The auditory temporal attending theory revisited

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Background. The temporal attending theory predicts that tone sequences presented at a regular rhythm entrain attentional oscillations and thereby facilitate the processing of sounds presented in phase with this rhythm (Jones et al., 2002). During the past decade the theory of auditory temporal attending has become widely popular (140 ISI citations by July 2014) and has inspired both music psychology as well as neuroscience research. The aim of the current study was to replicate the findings of Jones et al. (2002).

Method. The original paradigm is a pitch comparison task in which two tones - an initial standard tone and the last tone of a longer series, named the comparison tone - have to be compared. In between the two, distractor tones with variable pitch are presented at a regular sequence. A comparison tone presented in phase with the entrained rhythm is hypothesized to lead to better behavioral performance, thus higher task accuracy, compared to comparison tones presented at unexpected early or late intervals. Four different variations of the original paradigm were created and 106 participants were tested in total. The Goldsmiths Musical Sophistication Index (Gold-MSI) was included in all but the first experiment to test the influence of musicality on task performance.

Results and Conclusion. Over all four experiments only 38 of the 106 participants showed the desired pattern of an inverted U-shaped profile in task accuracy, and in none of the four variations did the group average effects replicate the pattern reported by Jones et al., (2002). However, evidence for a relationship between musicality and overall behavioral performance was found. Our results question the validity of the pitch comparison task for the study of auditory temporal attending.

Many natural sounds can be characterized to some degree by temporal regularity or periodicity. Previous research investigating temporal expectations has found evidence for facilitated motor behavior (Sanabria, Capizzi, & Correa, 2011) as well as improved discrimination ability (Rohenkohl, Carvo, Wyart, & Nobre, 2012) in response to temporally anticipated events. Temporal expectations are considered to be created exogenously when the input dynamics have a nonrandom temporal pattern, as for example in speech or music (Jones, 2010; Nobre, Correa, & Coull, 2007).

In the visual modality, evidence for the formation of expectations, was investigated by Mathewson, Fabiani, Gratton, Beck, & Lleras (2010) who showed that sensory entrainment can help to perceive otherwise masked stimuli. In the auditory modality, attention in time is reflected for instance in musical expectancies. Since auditory patterns unfold over time, the role of temporal expectancies as caused by stimulus timing can be considered crucial for auditory processing (Barnes & Jones, 2000). Indeed, various studies exist demonstrating that temporally expected sounds are preferentially processed (Lange & Röder, 2006; Lange 2009).

The observation of preferential processing was first addressed by the auditory temporal attending theory, which predicts that tone sequences presented at a regular rhythm entrain attentional oscillations and thus facilitate the processing of sounds presented in phase with this rhythm (Jones, Moynihan, MacKenzie, & Puente, 2002). During the past decade the auditory temporal attending theory has become widely popular both in neuroscience and music psychology research. However, in the study of Jones et al. (2002), the standard pitch was repeated once as the final distractor tone (for illustration see Figure 1). This manipulation was aimed at making the task less difficult, thus boosting task performance. In our view this repetition raises important methodological concerns as the task might be performed without perceiving distractor regularity. To overcome this methodological concern, we modified the paradigm and conducted four experiments aiming to replicate the findings.

Method

Participants

In total 106 normal hearing subjects aged 19 – 38 (73 female, *M* = 24.1, *SD* = 3.1; Experiment 1: *N* = 40, Experiment 2: *N* = 22, Experiment 3: *N* = 22, Experiment 4: *N* = 22) participated in the four experiments after providing written informed consent. All of them were right-handed, reported no history of neurological psychiatric diseases and none of the participants reported possessing absolute pitch. In Experiment 1 each subject had less than 6 years of formal musical training (*M* = 2.43, *SD* = 1.92). In Experiments 2 to 4 musicality was assessed with the Goldsmiths Musical Sophistication Index (General Musical Sophistication Factor, range = 33 – 108, *M* = 69, *SD* = 16). The study was approved by the local ethics committee.

Task

The general task is a pitch comparison task, where an initial tone (standard, 150 ms) has to be compared to a final tone (comparison, 150 ms) presented at the same, higher or lower pitch level (semitone difference; chance-level 33%). Between the standard and comparison tone a series of eight distractor tones (d1 to d8, 60 ms) is presented with a constant stimulus-onset asynchrony (SOA) of 600 ms (Experiment 1) or 500 ms (Experiment 2 to 4). Importantly, the comparison tone can be presented either at the expected SOA, in phase with the regular distractor sequence, or earlier or later (Experiment 1: 76 ms, Experiment 2 to 4: 63 ms). A comparison at an expected time interval is hypothesized to lead to better behavioral performance (task accuracy) than comparison tones occurring at unexpected early or late intervals. In the original paradigm, the standard tone was repeated as the last distractor tone.

Modifications

Experiment1. Repetition of standard tone as first two distractor tones.

Experiment2. Individual threshold of standard tone, 100 ms to 250 ms, in steps of 25 ms as determined by a staircase procedure.

Experiment3. Individual threshold of standard tone and shortening of comparison tone (100 ms).

Experiment4. Individual threshold of standard tone. Further, distractor tones were accompanied by metronome clicks and a 500 ms break after the standard tone was included.

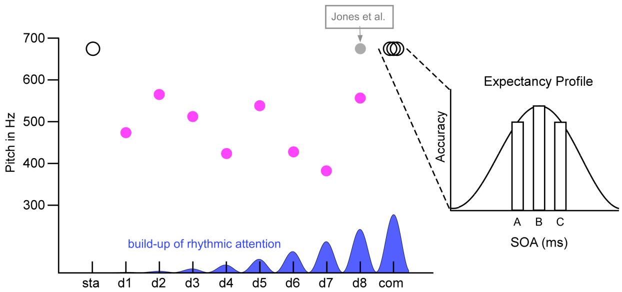

Figure 1. Comparison between standard tone and comparison tone (semitone difference). In-between, a series of eight distractor tones with variable pitch is presented at a constant SOA (600 ms / 500 ms). Intervening distractor tones varied randomly within three semitones centered on 659 Hz if the standard tone was 415 Hz, 440 Hz, or 466 Hz. Correspondingly, distractor tones varied in a range of three semitones and were centered on 440 Hz if the standard tone was 622 Hz, 659 Hz, or 698 Hz. The comparison tone is either presented in phase with the rhythm, or earlier or later (SOAs were 524 ms, 600 ms, and 676 ms for Experiment 1, and 437 ms, 500 ms, and 563 ms in Experiment 2 to 4 respectively).

Results

Across all four experiments only 38 out of 106 subjects showed the desired inverted U-shaped profile (Experiment 1: 17, Experiment 2: 7; Experiment 3: 5; Experiment 4: 9). Regarding the temporal manipulation no significant effects were found in any of the experiments. However, there was a systematic relationship between task accuracy and musical sophistication (Gold-MSI) in experiments 2 and 3 (Experiment 2: $r(20) = .63$, $p < .01$; Experiment 3: $r(20) = .61$, $p < .01$; Experiment 4: $r(20) = .34$, $p = .12$).

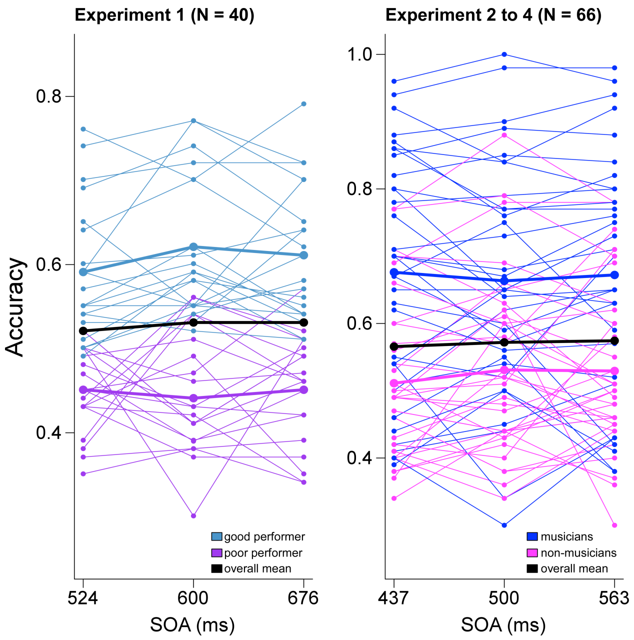

Figure 2. Individual profiles for task accuracy as well as the average performance. Left: Individual accuracy profiles for Experiment 1, subjects divided into good and poor performers. Right: Individual accuracy profiles for Experiments 2 to 4, subjects divided into musicians and non-musicians as determined via a median split on the General Musical Sophistication Factor. Not that chance was 33%.

Discussion

In none of the four variations did the group average effects replicate the findings of Jones et al. (2002). Thus, we found no behavioral effect that participants performed better at the pitch discrimination task when the comparison tone was presented at a temporally expected versus unexpected time. However, evidence for a relationship between musicality and overall task accuracy suggests that musicians in general performed the task better than non-musicians – suggesting that the variance in musicality was large enough to detect inter-individual differences.

The crucial manipulation in this experiment is the shift of the comparison tone in the time domain, leading to expected and unexpected comparison tones. However, the participants are required to judge whether the comparison tone is higher, lower or the same. Thus, their decision is based on the pitch rather than the time. One important implication arising from our findings is that the theory of auditory temporal attending may not be generalized to other judgments such as the pitch domain, but rather appears specific to time judgments as previously shown by Barnes and Jones (2002) as well as Large and Jones (1999). Further, the pitch comparison task requires a strong working memory component that might interfere with the auditory attentional entrainment as induced by the regular distractor sequence, which is thought to represent a stimulus-driven, bottom-up selective attention mechanism.

Taken together the results of all four experiments suggest that the pitch comparison task is not well suited to investigate the theory of auditory temporal attending.

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