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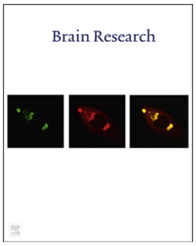

Research Report

The auditory dynamic attending theory revisited: A closer look at the pitch comparison task

Anna-Katharina R. Bauer[a,*], *Manuela Jaeger*[a,b], *Jeremy D. Thorne*[a], *Alexandra Bendixen*[b,c,d], *Stefan Debener*[a,b,c]

[a]*Neuropsychology Lab, Department of Psychology, European Medical School, University of Oldenburg, Oldenburg, Germany*
[b]*Research Center Neurosensory Science, University of Oldenburg, Oldenburg, Germany*
[c]*Cluster of Excellence Hearing4all, University of Oldenburg, Oldenburg, Germany*
[d]*Auditory Psychophysiology Lab, Department of Psychology, European Medical School, University of Oldenburg, Oldenburg, Germany*

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ABSTRACT

The dynamic attending theory as originally proposed by Jones, 1976. Psychol. Rev. 83(5), 323–355 posits that tone sequences presented at a regular rhythm entrain attentional oscillations and thereby facilitate the processing of sounds presented in phase with this rhythm. The increased interest in neural correlates of dynamic attending requires robust behavioral indicators of the phenomenon. Here we aimed to replicate and complement the most prominent experimental implementation of dynamic attending (Jones et al., 2002. Psychol. Sci. 13(4), 313–319). The paradigm uses a pitch comparison task in which two tones, the initial and the last of a longer series, have to be compared. In-between the two, distractor tones with variable pitch are presented, at a regular pace. A comparison tone presented in phase with the entrained rhythm is hypothesized to lead to better behavioral performance. Aiming for a conceptual replication, four different variations of the original paradigm were created which were followed by an exact replication attempt. Across all five experiments, only 40 of the 140 tested participants showed the hypothesized pattern of an inverted U-shaped profile in task accuracy, and the group average effects did not replicate the pattern reported by Jones et al., 2002. Psychol. Sci. 13(4), 313–319 in any of the five experiments. However, clear evidence for a relationship between musicality and overall behavioral performance was found. This study casts doubt on the suitability of the pitch comparison task for demonstrating auditory dynamic attending. We discuss alternative tasks that have been shown to support dynamic attending theory, thus lending themselves more readily to studying its neural correlates.

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*correspondence to: Neuropsychology Lab, Department of Psychology, Carl von Ossietzky University Oldenburg, Ammerländer Heerstraße 114-118, D-26129 Oldenburg, Germany. Fax: +49 411 798 5522.
E-mail address: katharina.bauer@uni-oldenburg.de (A.-K. Bauer).

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1. Introduction

Many sounds in our environment can be characterized to some degree by temporal regularity or periodicity, such as speech or music. Perceiving regularities is beneficial for understanding the acoustic information (Arnal and Giraud, 2012) and for increasing its perceptual coherence so that it stands out from other concurrent information (for a recent overview see Bendixen, 2014; Winkler et al., 2009). Temporally regular (i.e., rhythmic) stimulation has been shown to induce strong temporal expectations for upcoming events (Jones, 2010; Mathewson et al., 2010; Schroeder and Lakatos, 2009). Such expectations are considered to be created exogenously when the input dynamics have a nonrandom temporal pattern (Nobre et al., 2007). Previous research investigating temporal expectations has found evidence for facilitated motor behavior (Sanabria et al., 2011) as well as improved discrimination ability (Rohenkohl et al., 2012) in response to temporally anticipated events. 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 and Jones, 2000). Indeed, various studies demonstrate that temporally expected sounds are preferentially processed (e.g., Lange and Röder, 2006; Lange et al., 2003; Lange, 2009).

The concept of preferential processing was first described by the auditory dynamic attending theory (Jones and Boltz, 1989; Jones, 1976), 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 et al., 2002; Large and Jones, 1999). The neural substrate underlying this preferred processing is thought to be the ongoing neural oscillations that can be entrained by rhythmic stimuli and thus align their temporal dynamics to external patterns (Calderone et al., 2014; Thorne et al., 2011; for a recent review see: Henry and Herrmann, 2014). The term entrainment in general relates to one oscillator falling into step with another. Whereas *sensory entrainment* refers to the regular presentation of a series of sensory stimuli that entrain for example attentional oscillations, *neural entrainment* on the other hand relates to neural oscillations falling into step with a sequence of temporally regular events, such as a series of sensory stimuli (e.g., Henry and Obleser, 2012). As neural entrainment can optimize neural excitability to be high (or low) when a stimulus is expected (Arnal and Giraud, 2012; Lakatos et al., 2008, 2013), this mechanism can explain why predictable stimuli are more easily perceived than random, unpredictable stimuli (Barnes and Jones, 2000; Jones et al., 2002; Large and Jones, 1999; Mathewson et al., 2010; Rohenkohl et al., 2012). Interestingly, entrainment has also been proposed to underlie selective attention in the context of multiple concurrent stimulus streams (Lakatos et al., 2013; Schroeder and Lakatos, 2009).

Partly driven by uncovering such neural correlates and mechanisms of temporal attention, the dynamic attending theory (Jones, 1976) has experienced an upsurge in research interest and activity. One particular experimental implementation of dynamic attending by Jones et al. (2002) has become widely popular both in neuroscience and music psychology research during the past decade. In neuroscience the conceptual fit of the dynamic attending theory framework to the idea of neural entrainment has been observed, as stimulus events occurring at excitable phases of entrained neural oscillations are for example more likely to be detected or be responded to more quickly (Cravo et al., 2013; Henry and Herrmann, 2014; Schroeder and Lakatos, 2009; Stefanics et al., 2010). Henry and Herrmann (2014) further suggested that low-frequency oscillations in the delta-theta range might reflect correlates of the attentional oscillation, and that the excitable phase of neural oscillations might correspond to the peak of the attentional pulse in the dynamic attending theory framework.

Music psychology research on the other hand has used the idea of dynamic attending as the basis of an experimental approach to investigate the impact of rhythmicity on auditory processing. Accordingly, the Jones et al. (2002) paper has been widely cited (163 citations in Web of Knowledge and 251 citations in Google Scholar as of March, 2015). This suggests that the paradigm described therein gives a promising research tool for further studies on dynamic attending and its neural correlates. In the present study, we set out to test the robustness of this paradigm.

The original paradigm by Jones et al. (2002), which is illustrated in Fig. 1A, is a pitch comparison task, where an initial tone (standard) has to be compared to a final tone (comparison), presented at the same, higher or lower pitch level (not illustrated in Fig. 1A). Between the standard and comparison tones, a series of eight intervening tones (distractors) is presented with a constant stimulus-onset-asynchrony (SOA) of 600 ms, evoking a temporal expectancy. Importantly, the comparison tone can be presented either at the expected SOA (i.e., in phase with the distractor sequence), or earlier or later, thus out of phase (for a detailed description see Section 4.3). The dynamic attending theory predicts that task performance is on average better in trials when the comparison tone is in phase with the presented rhythm, as compared to either type of out-of-phase presentation (early or late). This leads to an inverted U-shaped expectancy profile describing the dependence of task performance on presentation time of the comparison tone. Further, the results were extended by Jones et al. (2002) in a second experiment by showing that the effect of an inverted U-shaped profile could be extrapolated into the future by inserting a silent cycle after the last distractor appearance.

However, in the study of Jones et al. (2002), the standard pitch was repeated once as the final distractor tone (for illustration see Fig. 1A). According to Jones et al. (2002) this manipulation was aimed at making the task less difficult, thus boosting task performance and additionally preventing spurious biasing from the pitch difference between the last distractor and the comparison tone. In our view this repetition raises important methodological concerns. The pitch-comparison task requires the pitch of the standard tone to be stored in memory, while the pitches of the intervening sequence are ignored, after which the comparison tone is then compared to the standard tone. Yet, if the last distractor tone is identical to the standard tone, there is no need for memory storage or even attention to the standard and consequently no need to suppress the intervening tones. Further, if the last distractor is beneficial for task performance it