Beat perception in 3D:

A comparative analysis between sight, sound, and touch

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Abstract

Beat perception (BP) is the uniquely human capacity to sense regularity in rhythmic sequences. Whether a beat is perceived or not varies according to how the rhythm is structured in time. ‘Metric simple’ (MS) rhythms, which are very regular rhythmic sequences, induce a robust sense of beat. ‘Metric complex’ (MC) rhythms, which are less regular, and ‘nonmetric’ (NM) rhythms, which are very irregular, do not induce BP. Most research on BP has focused on the auditory modality, where it has been shown that BP leads to better discrimination of rhythmic sequences. However, it is unclear whether BP can be reliably induced in the visual and tactile modalities. The purpose of this study was to examine whether BP occurs in response to auditory, tactile, and visual stimuli. Thirty-six participants performed a rhythm discrimination task. On each trial, a rhythm was presented twice followed by a subsequent rhythm. Participants were then required to indicate whether the subsequent rhythm was the same as or different from the original rhythm. Auditory rhythms were created from repeated tones. Visual rhythms were created from repeating visual stimuli. Tactile rhythms were ‘felt’ as vibrations on a loudspeaker. In each modality, MS, MC, and NM trials were randomly intermixed. Rhythm discrimination accuracy was measured to assess BP in each condition. BP was observed in both the tactile and auditory modalities, as evidenced by better discrimination in the MS than in the MC and NM conditions. However, no improvement for MS sequences was seen in the visual modality, resulting in a two-way interaction between modality and rhythm structure. Additionally, musicians showed better discrimination performance than non-musicians with MS rhythms, resulting in a significant interaction between musical experience and rhythm type. Results suggest that BP can be induced in the auditory and tactile modalities, but not in the visual modality.

Keywords: Beat perception, tactile, visual, auditory, rhythm

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Introduction

Precision in time perception is essential not only for normal human cognitive and motor functions, but also for the conception of a temporal reality. Therefore, humans must have mechanisms to accurately encode temporal phenomena. One mechanism, thought to be unique to humans, is called the "beat-based" timing system, which makes use of our ability to perceive regular beats in rhythm (Keller and Repp, 2005). Beat perception (BP) is the uniquely human capacity to sense underlying periodicities (the beat) in music and respond to it (Patel et al., 2005). That is, when music is perceived, listeners are able to feel a pulse-like regularity that can incite certain behaviours as tapping a foot and finger snapping.

BP is more pronounced for sequences in which there are regularly recurring onsets of time intervals in the sequence (Abecasis et al., 2005). The pattern of regularity is often termed a "metric" structure. Sequences with regular periodicities induce a strong sense of beat, and can be termed "metric simple" (MS). Some sequences are not as regular and do not induce BP. Such sequences include "metric complex" (MC) structures, which are less regular, than MS structures and "nonmetric" structures (NM), which have no regularity. The presence of BP in MS, but not in MC and NM sequences, has been corroborated by electrophysiological studies. In particular, one study measured the strength of BP with transient electrical potential shifts called event-related potentials (ERPs), and found a stronger BP measure in participants presented with MS sequences (Abecasis et al., 2005). That is, MS sequences produced larger ERPs than MC and NM sequences. ERPs are elicited in response to small intensity deviations in the sequences. The researchers compared ERP size in response to on-the-beat compared to non-beat positions and found that the amplitude of the ERP response was largest in the positions that were on-the-beat. MS and MC structures contain all the same time intervals, but in a different arrangement. The fact that MS structures incite a more robust response compared to MC and NM sequences suggests that a beat-based timing system does exist.

The scientific interest around BP is, in part, due to its role in facilitating memory for and motor performance of temporal sequences. Much of this evidence has been found in the auditory modality using sound stimuli (Patel et al., 2005). For instance, inducing BP improves accuracy in auditory tasks such as rhythm reproduction, discrimination, (Grahn and Brett, 2007), and synchronization (Patel et al., 2005). Another reason for the growing attention to this field is its potential for clinical application in motor disorders. Specific brain areas, such as the basal ganglia, which are robustly active during sound presentation of rhythms, are implicated in clinical disorders such as Parkinson's disease, raising questions about potential avenues of therapy. In Parkinson's patients, the basal ganglia are dysfunctional, significantly impeding patients' ability to accurately discriminate between regular and irregular rhythmic sequences (Grahn and Brett, 2009).

To date, work on BP has focused on the auditory modality (Grondin, 2010; Repp and Penel, 2002) and the capacity for sound stimuli to induce robust BP has been well-established. For instance, participants are able to tap to a beat more accurately when listening to highly regular auditory rhythms than to irregular auditory rhythms (Keller and Repp, 2005), and in a perceptual judgment task, participants are better able to detect shifts in auditory than in visual rhythms (Repp and Penel, 2002).

Instances of BP in other modalities, such as touch and vision, are not as well-examined. At present, it remains unclear as to whether beat perception is restricted to sound alone or if it can exist in other modalities as well. There is a clear need to supplement information that is missing in this area. Previous work has demonstrated that visual stimuli could not induce BP (Patel et al., 2005). Past studies have noted that the auditory modality outperforms the visual system in time perception tasks (Collier and Logan, 2000; Fendrich and Corballis, 2001; Repp and Penel, 2002). Additionally, previous work has been largely unsuccessful in eliciting discrimination performance that is comparably accurate as that in the auditory modality when using flashing lights (Repp and Penel, 2002).These findings, however, run counter to preliminary data analyzed at the Grahn Lab. In a recent pilot study using a different form of visual stimuli, it was observed that MS rhythms were discriminated more accurately than MC and NM rhythms, supporting the possibility of inducing BP through vision. Few studies have looked at BP via the tactile modality, although some evidence suggests that it is possible to feel the beat using tactile stimuli. In synchronization tasks, participants were able to regularly tap to a beat via purely tactile stimulation (Brochard et al., 2008).

Considering the role of BP in improving temporal processing, one would expect BP to confer an advantage if inducible in the other senses. Therefore, the apparent lack of BP in other modalities is odd. Currently, most research on BP has focused on the auditory modality, where accurate discrimination and sensorimotor synchronization with beats have been demonstrated (Grondin, 2010; Jantzen et al., 2005; Hove et al., 2010). Therefore, the purpose of this study is to examine whether BP appeared to exist in the visual and tactile modalities, and not just in the auditory modality, by measuring performance accuracy as a function of metrical structure using rhythm discrimination tasks.

Rhythm discrimination tasks are a common method to assess BP. The task requires participants to attend to and detect changes in a series of presented rhythms. Previous work indicates that BP leads to increased discrimination accuracy. Therefore, the proportion of correct responses can be used to assess BP in different conditions. We hypothesized that discrimination accuracy would be influenced by modality and rhythm type. Across modalities, we expected that the auditory modality would exhibit the highest discrimination accuracy. For rhythm type, we expected that the highest discrimination accuracy would be observed in the MS condition. While previous work suggests that significant interactions between modality and rhythm type are to be expected (with MS sequences benefitting auditory and perhaps tactile modalities, but not the visual modality), we were not predicting such an interaction based on aforementioned pilot data from the Grahn Lab.

Materials & Methods

Thirty-six participants (11 male, 25 female; age range, 18-20 years; mean of 18.5) were recruited from the UWO Psychology Research Participation Pool and were compensated one research credit for one hour of participation. Ethics approval was obtained from PREB before the experiment was run. Consent forms, letters of information, and debriefing forms were provided to participants prior to and after testing (see Appendix). Demographic information was also collected from participants to establish musical background (21 musicians, 15 non-musicians).

In a within-subjects design, participants completed discrimination tasks in three modalities: auditory, visual, and tactile. In each modality, participants completed 45 test trials of a discrimination task consisting of stimuli in that modality. Fifteen trials each of three rhythm types (MS, MC, and NM) were presented in random order. An illustration of each rhythm structure is shown in Figure 1. In each rhythm type condition, intervals were related to ratios of 1:2:3:4, where the length of “1” interval was 200ms, 233ms, or 267ms. The remaining intervals were multiples of the length of “1” interval. For instance, with “1” representing 200ms, a sequence of 11343 would have interval lengths of 200 200 600 800 600 (ms). In the MS condition, intervals were arranged such that there would be a regular onset. In the MC condition, intervals were the same as in the MS condition but were rearranged such that there was no regular onset. In the NM condition, intervals used were similar to the MC condition but used non-integer ratios of the intervals (Grahn and Brett, 2007). It is important to note that while interval lengths in the MS and MC rhythms have simple integer-ratio relationships, only the MS arrangement induces a beat. The distinction between MC and NM rhythms is not relevant to the current investigation.

Auditory rhythms were created from repeated sine tones at 440 Hz using Audacity®. Tactile rhythms were the same as the auditory rhythms, but participants 'felt' the rhythm by resting a finger on a flat surface of a loudspeaker that delivered the tones. Sound-cancelling headphones were used to deliver a masking tone at 440 Hz to control for external noise from the loudspeaker. Visual rhythms were created from repeating visual images that appeared for the specific time intervals designated by the rhythm in sequence (Figure 2). Intervals used for the timed image presentation were the same as those in the auditory condition.

In each trial, one rhythm sequence was presented twice followed by a comparison sequence, which was either identical (non-deviant) to or different (deviant) from the original rhythm. To create the deviant rhythms, two intervals in the original rhythm were transposed. Participants were then required to respond within three seconds by indicating whether the comparison sequence was deviant or non-deviant using a computer keyboard. Four practice trials preceded the test trials in each modality.

All rhythms for each modality had identical temporal specifications. Programs for stimuli presentation were designed using E-Prime® 2.0. The order in which modalities were being tested was counterbalanced across participants to control for potential order effects. Scores were analyzed using a 3 x 3 repeated measures analysis of variance (ANOVA) with the factors modality (auditory, tactile, and visual) and rhythm type (MS, MC, and NM) in SPSS. Subsequent one-way repeated measures ANOVAs and Bonferroni corrected post-hoc analyses were used to determine the nature of the significant main effects and interactions in the original 3 x 3 ANOVA.

Results

After performing a two-way repeated measures ANOVA, main effects were observed for rhythm type ($F(1, 34) = 10.751$, $p <0.01$) and for modality ($F(1, 34) = 7.874$, $p < .01$), however, these results should be interpreted with caution in light of significant two-way interactions. On average, performance in the MS condition (76% correct) was more accurate compared to performances in the MC (69% correct) and NM (72% correct) conditions. Across modalities, participants performed better, on average, when presented with auditory stimuli (77% correct) compared to when they were presented with tactile (70% correct) or visual stimuli (70% correct). Significant two-way interactions were found between rhythm type and modality ($F(1, 34) = 10.278$, $p < .01$), and between rhythm type and musical experience ($F(1, 34) = 5.586$, $p < .05$).

Auditory results

In the auditory modality, participants were significantly better able to discriminate rhythm changes in the MS condition than in the MC and NM conditions. Performance in the NM and MC conditions did not significantly differ. Results were confirmed by Bonferroni post-hoc analysis— MS versus MC: $t(2, 35) = 4.25$, $p < .001$; MS versus NM: $t(2, 35) = 4.18$, $p < .001$; MC versus NM: $t(2, 35) = .73$, $p = .47$. Differences in performance were also observed with regards to musical experience. For musicians, performance of MS rhythms was significantly more accurate than MC and NM rhythms, with scores lowest for NM rhythms. Results were confirmed by Bonferroni post-hoc tests— MS versus MC: $t(2, 20) = 3.13$, $p = .005$; MS versus NM: $t(2, 20) = 3.95$, $p = .001$; MC versus NM: $t(2, 20) = 2.52$, $p = .020$. For non-musicians, performance was significantly more accurate in the MS rhythms compared to that in the MC rhythms. However, comparisons between MS and NM rhythms and between MC and NM rhythms were not significant as indicated by Bonferroni post-hoc analysis — MS versus MC: $t(2, 14) = 2.94$, $p = .011$; MS versus NM: $t(2, 14) = 1.79$, $p = .095$; MC versus NM: $t(2, 14) = -1.54$,

$p = .145$ (Figure 3). Musically trained participants outperformed non-trained participants in the MS and MC conditions (MS: $t(2, 34) = 2.30$, $p = .03$; MC: $t(2, 34) = 3.87$, $p < .001$). Similar results were found when discrimination accuracy was converted to D prime (d') scores (Figure 4).

Tactile results

In the tactile modality, participants were significantly better at discriminating between rhythms in the MS condition than in the MC condition. However, performance was not significantly different between MS and NM conditions (although this was marginally significant), or between NM and MC conditions. Results were confirmed by Bonferroni post-hoc analysis— MS versus MC: $t(2, 35) = 3.93$, $p < .01$; MS versus NM: $t(2, 35) = 1.80$, $p = .08$; MC versus NM: $t(2, 35) = 2.06$, $p = .005$. Musicians performed significantly better in the MS condition compared to the MC and NM conditions. Post-hoc Bonferroni tests confirmed scores in the NM and MC conditions were not significantly different— MS versus MC: $t(2, 20) = 4.14$, $p = .001$; MS versus NM: $t(2, 20) = 3.17$, $p = .005$; MC versus NM: $t(2, 20) = -.88$, $p = .39$. Performance outcomes of non-musicians were somewhat unexpected, as they performed significantly better in the NM than in the MC condition ($t(2, 14) = -4.04$, $p = .001$). Performance was not significantly different in other paired comparisons— MS versus MC: $t(2, 14) = 1.61$, $p = .13$; MS versus NM: $t(2, 14) = -.35$, $p = .73$ (Figure 5). Musicians outperformed non-musicians in the MS condition: $t(2, 34) = 2.11$, $p = .042$. When converted to d' scores, a similar pattern in performance was observed (Figure 6).

Visual results

In the visual modality, there were no significant differences in performance in all conditions as depicted in Figure 7 (MS versus MC: $t(2, 35) = .93$, $p = .36$; MS versus NM: $t(2, 35) = -.41$, $p = .69$; MC versus NM: $t(2, 35) = -1.42$, $p = .17$). Discrimination performance was not affected by musical experience as confirmed by Bonferroni post-hoc analyses. In musically trained participants, performance was not significantly different in subsequent comparisons— MS versus MC: $t(2, 35) = .70$, $p = .50$; MS versus NM: $t(2, 35) = -.07$, $p = .95$; MC versus NM: $t(2, 35) = -.708$, $p = .49$. Similarly, no significant differences were found in the comparisons within non-trained participants— MS versus MC: $t(2, 35) = .59$, $p = .57$; MS versus NM: $t(2, 35) = -.49$, $p = .63$; MC versus NM: $t(2, 35) = -1.49$, $p = .16$). Conversion to d' scores parallel the pattern in performance (Figure 8).

Discussion

Previous work has long categorized BP as being restricted to auditory processing (Patel et al., 2005; Repp and Penel, 2002). In the present study, we sought to assess whether BP could be reliably induced in three modalities: auditory, tactile, and visual. To accomplish this, we required participants to perform a rhythm discrimination task with auditory, tactile, and visual stimuli. The pattern of performance across the conditions was then assessed to determine whether BP was induced or not. The indicator of BP was the presence of significantly better performance in regular rhythmic structures. Based on previous work, better performance would be expected in the MS condition relative to the MC and NM conditions. This is because even though the MS and MC rhythms contain all the same time intervals between event onsets, the intervals are arranged differently such that MC rhythms are less regular than MS rhythms, creating a controlled comparison. NM rhythms have an additional level of irregularity (the ratio relationships between the intervals is complex), in which no BP is possible.

BP was observed in the auditory and tactile modalities, as evidenced by higher discrimination accuracy scores in the MS condition than in the MC and NM conditions. BP was not observed in the visual modality, where participants' performance did not significantly differ between any of the conditions. This pattern of results led to a two-way interaction between modality and rhythm structure. That is, discrimination accuracy improvement was observed for MS rhythms relative to MC and NM rhythms in the auditory and tactile modalities, but not the visual modality. Additionally, musically trained participants showed higher discrimination accuracy scores than non-trained participants in the MS condition, resulting in a two-way interaction between musical experience and rhythm structure. This suggests that musicians benefitted more than non-musicians from BP, but only in the MS condition.

Auditory modality

BP was induced in the auditory modality as expected. Participants were best able to discriminate between rhythms when presented with sound stimuli, particularly in the MS condition compared to the MC and NM conditions (Figure 3). These results are consistent with previous studies that have observed robust BP using sound stimuli (Keller and Repp, 2005; Patel et al., 2005; Repp and Penel, 2002).

In addition to rhythm structure, musical experience also played a role in discrimination performance. Musicians performed significantly better than non-musicians in discriminating rhythm changes in the MS and in the MC conditions. It is possible that the frequent utilization of memory components and motor movements involved in musical training may have played a role in facilitating performance in musicians (Drake and Penel, 2000). In a synchronization task, Drake and Penel (2000) demonstrated that musicians were better able to organize regular structures than non-musicians over a longer period of time and that they had a more extensive beat representation of music than non-musicians.

As shown in Figure 3, the musically trained participants do not show the typically expected pattern for BP. That is, discrimination accuracy score was significantly higher in the MS condition, followed by performance in MC condition, and performance in the NM condition. We did expect that performance would be better in the MS condition than in the MC and in the

NM conditions, but not that performance in the MC condition would be significantly more accurate than performance in the NM condition. One reason may be the unequal representation of musical experience in the group, with only 13 of the 21 musicians having more than five years of musical training, with 4 of the 13 having more than 10 years of experience. Perhaps, the skew towards longer periods of training positively affected performance such that highly trained musicians were better able to tease apart more metrical structures (MS and MC rhythms) than nonmetrical structures (NM rhythms).

Tactile modality

As predicted, BP was also induced in the tactile modality. Participants were significantly better able to discriminate between tactile rhythms in the MS condition than in the MC and NM conditions. This is consistent with recent work (Brochard et al., 2008) demonstrating that BP could be induced in a non-auditory modality as touch. Brochard and colleagues (2008) observed that participants more accurately synchronized their taps to tactile MS rhythms than more irregular rhythms. The authors attributed the better synchronization to the ability of the participants to abstract metric structures from purely tactile rhythms and use it to synchronize their taps to the beat induced by such rhythms.

Musical experience also appears to influence performance in the tactile modality. Musically trained participants were significantly better able to discriminate between rhythms in the MS condition than the non-musically trained participants. However, performance in the non-musician group was unexpected in that performance was, on average, higher in the NM condition compared to the MS and MC conditions (Figure 5). While only the comparison between NM and MC conditions was significant, and not between NM and MS conditions, one would expect that NM (irregular) rhythms would be harder to discriminate than MS or MC rhythms. This is not what was observed.

One reason for this unexpected pattern might be the lack of musical training in the participants. Since musically trained participants have been shown to be more attuned to hierarchical metric structures than non-musicians (Drake and Penel, 2000), it follows that musicians would perform significantly better in the MS conditions. In the case of non-trained participants, however, this facilitation for structure may not be as strong. It is possible that, since NM structures are highly irregular, the non-trained participants were not able to accurately tease apart the rhythms accurately, and instead 'chunked' intervals together as a tactic to better encode the beat on a lower hierarchical level of organization. However, this strategy appeared to occur only for NM structures, since non-musicians still perform poorly in the MS and in the MC conditions.

Visual modality

BP was not observed in the visual modality. Performances between conditions were not significantly different. These results challenge our preliminary findings and the hypothesis that BP could be induced using this type of visual stimulus (Figure 2). It is possible that the use of an image seemingly 'rotating' in space may not be as ecologically relevant as originally thought, despite promising findings in our previous pilot study. Results here corroborate previous investigations showing no evidence of visual BP using flashing lights (Patel et al., 2005; Repp and Penel, 2002; Grondin, 2010).

Despite the lack of evidence of BP in the visual modality, some questions remain before visual BP can be conclusively ruled out. First, if BP in the visual modality does not exist, how are musicians reliably able to follow the beat of a conductor in time? Previous work has demonstrated how seeing spatio-temporal human movements can produce a sense of beat in synchronization tasks (Luck and Toiviainen, 2006; Luck and Sloboda, 2007; Luck and Sloboda, 2008) and how synchronization performance was better when visual stimuli were paired with directionally compatible motor movements of participants than with incompatible movements (Hove et al., 2010). Second, would it not be advantageous for BP to exist in the modalities that have cross-modal interactions during rhythm presentation (Grahn et al., 2011)? Grahn and colleagues (2011) demonstrated an instance of cross-modal interaction using functional magnetic resonance imaging (fMRI) to measure brain responses when participants were presented with auditory and visual rhythms. The researchers found that visual sequences produced a stronger sense of beat when preceded by auditory sequences of identical metrical structure. In effect, participants' performance with visual sequences was "primed" by the preceding auditory sequences such that BP occurred during the visual rhythm presentation. Evidence in this type of cross-modal interaction suggests an advantage for BP to exist in the visual modality. Third, what type of visual stimuli might be more ecologically valid than the type used here? Pursuing alternative dynamic forms of visual stimuli might be successful in eliciting BP. One possibility would be to explore stimuli that have biological motion that are recognized as point-lights attached to a major joint of a moving body part (Vaina et al., 2001; Vanrie and Verfaillie, 2004). A modified version of this could be to use a vertically bouncing ball, or to use a modified visual representation of a conductor's wand moving up and down, as a means of visual stimuli. Using visual stimuli that mimic biological motion may be more effective in conveying beat structure than the type of stimuli used here.

Conclusion

In this study, we have shown that BP can occur outside the auditory domain. The existence of BP in the tactile modality opens possibilities for future investigation into the anatomical representation of BP and beat generation in the subcortical areas of the brain. Are similar areas responsible for beat perception in auditory and tactile stimuli? Or, is beat perception in each modality mediated by modality-specific mechanisms?

We've also shown that performance was positively affected by musical training. Effects stemming from musical experience may be a result of active and long-term involvement of memory and motor movements related to rhythmic perception. Possible subcortical connections between the putamen, supplementary motor area, and premotor cortex in the brain have been suggested to facilitate more accurate performance in musically trained individuals (Grahn and Rowe, 2009). This, in conjunction with regular practice and engagement in encoding musical beats, may have also played a role in this facilitation.

Investigations into the method of encoding temporal information and the modality by which it is received are fundamental pursuits in the field of neuroscience. Knowing how the brain is able to "keep time" and encode temporal information from the environment is essential to understanding human cognitive and motor functions, specifically how we sense and reproduce beats. By looking at BP in a multimodal approach, we attempt to answer some of the questions about what makes us as fascinating as we are human.

Acknowledgments

I would like to thank Dr. Jessica Grahn for the opportunity to work with her in this field of research. I am deeply grateful for her much-needed insight and guidance in the process of completing this project. It is with pleasure that I also acknowledge members of the Grahn Lab (Tram Nguyen, Taylor Parrot, Dan Cameron, and Paul Armstrong) for their support and assistance in the course of implementing this study.

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APPENDIX

Letter of Information

Title of Research:

Beat perception in 3D: A comparative analysis through sight, sound, and touch.

Research Investigators:
Heather Khey Beldman (Research Assistant)
E-mail: hkhey@uwo.ca
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Dr. Jessica Grahn (Principal Investigator)
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This study is investigating the differences of beat perception through auditory, visual, and tactile modalities and is being conducted by Heather Khey Beldman and Dr. Jessica Grahn. The procedure will involve attending to a variety of sensory cues and making discriminatory responses. All of your responses will be made using a computer keyboard.

All information gathered in this study is kept confidential and anonymous and is used for research purposes only. The study will take approximately one hour to complete, and participants will receive compensation of 1 research credit for their participation. Participants are free to refuse response to any questions and are free to withdraw from the experiment at any time without loss of promised compensation. There are no known risks to participating in this study.

Upon completion of the study, the participant will have a chance to have any questions regarding the study answered. Should you have any further questions or concerns regarding this study please feel free to contact Heather Khey Beldman at hkhey@uwo.ca or Dr. Jessica Grahn at jgrahn@uwo.ca.

If you have any questions about the conduct of this study or your rights as a research participant you may contact the Director, Office of Research Ethics, The University of Western Ontario, 519-661-3036 or email at: ethics@uwo.ca.

Consent Statement

Title of Research:
Beat perception in 3D: A comparative analysis through sight, sound, and touch.

Research Investigators:
Heather Khey Beldman (hkhey@uwo.ca)

Dr. Jessica Grahn (jgrahn@uwo.ca)

I have read the Letter of Information, have had the nature of the study explained to me, and I agree to participate. All questions have been answered to my satisfaction.

______________________________	______________________________	_____________
Participant's Name (Please Print)	Participant's Signature	Date
______________________________	______________________________	_____________
Researcher's Name (Please Print)	Researcher's Signature	Date

Debriefing Form

Title of Research:
Beat perception in 3D: A comparative analysis through sight, sound, and touch.

Investigators:
Heather Khey Beldman (Honors Thesis Student)
Dr. Jessica Grahn (Principal Investigator)

Beat perception (BP) is of great scientific interest in part because of its role in facilitating memory and motor performance. Specifically, it has been shown that inducing BP in the auditory system improves accuracy in tasks of rhythm reproduction, discrimination, and synchronization (Grahn and Brett, 2007). Additionally, previous work has observed that the auditory modality outperforms the visual system in timing tasks (Patel et al., 2005). Fewer studies have looked at BP via touch, although there is some evidence that beats could potentially be perceived in the tactile modality (Brochard et al., 2008)

Generally, the evidence for beat perception tends to favour a modality specific model, where the auditory system dominates. However, while previous studies have shown that visual stimuli do not induce BP (Patel et al., 2005), recent findings from a pilot study conducted in the Grahn Lab at the University of Western Ontario (UWO) have found evidence of BP when using a particular type of visual stimulus presentation (such as the one you saw today). In addition, little is known about beat representation in the purely tactile modality other than its potential for encoding beats (Brochard et al., 2008). Considering the role of BP in temporal processing, one would anticipate BP to confer an advantage when active in other senses, which is why we do not expect to find a lack of an equally robust BP in other modalities. Therefore, the purpose of this study is to further clarify how BP differs between the auditory, visual, and tactile modalities as a function of metrical structure by measuring performance in discrimination tasks.

In the present study, we predict discrimination accuracy to be influenced in two ways. First, we expect that a main effect will be observed for modality, with the auditory modality exhibiting the highest discrimination accuracy. Second, we anticipate a main effect for rhythm type, with the highest discrimination accuracy in the "strongly metric" condition, as individuals often sense a beat in this condition.

Your responses and participation are greatly appreciated. If you have any further questions about this study please contact Heather Khey Beldman (email: hkhey@uwo.ca, number: 519 661 2111 ext. 80434) or Dr. Jessica Grahn (email: jgrahn@uwo.ca, office: NSC 229, number: 519 661 2111 ext. 84804). If you have questions about your rights as a research participant, you should contact the Director of the Office of Research Ethics at ethics@uwo.ca or 519 661 3036.

For further information on this topic, you may wish to read the following articles:

Brochard R, Touzalin P, Després O, Dufour A. 2008. Evidence of beat perception via purely tactile stimulation. Brain Res 1223:59-59-64.

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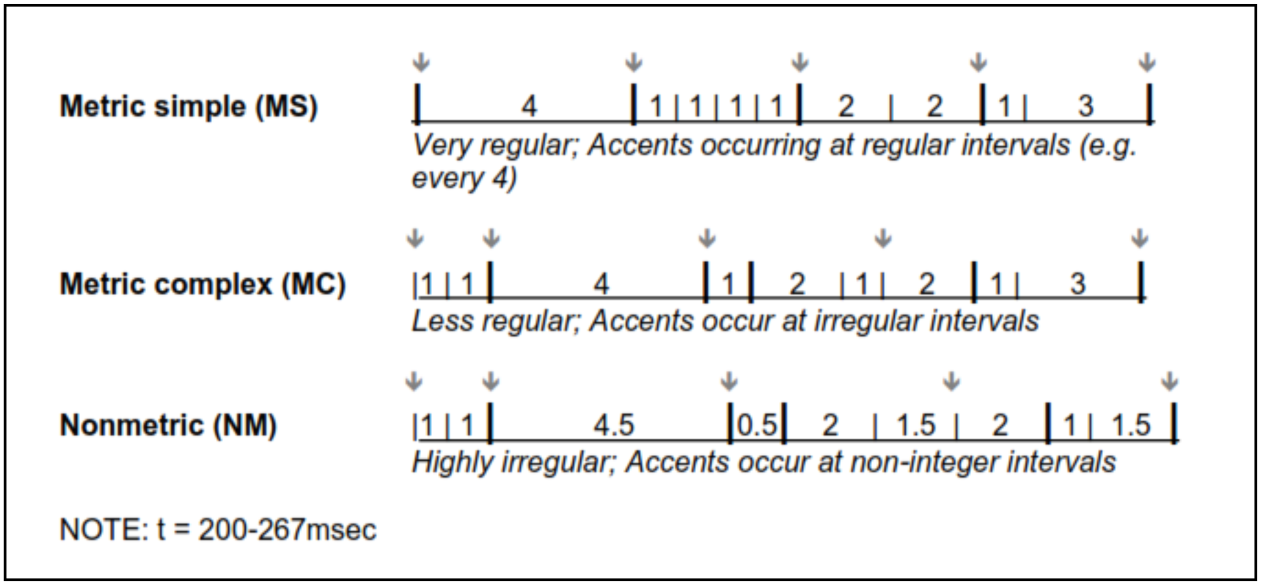

Figure 1. **An illustration of rhythmic structures**. Vertical lines represent even onsets. Arrows represent accents. Intervals range from a 200-267ms period. All rhythms are less than 2 seconds in length.

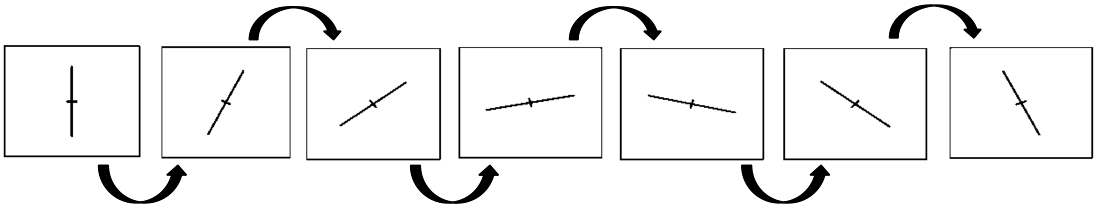

Figure 2. Visual stimuli sample. Visual rhythms were created using images presented in sequence. Timing was set and programmed using E-prime® 2.0.

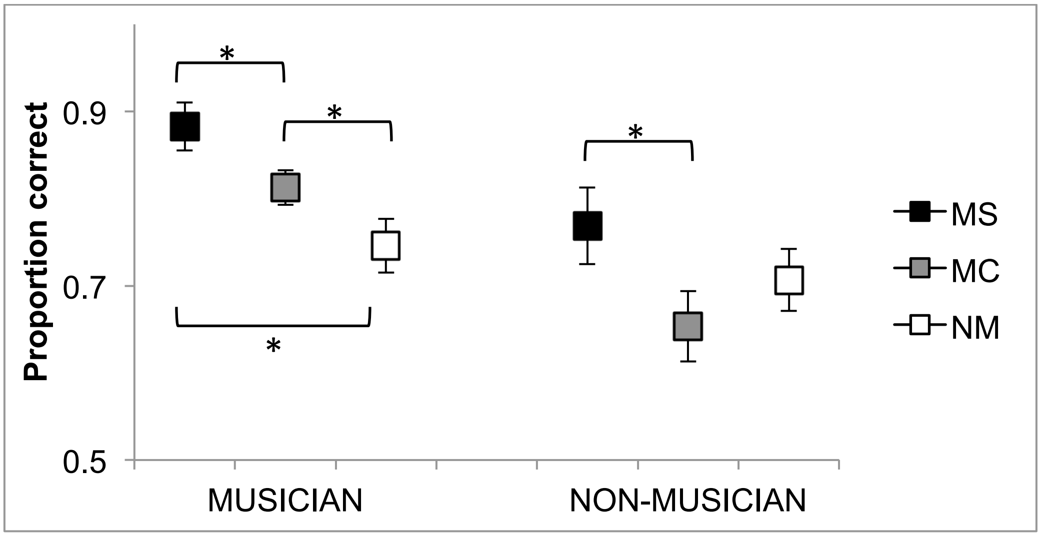

Figure 3. Mean discrimination accuracy in the auditory condition. Means are in proportion correct. Musicians and non-musicians performed significantly better in the MS condition. Error bars represent standard error of the mean. *Means are significantly different ($p < 0.05$).

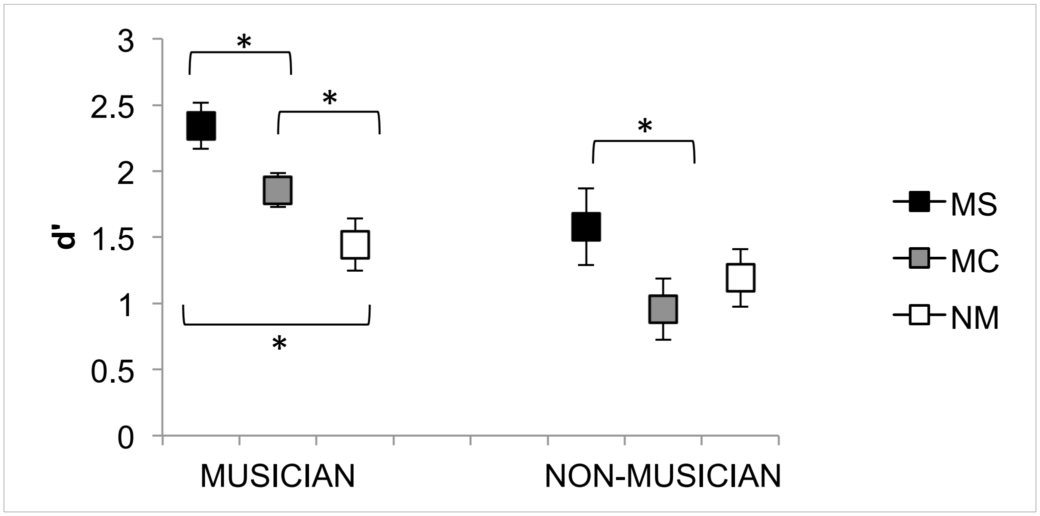

Figure 4. Mean d' scores in the auditory condition. Error bars represent standard error of the mean. *Means are significantly different ($p < 0.05$).

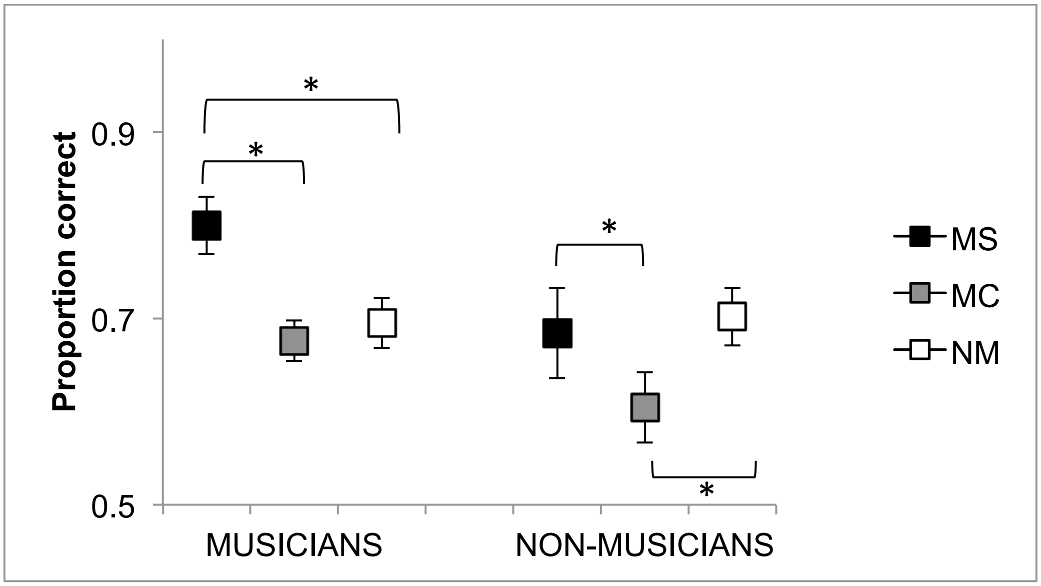

Figure 5. Mean discrimination accuracy in the tactile modality. Performance is measured in proportion correct. Musicians performed significantly better in the MS condition. Non-musicians performed significantly worse in the MC condition. Error bars represent standard error of the mean. *Means are significantly different ($p < 0.05$).

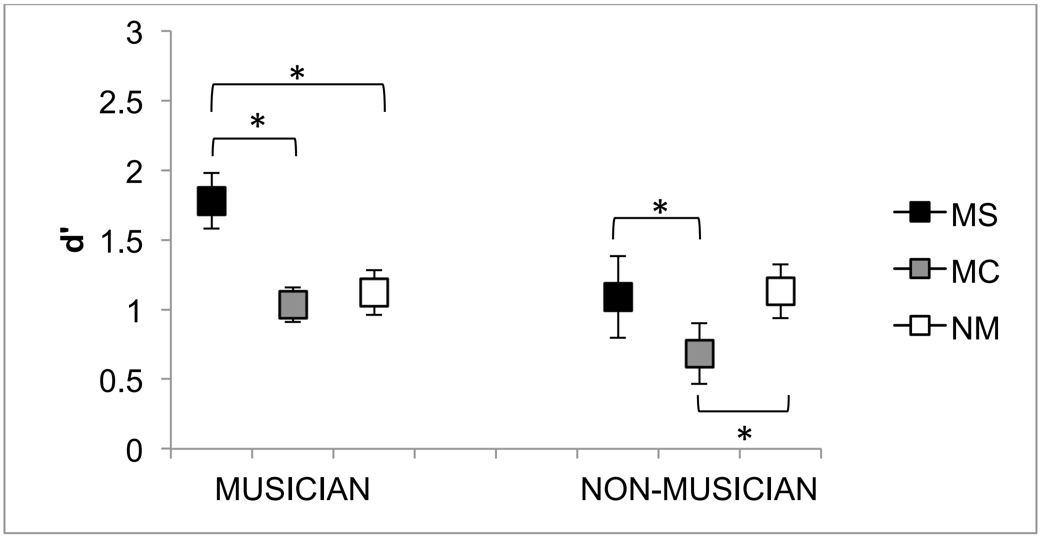

Figure 6. Mean d' scores in the tactile modality. Error bars represent standard error of the mean. *Means are significantly different ($p < 0.05$).

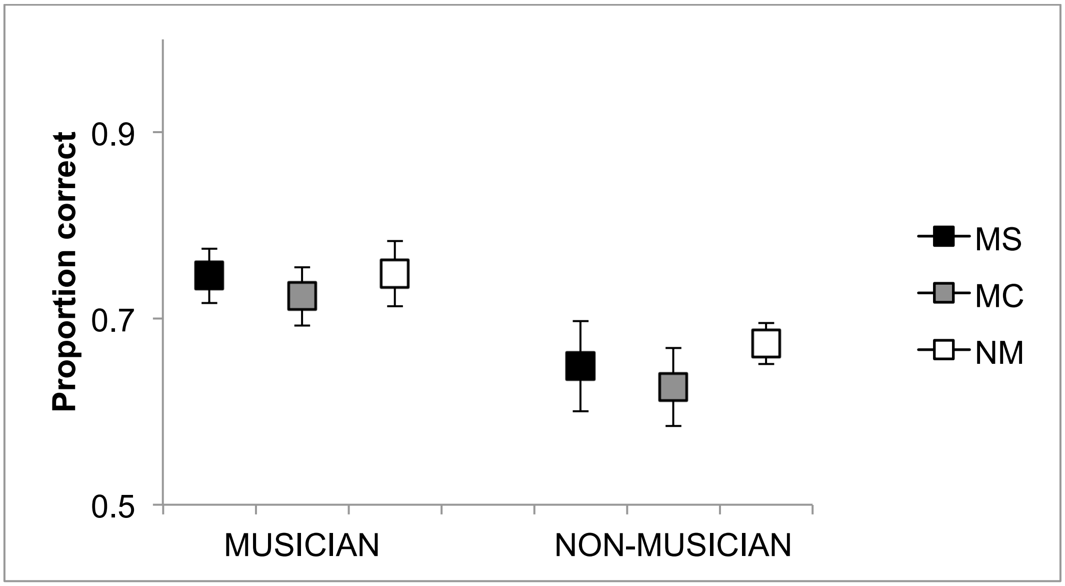

Figure 7. Mean discrimination accuracy in the visual modality. Scores are shown in proportion correct. Error bars represent standard error of the mean. Means were not significantly different.

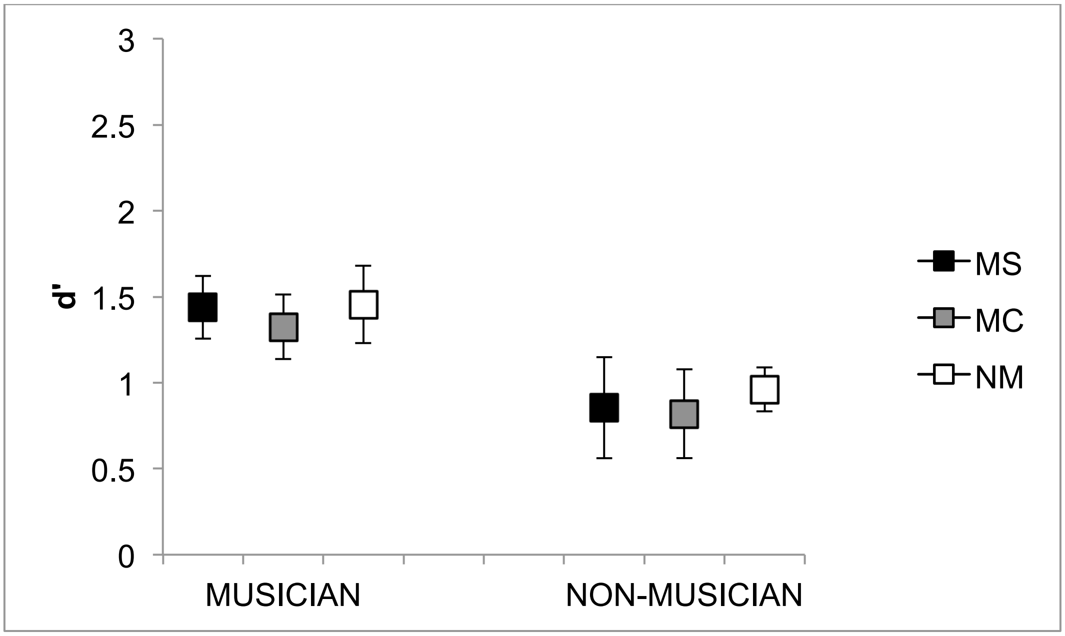

Figure 8. Mean d' scores in the visual modality. Error bars represent standard error of the mean. Means were not significantly different.