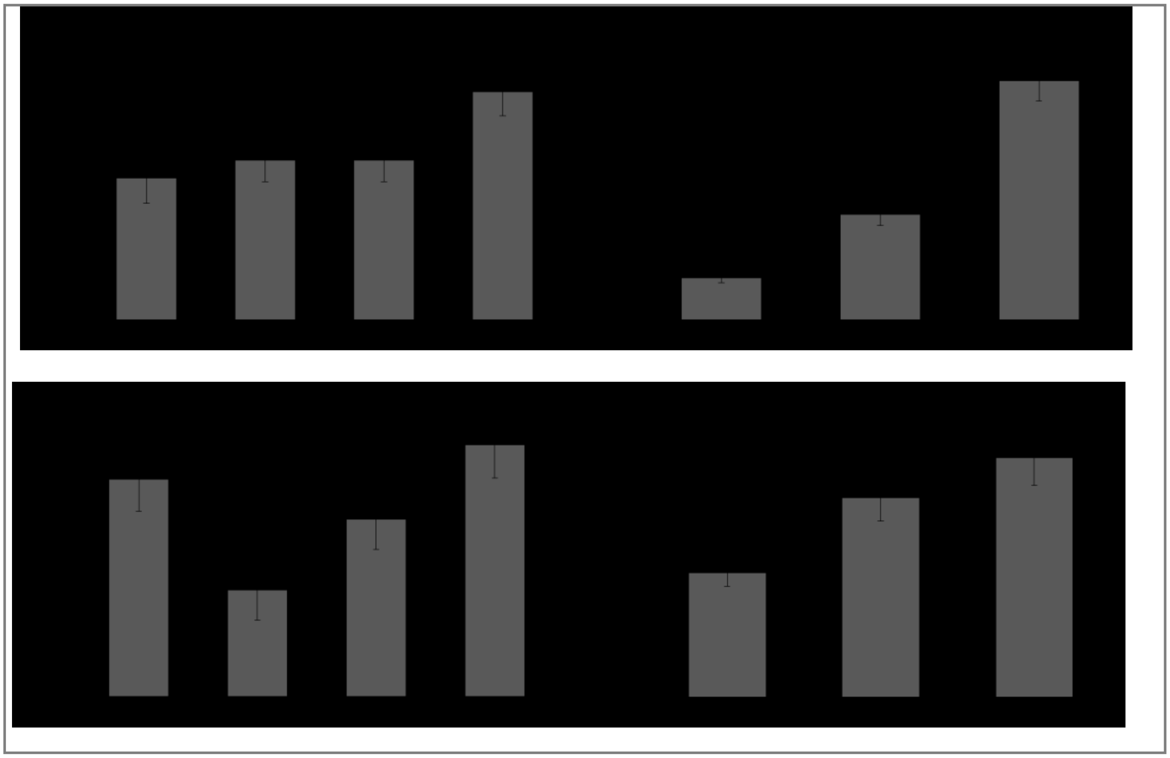

Figure 5. Wing-Kristofferson variability measures for the Tap-Continuation task. A) Timer variability of the four musician groups averaged over the four levels of metrical complexity. B) Timer variability for each metrical complexity averaged over the four musician groups. C) Motor variability of the four musician groups averaged over the four levels of metrical complexity. D) Motor variability for each metrical complexity averaged over the four musician groups. * $p < .05$, ** $p < .01$.

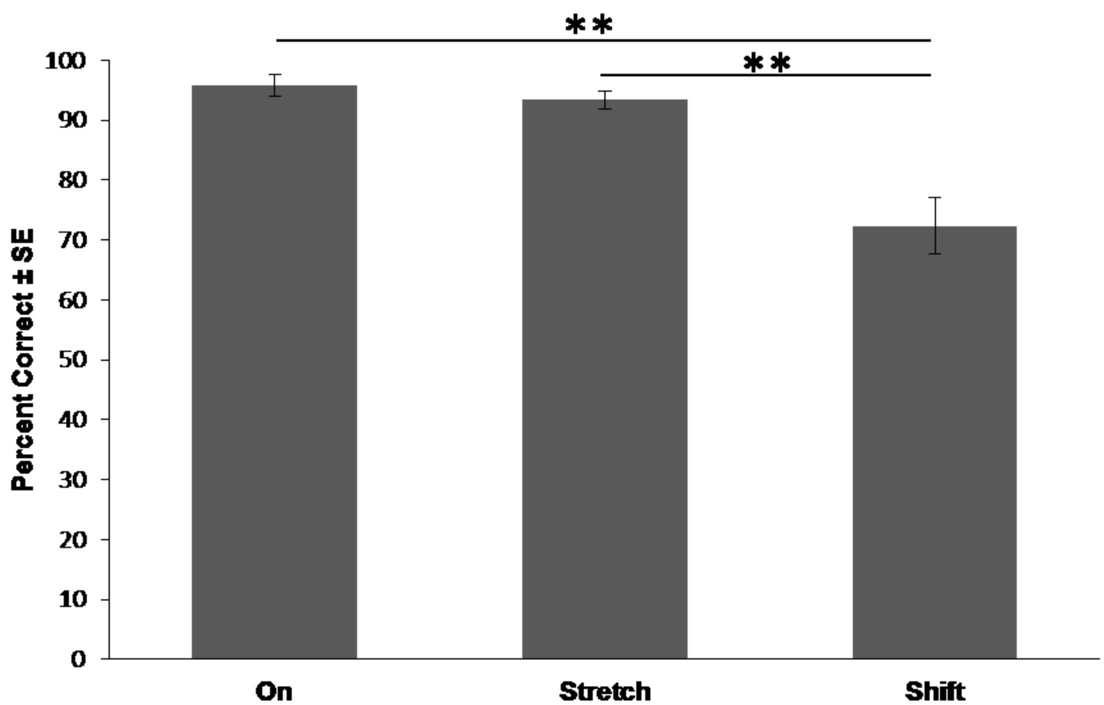

Figure 6. Percent of correct responses on Beat Alignment Perception Test. Stretch = metronome is slower than beat. Shift = metronome is phase-shifted relative to beat. * $p < .05$, ** $p < .01$.