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Publication date

2012

Document Version

Final published version

Published in

Proceedings of the 12th International Conference on Music Perception and Cognition and 8th Triennial Conference of the European Society for the Cognitive Sciences of Music

[Link to publication](#)

Citation for published version (APA):

Bouwer, F., & Honing, H. (2012). Rhythmic regularity revisited: Is beat induction indeed pre-attentive? In E. Cambouropoulos, C. Tsougras, P. Mavromatis, & K. Pasiadis (Eds.), *Proceedings of the 12th International Conference on Music Perception and Cognition and 8th Triennial Conference of the European Society for the Cognitive Sciences of Music: July 23-28, 2012, Thessaloniki, Greece* (pp. 122-127). Aristotle University of Thessaloniki. http://icmpc-escom2012.web.auth.gr/files/papers/122_Proc.pdf

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Rhythmic Regularity Revisited: Is Beat Induction Indeed Pre-attentive?

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ABSTRACT

When listening to musical rhythm, regularity in time is often perceived in the form of a beat or pulse. External rhythmic events can give rise to the perception of a beat, through a process known as *beat induction*. In addition, internal processes, like long-term memory, working memory and automatic grouping can influence how we perceive a beat. Beat perception thus is an interplay between bottom-up and top-down processes. Beat perception is thought to be a very basic process. However, whether or not beat perception depends on attention is subject to debate. Some studies have shown that beat perception is a pre-attentive process, while others provide support for the view that attention is a prerequisite for beat perception. In this paper, we review the current literature on beat perception and attention. We propose a framework for future work in this area, differentiating between bottom-up and top-down processes involved in beat perception. We introduce two hypotheses about the relation between beat perception and attention. The first hypothesis entails that without attention there can be no beat induction and thus no beat perception. The second hypothesis states that beat induction is independent of attention, while attention can indirectly modulate the perception of a beat by influencing the top-down processes involved in beat perception.

I. INTRODUCTION

Rhythm refers to the organization of events in time. While rhythm can be found in many domains, musical rhythm constitutes a special case (London, 2007/2012). In musical rhythm, we tend to perceive temporal regularity in the form of “regularly recurring, precisely equivalent” psychological events (Cooper & Meyer, 1960, p. 3). These regular events are organized at different hierarchical levels. The most salient level of regularity is referred to as the beat, the pulse or the *tactus* (Lerdahl & Jackendoff, 1983). This is the level of regularity at which people tap along with the music. Higher order regularities in the form of recurrent strong and weak beats are referred to as meter and lower order regularities are termed subdivisions of the beat. Together, these components create a framework – the metrical structure – that influences the way a rhythm is perceived (Grube & Griffith, 2009) and that creates expectations about when rhythmic events are likely to occur (Honing, in press).

It has been argued that the ability to hear beat and meter is fundamental to music processing, because it allows us to make music and move in synchrony (Honing, 2012). Also, whereas the processing of other aspects of music is thought to be partly overlapping with linguistic processing, the perception of metrical structure seems to be specific to music (Patel, 2008). As such, understanding the processes underlying the perception of metrical structure is essential to understanding music processing in general.

Most research in this area has focused on the perception of the beat, the most salient level in the metrical structure. Like other musical perceptual abilities, beat perception seems to be a very basic process. Earlier, it was shown that people are remarkably apt at perceiving musical features like key and harmony without having received formal music education (Bigand & Poulin-Charronnat, 2006). The same seems to hold for beat perception. Adults without any formal musical training can tap along with a beat at a concert and infants were shown to be sensitive to the beat already at a very young age (Hannon & Johnson, 2005; Zentner & Eerola, 2010). It has even been suggested that beat perception is already functional at birth (Winkler, Háden, Ladinig, Sziller & Honing, 2009). These findings raise the question whether perceiving a beat is not only a very basic process, but possibly even a pre-attentive process, which can take place outside of our awareness. The relation between beat perception and selective attention is currently unclear. While some argue that attention is a prerequisite for beat perception (Chapin et al., 2010), others have shown that people can perceive a beat without attending to a rhythm (Ladinig, Honing, Háden & Winkler, 2009).

In this paper, we will present an overview of recent work concerning the relation between beat perception and attention. First, we will highlight some of the proposed mechanisms of beat perception. Next, we will review the current literature on beat perception and attention and provide possible explanations for conflicting findings. Finally, we will propose a framework for future work examining the relation between beat perception and attention. Please note that when using the term perception, as in beat perception, we refer to the wide range of processes involved in decoding sensory information, independent of whether or not these processes become available to conscious experience.

II. BEAT PERCEPTION

A. Beat Perception and Sensory Input

External auditory events occurring at regularly spaced moments in time can give rise to the perception of a beat through a process known as *beat induction*. Beat induction is guided by structured accents in various forms and thus depends largely on bottom-up, sensory input. We perceive tones with a high intensity and tones that are a high point in a melody as accented. Accents can also be purely temporal. For example, we tend to hear an isolated tone and the second of two consecutive tones as accented (Povel & Essens, 1985).

It is important to note that beat is a psychological concept, and as such, not necessarily present in the sound. Once a beat is induced, it is stable over time and resistant to change. This is very apparent from the existence of syncopated rhythms, in

which the perception of a beat is unaffected by the presence of conflicting sensory information (Longuet-Higgins & Lee, 1984). However, if the evidence is strong enough, we are likely to adjust the phase and period of the endogenous regularity we perceive to the structure of the external accents, a process known as rhythmic entrainment (Grahn, 2009b).

B. Beat Perception and Internal Processes

Beat perception is not only guided by external events, but can also be influenced by internal processes. This makes it possible to perceive a beat in rhythms in which the frequency of the beat is not present in the sound (Chapin et al., 2010). Beat perception as such is often the result of an interplay between bottom-up and top-down processes. Several processes that are not solely depending on sensory input are likely to influence how the beat is perceived.

First, long-term memory in the form of prolonged exposure to culturally specific metrical structures has been shown to shape our perception of a rhythm (Hannon & Trehub, 2005). Second, working memory has been implicated in perceiving ambiguous and syncopated rhythms. We can actively project a metrical structure onto an ambiguous rhythm, making it possible that two physically identical rhythms can be perceived as different (Iversen, Repp & Patel, 2009). In a similar fashion, an ambiguous rhythm can be heard as syncopated or not, depending on our interpretation (Honing, 2012). When a rhythm contains strong syncopations, it has been shown that maintaining the perception of a beat involves frontal lobe activity (Chapin et al., 2010; Vuust, Roepstorff, Wallentin, Mouridsen, & Østergaard, 2006), also suggesting a role for working memory. A third process that might contribute to beat perception is known as *subjective rhythmicization* (Abecasis, Brochard, Granot & Drake, 2005). This term refers to our tendency to automatically group rhythmic events in groups of two, hearing an isochronous sequence as a succession of stronger and weaker tones (Potter, Fenwick, Abecasis & Brochard, 2009).

Thus, together with sensory input, internal processes like long-term memory, working memory and automatic grouping determine how a beat is perceived. Their influence could range from a direct effect on how the sensory input is processed, to an effect on the process of beat induction, to an influence on the perception of the beat, once it has been established. The internal processes mentioned here are of a very diverse nature, making it likely that they have an effect at different levels of processing. Thus, how exactly internal processes and sensory input interact in beat perception remains to be specified. Figure 1 shows a schematic diagram of the processes involved in the perception of a beat.

C. Beat Perception and Dynamic Attending

Dynamic Attending Theory (DAT) explains beat perception as regular fluctuations in attentional energy over time (Drake, Jones & Baruch, 2000; Large & Jones, 1999). On the beat, attentional energy is heightened, leading to enhanced processing of events on the beat compared to events that fall on weak metrical positions. Also, the regular fluctuations in attentional energy create expectations for when events are likely to occur (Large & Jones). At a neural level, DAT has been linked to regular oscillations entrained to the beat (Large, 2008). Empirical support for DAT comes from

behavioural studies showing a processing benefit for events on the beat (Large & Jones) and more recently from neuroimaging studies showing that high frequency neural oscillations reflect rhythmical expectation (Iversen et al., 2009; Snyder & Large, 2005; Zanto, Large, Fuchs & Kelso, 2005). In the aforementioned studies, the subjects' attention was always directed towards the auditory rhythm. Thus, the relation between the fluctuation in attentional energy and selective attention, and therefore the relation between beat perception and selective attention remains unspecified.

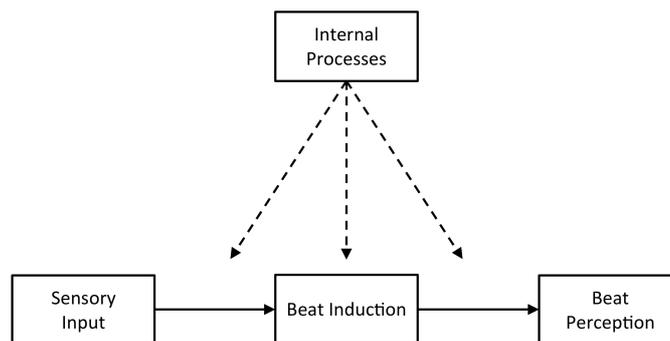


Figure 1. Schematic diagram of the processes involved in the perception of a beat. Sensory input with a regular accent structure leads to beat induction and thus, beat perception. This process can be influenced by several internal factors. At present, we leave these factors and the level of their effect unspecified.

III. BEAT PERCEPTION AND ATTENTION

D. Measuring Pre-Attentive Processes

Whether or not the perception of a beat depends on selective attention has been addressed by several studies using mismatch negativity (MMN) as an index of metrical expectations (Geiser, Sandmann, Jäncke, & Meyer, 2010; Geiser, Ziegler, Jäncke & Meyer, 2009; Ladinig et al., 2009; Vuust, Østergaard, Pallesen, Bailey, & Roepstorff, 2009). MMN is a negative deflection in the EEG signal at a latency of around 150 ms that is known to be independent of attention (Näätänen, Paavilainen, Rinne, & Alho, 2007; Sussman, 2007; Winkler, 2007). MMN is thought to be elicited when a previously established regularity is violated. The auditory system continuously extracts regularities from the environment that create expectations for incoming sensory information. As such, the auditory system has a predictive nature. When incoming information does not match the prediction, an error signal in the form of an MMN is generated (Bendixen, Schröger & Winkler, 2009). It is assumed that when an MMN is elicited, the brain has detected a deviation, which also indicates that a regularity preceding it has been extracted. The amplitude and latency of the MMN response depend on the magnitude of the violation (Näätänen et al.; Schröger & Winkler, 1995). MMN can therefore be used as an index of the saliency of a deviant. Because MMN has been linked to regularity detection and the formation of expectations, it could be useful in examining metrical expectations (Honing, 2012).

E. Evidence for Pre-Attentive Beat Perception

Winkler et al. (2009) provided support for pre-attentive beat perception in newborns using an MMN paradigm. Sleeping newborns were presented with a varying rhythm, consisting of five different patterns. These patterns were based on a standard rock rhythm of eight consecutive sounds, organized in a two-four bar. In different positions, sounds were omitted to create variety in the rhythm. Regularity was established by four different standard patterns (S1-S4) that were all strictly metrical. In these patterns, omissions only occurred in metrically weak positions, leaving the metrical structure undisturbed. The regularity induced by the standards was violated by one deviant pattern (D1). In this deviant, the omission coincided with the first beat of the bar, creating a strong syncopation. Omissions thus occurred in both standards and deviants. Winkler et al. therefore reasoned that an omission in itself was not a regularity violation. Only when an omission was on the beat it could be considered an unexpected event. Results showed that an MMN was elicited by the omission in pattern D1, indicating that the auditory system indeed regarded the omissions on the beat as unexpected. Winkler et al. concluded from these results that subjects could differentiate between omissions in weak and strong metrical positions without attending to the rhythm. This was viewed as support for pre-attentive beat perception in newborns.

Ladinig et al. (2009) used the same stimuli to examine pre-attentive perception of metrical structure in adults. In addition to the five patterns used by Winkler et al. (2009) they introduced a second deviant (D2). Whereas in pattern D1 the first beat of the bar was omitted, in pattern D2, the second beat of the bar was omitted. Because the first beat of the bar is theoretically a more salient position than the second beat, the syncopation created by D2 was thought to be weaker than the syncopation created by D1. Thus, this study looked at the perception of strong and weak beats, a higher level in the metrical hierarchy. Results showed that an MMN was elicited by both deviants, indicating that like newborns, adults differentiated between omissions in weak and strong metrical positions, while attending elsewhere. A direct comparison of the response to D1 and D2 showed that the latency of the response to D1 was slightly shorter than the latency of the response to D2. No difference in amplitude of the MMN to D1 and D2 was found (Ladinig, Honing, Håden and Winkler, 2011). Both amplitude and latency are viewed as indexes of the magnitude of a deviation (Näätänen et al., 2007; Winkler, 2007). The fact that only one of these two measures was affected by the strength of the omitted beat makes it difficult to draw any conclusions regarding pre-attentive meter perception.

A potential flaw in the design used by both Ladinig et al. (2009) and Winkler et al. (2009) is that the sound in metrically strong positions differed from the sound in metrically weak positions. The beat, which was omitted in D1 and D2, was marked by a bass drum sound concurrent with a hi-hat sound. However, the positions that were omitted in the standards consisted of only a hi-hat sound. The standards were regular events, making up 90 percent of the total patterns presented, while only 10 percent of the patterns were deviant patterns. This means that the omission of a hi-hat sound was a regular event, while the omission of a bass drum sound was a

rare event and therefore possibly unexpected. Thus, the omissions in the deviants could not only be differentiated from the omissions in the standards because of their metrical position, but also because a different sound was omitted (for a similar critique, see Winkler et al.). The elicitation of an MMN could therefore possibly be attributed to factors other than beat perception.

In addition, Ladinig et al. (2009) and Winkler et al. (2009) did not test the assumption that the patterns were represented as a whole in the MMN system, instead of as eight separate tones. Previously, it has been shown that the auditory system does not always recognize a pattern consisting of multiple sounds as a whole. When a pattern is perceived as individual sounds instead of as a whole, tones that belong to a regular pattern at a larger timescale can be perceived as irregular on a small timescale (Sussman, Winkler, Huotilainen, Ritter, & Näätänen, 2002). Nevertheless, if the presentation rate of a stimulus is fast enough, the auditory system can automatically group successive tones together, perceiving them as a single pattern instead of individual tones (Sussman & Gumenyuk, 2005). The stimuli used by Ladinig et al. were presented at a rate of 150 ms per tone, which was faster than the rate at which Sussman and Gumenyuk found integration of successive tones. However, the patterns used by Ladinig et al. were longer than the patterns used by Sussman and Gumenyuk both in time and number of tones. This leaves open the possibility that the auditory system processed the patterns used by Ladinig et al. and Winkler et al. as eight separate tones, rather than as a single pattern. In this case, every omission could have been perceived as unexpected and could have elicited an MMN.

Thus, two alternative explanations are possible for the results found by Ladinig et al. (2009) and Winkler et al. (2009). First, the MMN response could be due to differences in the sounds that were omitted in standard and deviant patterns. Second, the MMN could be the simple response to an omission. Either interpretation would weaken the assumption that the paradigm used in these studies indeed probes beat perception.

Geiser et al. (2010) provided additional evidence for pre-attentive beat perception. They used rhythmic stimuli with temporal accents to induce a beat, circumventing the issues with acoustic differences between sounds. Subjects listened to these rhythms while attending to a silenced movie. Deviants in the form of sound increments could occur in two positions in the rhythm, either on the beat or on a subdivision of the beat, the latter being a metrically weak position. An MMN was elicited by all deviants. The amplitude of the MMN to deviants in weak metrical positions was larger than the amplitude of the MMN to deviants in strong metrical positions. This suggests that subjects differentiated between different metrical positions and that subjects perceived the beat while attending elsewhere.

While their conclusions are similar, two discrepancies between the results of Ladinig et al. (2009) and Geiser et al. (2010) must be noted. First, Ladinig et al. found a latency difference between the MMN responses to deviants in different metrical positions but no amplitude difference. By contrast, Geiser et al. found an amplitude difference but no latency difference. These conflicting findings and the lack of an effect in the amplitudes of the responses on the one hand (Ladinig et al.) and in the latency of the responses on the other hand

(Geiser et al.) question the reliability of the results.

Second, Ladinig et al. (2009) proposed that unexpected events in strong metrical positions were more salient than unexpected events in weak metrical positions. However, Geiser et al. (2010) showed that the response to unexpected events was bigger in weak metrical positions than in strong metrical positions. This difference can easily be explained by the nature of the unexpected events. Whereas Ladinig et al. used sound decrements (in the form of omissions) as deviants, Geiser et al. used sound increments. In a metrical structure, louder tones are expected at stronger metrical positions. Thus, a sound increment is more unexpected in weak metrical positions (Geiser et al.), while a sound decrement is more unexpected in strong metrical positions (Ladinig et al.). While this explanation might make intuitive sense, it is not in agreement with DAT. According to DAT, because of the peak in attentional energy, processing is enhanced on the beat. This is regardless of the nature of the event and would predict a larger response to unexpected events in strong metrical positions than weak metrical positions, exactly opposite to the results of Geiser et al.

F. Evidence against Pre-Attentive Beat Perception

In an fMRI study, Chapin et al. (2010) provided evidence against the pre-attentive perception of beat. They used highly syncopated rhythms that, contrary to the stimuli used by Ladinig et al. (2009) and Geiser et al. (2010), contained no sensory cues for the metrical structure. When subjects attended to these rhythms, an increase in activity in the basal ganglia, a subcortical structure associated with beat perception (Grahn, 2009a), was found. Without attention however, listening to the rhythms did not induce activity in the basal ganglia. Chapin et al. concluded that attention is needed for the perception of a beat when listening to a complex rhythm, which does not contain energy at the pulse frequency.

Geiser et al. (2009) also found support against pre-attentive beat perception. In an unattended paradigm, they found that violations of rhythmic expectation elicited an MMN, while violations of metrical expectation did not. They concluded that beat perception is not a pre-attentive process. However, the stimuli they used were exactly the same as the stimuli used by Geiser et al. (2010), who showed that a beat can be perceived pre-attentively. Confusingly, the results of these two highly similar studies thus seem to suggest exactly the opposite, one showing that beat perception is pre-attentive and the other showing it is not.

To summarize, studies concerning beat perception and attention have yielded conflicting results. Experiments addressing some of the issues mentioned above are currently underway in our lab and will be reported elsewhere. Below, we propose two hypotheses to guide future research on the relation between beat perception and selective attention.

IV. A FRAMEWORK FOR STUDYING BEAT PERCEPTION AND ATTENTION

The first hypothesis assumes that without attention there cannot be beat perception (Hypothesis A). Woldorff et al. (1993) have shown that selective attention can enhance early processing of an auditory signal. Attention has also been associated with far-reaching feedforward activity (Lamme, 2010). Therefore, Hypothesis A states that selective attention

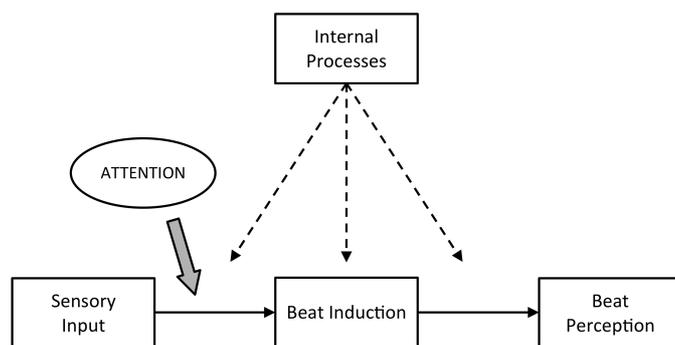


Figure 2a. Hypothesis A: beat induction and perception depend on attention. If attention is necessary for the information flow from sensory input to the mechanisms involved in beat induction, the latter will not occur in the absence of attention.

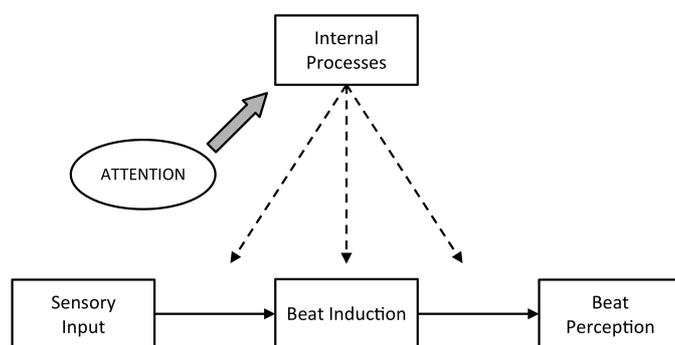


Figure 2b. Hypothesis B: beat perception does not depend on attention, but can be modulated by attention indirectly. In this case, beat induction is a pre-attentive process, but the internal processes affecting beat perception depend (to a certain extent) on attention.

is necessary to enhance processing of an auditory rhythm in order for beat induction to take place. Without attention, activity associated with a rhythm is not processed deeply enough to induce a beat and therefore, no beat is perceived. Hypothesis A is depicted in Figure 2a.

The second possibility is that beat induction is independent of attention. This is in accordance with the view that the auditory system is an intelligent system that can extract regularity from the acoustic environment without attending to it (Nääätänen, Astikainen, Ruusuvirta, & Huotilainen, 2010). However, the internal processes we mentioned as likely candidates to influence beat perception, long-term memory, working memory and automatic grouping, might be affected by the presence or absence of attention. Thus, Hypothesis B states that beat perception does not need attention, though it can be indirectly modulated by it. This hypothesis is depicted in Figure 2b.

As discussed earlier, it is still unclear how the different internal processes affect beat perception. Therefore, we do not specify which of these processes is affected by attention. Hence, we regard the framework depicted in Figure 2 as a starting point for further research, rather than a conclusive model. Both hypotheses provide testable predictions regarding beat perception and attention.

First, to test Hypothesis A, future research should focus on controlling acoustic factors more stringent. Hypothesis A suggests that there can be no beat perception without attention. This is contrary to the conclusions of Ladinig et al. (2009) and Geiser et al. (2010). However, as discussed above, the results of Ladinig et al. could well be explained by acoustic factors, while the results of Geiser et al. are contrary to predictions made by DAT. In addition, as discussed, the reliability of the results found by Ladinig et al. and Geiser et al. can be questioned. If the perception of a beat in response to clear external cues can be shown in a pre-attentive paradigm, while controlling for acoustic factors, Hypothesis A will have been refuted.

Second, to test Hypothesis B, future research should examine beat perception with stimuli that contain no external cues for a metrical structure. Chapin et al. (2010) found no evidence of beat perception in the absence of attention using highly syncopated rhythms. It could be argued that these stimuli indeed did not contain any external cues for a metrical structure. However, it is more likely that the patterns used by Chapin et al. in fact did contain cues for a metrical structure, but that this would be a metrical structure that changed rapidly over time. This would probably have yielded a very unstable perception of the beat, which could explain the lack of basal ganglia activity. Therefore, to test Hypothesis B, stimuli must be used that are less syncopated, since syncopation in the absence of other external cues could be interpreted as an external cue favouring a conflicting metrical structure.

Examining beat perception in the absence of external cues can also aid in unravelling the different internal processes affecting beat perception. While working memory processes are likely to depend on selective attention, automatic grouping could possibly function without attention. Thus, by using rhythmic stimuli that depend more or less on the different internal processes mentioned here, attention may be used as a tool to differentiate between these processes. Finally, research on these issues should be extended to the perception of different levels in the hierarchy of the metrical structure, as it is still unclear whether beat perception entails the same processes as the perception of meter and subdivisions of the beat.

V. CONCLUSION

In summary, we have proposed two different ways in which selective attention could affect the perception of a beat. In one case, beat induction is not pre-attentive, while in the other case, it is. We have provided directions and testable hypotheses for future research. Ultimately, this has to clarify whether beat perception is not only a very basic process and fundamental to music processing, but also pre-attentive.

ACKNOWLEDGMENTS

This research was supported by the Research Priority Area "Brain & Cognition" of the University of Amsterdam. Henkjan Honing is supported by the Hendrik Muller chair designated on behalf of the Royal Netherlands Academy of Arts and Sciences (KNAW). We thank Titia van Zuijlen and Gábor Háden for their help in preparing this manuscript.

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