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# Influence of mantra meditation on intensity mismatch negativity

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## Abstract

Studies investigating the effects of focused attention (FA) meditation on mismatch negativity (MMN) have produced inconsistent and conflicting findings, highlighting the need for well-powered studies exploring different meditation styles to fully understand MMN modulation. Addressing methodological concerns from prior research, the current study specifically examines expertise in mantra meditation, a form of focused attention meditation, utilizing a sufficiently powered investigation with an intensity MMN paradigm. This paradigm incorporates both louder and quieter deviant stimuli to assess the impact of meditation expertise and to discern whether meditation-induced MMN effects reflect higher-order cognitive processes or result from sensory adaptation. While the results suggest a trend of higher MMN in novices compared to experts, statistical significance was not achieved. The modest effect observed is likely due to using novices as an active control group, benefiting from enhanced attention skills fostered by the repetitive speech and rhythmic nature inherent in mantra meditation. The consistent unidirectional polarity shift in event-related potential (ERP) responses to both types of deviant stimuli implies that intensity-related MMN effects may not solely depend on loudness-dependent modulation of sensory components but could signify higher-order deviance detection. Complementary findings from eLORETA source localization indicate consistent bilateral temporal and frontal cortex activity, with lower amplitudes observed in the expert mantra meditator group compared to novices.

**Keywords: mantra meditation; mismatch negativity; intensity transition; attention; deviance detection**

## Introduction

Meditation has garnered considerable attention in research for its positive effects on mental health, cognition, and emotion regulation, supported by neurophysiological data (Brefczynski-Lewis, Lutz, Schaefer, Levinson, & Davidson, 2007; Cahn & Polich, 2006; Fox et al., 2016; Manna et al., 2010; Tracy Brandmeyer, 2019; Deolindo et al., 2020). Despite the documented correlation between meditation and cognitive improvement, only a limited number of studies have explored its impact on mismatch negativity (MMN), an event-related potential (ERP) reflecting the brain's ability to recognize unexpected auditory changes (Na & Paavilainen, 2007). While such abilities are desirable, a heightened sensitivity to unexpected acoustic changes can impair the task at hand.

Previous studies examining the impact of focused attention (FA) meditation on MMN have produced varied and inconclusive results. Enhanced MMN has been observed during focused attention meditation, both as a state and trait effect in both expert and novice practitioners (Srinivasan & Baijal, 2007; Braboszcz & Delorme, 2011; Biedermann et al., 2016; Fucci et al., 2018). However, recent research questions the reliability of these findings, emphasizing the need for adequately powered studies (Fucci, Poublan-Couzardot, Abdoun, & Lutz, 2022). A well-powered replication study (Fucci et al., 2022) attempted to replicate previous findings but found no significant effects, attributing potential issues to publication bias and low sample size. Conversely, the study also acknowledges that inconsistent results across studies could be attributed to differences in the complexity of the MMN task, which may involve emotional contexts and multiple testing blocks leading to auditory fatigue that could mask the effects. Despite null effects reported by Fucci et al. (2022), a recent large-scale study by Medvedev et al. (2022), showing a decrease in MMN amplitude during traditional Buddhist meditation, has reignited interest in the debate. Consequently, given the inconclusive nature of previous studies, there is now a call for well-powered investigations exploring diverse FA meditation styles (Fucci et al., 2022; Medvedev et al., 2022).

The current study contributes to this debate by employing a robust and well-powered design using an intensity oddball paradigm to investigate a form of FA meditation known as mantra meditation, which has received minimal attention in the literature. This ancient practice, rooted in various spiritual traditions spanning thousands of years, involves the vocalized or sub-vocalized repetition of words or sounds known as "mantras". The term "mantra" is derived from the Sanskrit words "manas" (mind) and "tra" (instrument), representing a mental tool that promotes calmness and mental tranquility without requiring intense concentration (Feuerstein, 2003). Mantra meditation involves silently or audibly repeating a mantra to reduce mind-wandering and induce mental calm (Travis, 2014; Fox et al., 2016). The practice of mantra meditation exhibits nuances across different traditions. For example, some traditions like Kundalini Yoga and ACEM involve silently repeating words, while others, such as Hare Krishna Chanting or Vedic chanting (Perry et al., 2021; Braboszcz et al., 2010), vocally repeat meaningful phrases within a spiritual context. Mantra meditation gained popularity in the Western world during the 1960s and 1970s through practices like transcendental meditation and Hare Krishna meditation. The current study examines trait effects by comparing

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individuals with long-term experience in mantra meditation to novices in this practice.

We hypothesized that if mantra meditation practice leads to a heightened ability to sustain attention, experts will demonstrate higher concentration on the distractor task than novices. Consequently, we anticipate that attentional drift in experts will be less pronounced than in novices. Based on the literature suggesting that higher MMN occurs when attention is more focused on background tones (Erlbeck, Kübler, Kotchoubey, & Veser, 2014; E. S. Sussman, 2013; Huotilainen, Ritter, Naatanen, & Sussman, 2002), we predict that novices will exhibit greater MMN compared to experts, reflecting increased attentional drift towards background tones.

Further, to properly interpret the sensory or cognitive nature of MMN effects, our study utilizes the intensity oddball paradigm instead of the commonly used frequency oddball paradigm. The decision to employ the intensity oddball paradigm was deliberate due to the prevalence of the frequency oddball paradigm in traditional MMN studies, which resulted in uncertainties regarding the effects on higher-order cognition or sensory adaptation. Interpreting difference waveforms as definitive evidence of deviance detection in these paradigms is challenging because standard and deviant stimuli differ in physical properties, and these differences can impact event-related potential (ERP) amplitudes. To address potential confounding variables, we utilized an intensity oddball paradigm where both standard and deviant stimuli share the same frequency but differ in intensity. It's important to acknowledge that a recent study (O'Reilly, 2021) showed that the absence of auditory ERP in response to a louder deviant stimulus does not rule out the possibility that variations in loudness can influence intensity MMN. The loudness dependence of auditory evoked potentials (LDAEP) is a well-established phenomenon in neurophysiology, indicating that changes in sound loudness can modulate ERP amplitudes. Given these considerations, we included both quieter and louder deviant stimuli in our auditory presentation, all maintaining the same frequency.This approach aims to investigate whether the effects of mantra meditation on MMN are associated with sensory modulation or higher-order cognitive processes (O'Reilly & O'Reilly, 2021; E. S. Sussman, Chen, Sussman-Fort, & Dinces, 2014; E. Sussman, Ritter, & Vaughan, 1999).

We hypothesized that if MMN were solely an artifact of intensity transitions, we would observe opposite-direction shifts in amplitude for quieter and louder deviant waveforms compared to standard waveforms (intensity transition hypothesis). Alternatively, if deviance detection is the cause, we would observe a consistent unidirectional shift in amplitude away from the standard waveform for both types of deviants. The current study is possibly the first meditation study to use an intensity MMN paradigm, avoiding sensory confounds of the frequency paradigm.

# Methods

## Participants

The study was approved by the Ethical Review Board of the Indian Institute of Technology Bombay, and consent information was taken from each participant before data collection. Using a priori analysis, we estimated a sample size of twenty-seven per group for two within-factor and two between-group factor mixed analysis of variance to achieve a power of 0.95 and an effect size of 0.25 (Cohen, 1988). This sample size is also comparable with a sample size used by Fucci et al. (2022). The experimental group consists of expert meditators with at least ten years of experience (7,200 hours of practice). Unlike previous studies, active control was used in the current study to balance extraneous factors such as the novelty of meditation tasks, motivation, and interest, which could confound the results. Active control groups included novices familiar with mantra meditation but practiced it occasionally, once or twice a week. Moreover, the experimental (M = 31.3 years, SD = 3.8 years)and control groups (M = 30.6 years, SD = 6.1 years) were matched on age. All of the subjects had normal hearing and no history of psychiatric or other neurological disorders.

## Experiment procedure and task apparatus

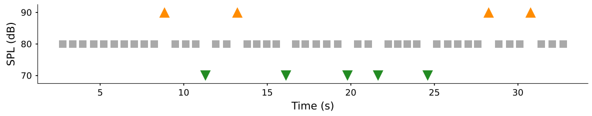

Figure 1: Intensity oddball paradigm. Standards (80 db, gray square), louder deviant (90 dB, orange triangle) and quieter deviant (70 db, green triangle)

We employed a cross-sectional study design to investigate the effect of meditation expertise on MMN. The experimental group comprised seasoned meditators with a minimum of ten years of experience, while the control group consisted of age-matched novices with less than one year of training. To ensure consistency with previous MMN studies on meditation and facilitate result comparisons, we designated electrode Fz as the region of interest for all our statistical analyses. In this study, participants underwent an intensity oddball paradigm featuring intensity variations with louder and quieter deviants (Figure 1). The intensity oddball paradigm featured 80 dB standard stimuli (constituting 80 percent of the stimuli) and 70 dB and 90 dB deviant stimuli (each making up 10 percent of the stimuli). These stimuli were presented with an interstimulus interval ranging from 450 to 550 ms. Two oddball blocks, each consisting of 500 stimuli, were employed, with 100 being louder (90 dB) deviants and 100 quieter (70 dB) deviants. To ensure precision, the auditory stimuli underwent calibration using a sound level meter (SL4012; Mextech Technologies, India) and were then delivered through bilateral loudspeakers (Logitech Stereo Speakers Z120, model:

S-00109; manufacturer: Logitech, made in China). These loudspeakers were positioned 80 cm in front of the subject and 40 cm on either side of their midline. Throughout the experiment, participants were engaged in a fixation task designed to divert their attention away from incoming sounds. Both the stimuli and event codes were generated using a custom script. The distractor task was designed to ensure that participants remained attentive and alert throughout the task. A cross was displayed on the screen, and it underwent random color changes from black to grey or vice versa. Participants were tasked with mentally keeping track of how many times the cross changed its color during the task block. Importantly, participants were explicitly instructed to maintain this count mentally and refrain from using their fingers or pressing any buttons to record it. This precaution was taken to prevent any contamination of the event-related potentials by motor potentials or movement artifacts.

## EEG data acquisition

We employed an EEG recording system (g.Nautilus Research; gTec, Austria) to monitor electrical brain activity while subjects engaged in passive listening to sequences of auditory stimuli. The recording setup included thirty-two recording channels, which were positioned in accordance with the International 10-20 System: Fp1, Fp2, AF3, AF4, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, CP1, CP2, P7, P3, Pz, P4, P8, PO7, PO3, PO4, Oz, with channel AFz serving as the ground, and a reference electrode connected to the right ear lobe.

Additionally, two electrodes were used to detect horizontal and vertical eye movements, essential for artifact rejection. The horizontal electrooculogram (EOG) electrode was positioned at the left outer canthi, while the vertical EOG electrode was placed below the right eye. Each recording channel was sampled at a rate of 250 Hz, and the data underwent bandpass filtering from 0.1 to 100 Hz, along with a notch filter at 50 Hz to eliminate line noise. These signals were saved for subsequent post-processing and analysis.For data acquisition and preprocessing, we utilized Matlab (Version: 9.8.0.1873465 (R2020a); Mathworks Inc., Natick, MA, USA), the g.Nautilus Research 32-channel system from g.tec Medical Engineering in Austria, and EEGLAB (Version: 2023.0). Stimulus presentation was carried out using Python 3.8.10 and PsychoPy (Version: 2022.1.4). Posthoc data analysis and visualization were performed using Python 3.10.9, MatPlotLib 3.7.0, MNE-Python 1.4.0 [10], and NumPy 1.23.5.

## ERP data processing and source localization

The EEG data collected from both oddball blocks were combined into a unified block, and the signals underwent bandpass filtering (0.5-30 Hz, 12 dB/octave) to remove slow drift. Subsequently, independent component analysis (ICA) was applied to correct eyeblink artifacts in the data, followed by interpolation to manage bad channels. EEG segments were then segmented into epochs based on event markers, with subsequent artifact rejection. Finally, epochs for each subject were averaged within a time window of (-100 to 500 ms) relative to the occurrence of oddball or standard stimuli. These averaged signals were employed to compute the MMN waveform for each subject, with a subsequent application of a low-pass filter to eliminate high-frequency noise. Difference waveforms and grand average waveforms were derived from these averaged signals for testing both within-group and between-group effects.

Pre-processed files from EEGLab were exported to MNE Python for computing source localization. We used MNE-Python to perform exact low-resolution electromagnetic tomography (eLORETA) source localization with the “fsaverage” template head and ideal channel locations to approximate group-averaged source and sensor space geometry. Sources were constrained to the cortex ($\geq 5.0$ mm from the inner skull) with “ico5” icosahedral spacing and fixed surface-normal orientation, producing 20,484 vertices across both hemispheres. A three-layer boundary element method forward conduction model was computed with brain, skull, and scalp conductivities of 0.3, 0.006, and 0.3 S/m, respectively. For whitening the data, noise covariance was computed from expert and novice meditators separately by concatenating subject ERP waveforms and computing sample covariance in the pre-stimulus window. The eLORETA inverse solution was applied to group-wise averaged D90 MMN and D70 MMN scalp waveforms to estimate their underlying distributions of cortical current source densities. To apply eLORETA to these group-averaged data, the “lambda2” regularization parameter was set to zero, reflecting the assumption of unlimited signal-to-noise ratio; resulting current source estimates account for 100 percent of the variance observed in scalp-recorded ERP waveforms.

# Results

## Meditation expertise effects on MMN

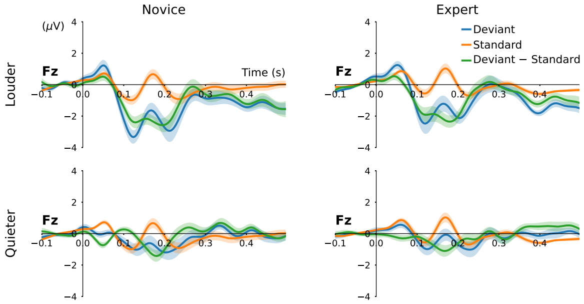

Figure 2: ERP waveforms for each tone type and resulting MMN waveforms for both expert and novice meditators

To analyze the interaction between meditation expertise and MMN amplitude for both kinds of deviants (D90-louder deviant and D70-quieter deviant) in the context of standards, we conducted mixed-design ANOVA. Meditation expertise (novice, experts) was treated as a between-subject factor, while tone types (Standard, deviant) were considered within-subject factors. Analyzing louder deviants in the context of standards aimed to understand how meditation expertise influenced the louder MMN component, while a similar analysis for quieter deviants sought insights into the influence on the quieter MMN component. For louder deviants, the analysis revealed a non-significant interaction between tone types and meditation expertise, indicated by F(1, 28) = 0.69, p = 0.413, and $\eta_p{}^2$ = 0.005. Furthermore, there was no statistically significant main effect for meditation expertise (F(1, 28) = 1.01, p = 0.324, $\eta_p{}^2$ = 0.028). However, a significant main effect for tone types was observed, with F(1, 28) = 74.22, p ¡ 0.05, $\eta_p{}^2$ = 0.35. Similarly, the mixed ANOVA conducted for quieter deviants yielded a non-significant interaction between tone types and meditation expertise (F(1, 28) = 0.03, p = 0.862,$\eta_p{}^2$ = 0.001). Additionally, there was no statistically significant main effect for meditation expertise (F(1, 28) = 0.59, p = 0.446, $\eta_p{}^2$ = 0.017). However, a significant main effect for tone types was observed, with F(1, 28) = 15.75, ($p < 0.05$), and $\eta_p{}^2$ = 0.093. ERP waveforms resulting for each tone type and resulting MMN waveforms for both expert and novice meditators are depicted in Figure 2.

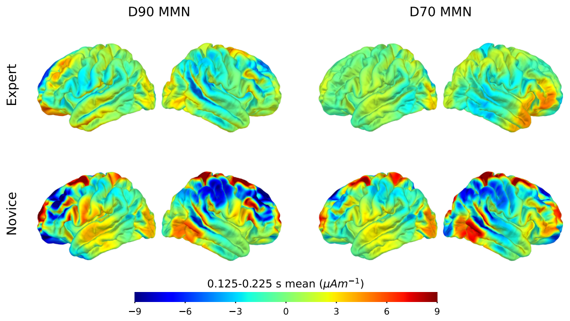

Figure 3: A comparison of source localization estimates from grand ERP data for experts and novices.

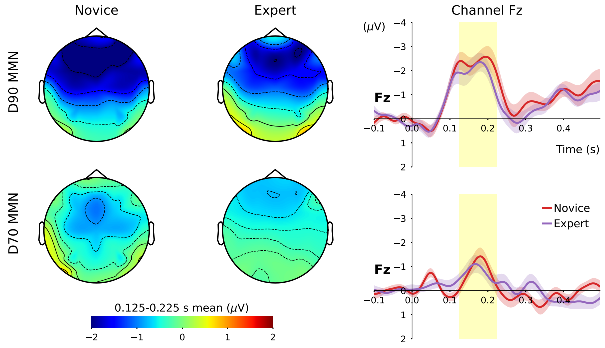

Figure 4: A comparison of MMN waveform and scalp plots for louder and quieter deviants in experts and novices.

The results of source localization and the grand ERP data on these subjects show bilateral temporal and frontal cortex activity consistent with previous studies with novices showing a higher intensity for novices than experts as depicted in Figure 3. Further, analysis on difference waves (deviant ERP -standard ERP) were carried out to compare experts and novices. Two sample t-tests on difference ERP showed a trend towards higher MMN for novices (M = -2.3, SD = 1.4) than experts (M = -1.9, SD = 1.3) , t(28) = 0.83, p = .412. While the results did not reach statistical significance, the trend is quite evident in ERPs comparing louder MMN for experts and novices in Figure 4.

## Intensity transition effects on MMN

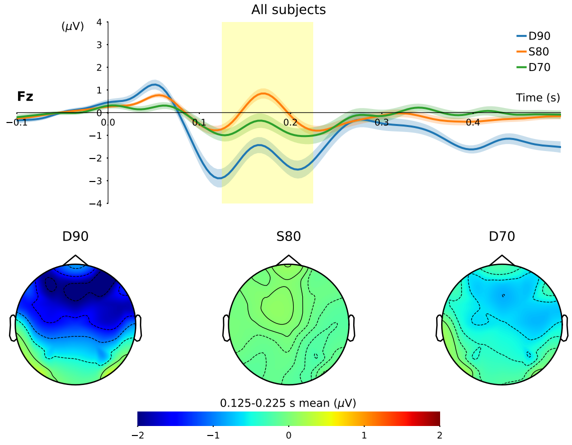

Figure 5: A comparison of ERP waveform showing a unidirectional shift of louder and quieter deviants from standards along with corresponding scalp maps.

To examine the intensity transition effects on MMN , a one-way repeated measures ANOVA was conducted on all subjects, considering tone conditions as within-subject factors. The results indicated a significant difference in the mean ERP amplitude among the different tone types, F(2, 58) = 46.94, ($p < 0.001$), with means of -2.11 for louder deviant (D90), 0.021 for Standard (S80), and -0.76 for quieter deviant (D70). Post hoc pairwise comparisons, adjusted using the Bonferroni method, revealed that the mean amplitude ERP for louder deviant tone (D90) was significantly greater than that for the Standard tone ($p < 0.001$), confirming the presence of an MMN effect for the louder deviant. Similarly, the mean amplitude ERP for the quieter deviant tone (D70) was also higher than that for the Standard tone ($p < 0.05$), indicating an MMN effect for the quieter tone. Additionally, the mean amplitude ERP for louder deviant tone (D90) was significantly higher than that for quieter deviant tone (D70) ($p < 0.05$). Effect sizes (Cohen's d) computed were large, emphasizing both statistical significance and practical importance. ERP and scalp maps for S80, D90, and D70 are depicted in Figure 5. In summary, our statistical analysis, marked by a significant main effect and a unidirectional shift in ERP amplitude, strongly supports rejecting a loudness-dependent explanation for the observed effects.

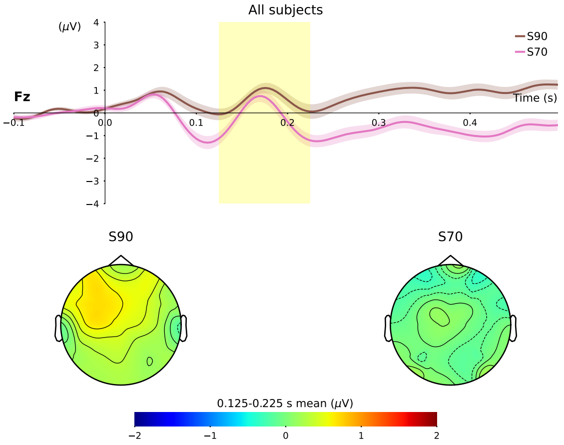

Figure 6: ERP waveforms and scalp map corresponding to S90 (standard following louder deviant) and S70 (standard following quieter deviant).

However, an additional analysis was conducted to "compare standards after louder deviant (S90)" and "standards after quieter deviant (S70)" to explore potential intensity-related confounds that could not be entirely ruled out. A paired t-test revealed a significant moderate difference between S90 (M = 0.5, SD = 1.2) and S70 (M = -0.2, SD = 1.2), t(29) = 3, p = .006, d = 0.54. Figure 6 presents the ERP and scalp map corresponding to S90 and S70 standards. Due to this significant moderate effect, the role of sensory processes resulting from intensity transition in modulating MMN amplitude may not be entirely dismissed.

# Discussion

## Influence of meditation expertise on MMN

The objective of the study was to examine the influence of mantra meditation expertise on MMN modulation using a cross-sectional design and a conventional MMN paradigm. As predicted, obtained results indicate a trend of higher MMN in novices compared to experts, however, the effects did not reach statistical significance. The enhanced attentional control abilities of experts keep them focused on distractor tasks, preventing attention drift towards background stimuli. In contrast, novices are more susceptible to attention drift, leading to increased processing of background stimuli and consequently higher MMN. The modest effect that did not reach statistical significance may be due to the enhanced attention skills observed in novices who practice mantra meditation, even for a shorter duration each week. The inherent components of mantra meditation may contribute to a quicker acquisition of attention skills.

Studying a proposed model of mantra meditation offers insights into the components that might support the learning process. The framework of mantra meditation outlines five essential components: repetition, rhythm, attention, synchrony, and belief (Perry, Polito, & Thompson, 2021). The first four components—repetition, rhythm, attention, and synchrony—pertain to the physiological or acoustic features of the mantra. In contrast, the fifth component (belief) relates to the meaning of the mantra and its broader devotional and spiritual context in practice. The style of mantra meditation employed in our study emphasized repetition, rhythm, and attention, excluding components such as synchrony and belief. Among these aspects, the practice of directing attention to the present moment and refocusing it when diverted shares similarities with other forms of focused attention practices such as breath-focused meditation. However, differences in how repetition and rhythm of speech might engage psychological processes compared to focusing on the breath could impact the ease of learning attention skills in mantra meditation.

Recent studies (Berkovich-Ohana, Wilf, Kahana, Arieli, & Malach, 2015) suggest that "repetitive speech" is a critical element of mantra meditation, contributing to its calming effects on the brain and reducing mind wandering. The repetitive speech component of mantra meditation is also characterized by its "rhythmic" nature. Research indicates that the brain responds to rhythmic external stimuli by synchronizing its oscillations to the temporal dynamics of these stimuli (Poeppel & Teng, 2020; Ding & Simon, 2014). This synchronization of brain oscillations to external rhythmic stimuli is known as neural entrainment (Calderone, Lakatos, Butler, & Castellanos, 2014). In mantra meditation, this neural entrainment may reduce mind-wandering episodes by aligning individuals with the rhythm of the mantra, thus promoting sustained attention. Therefore, it is conceivable that the repetitive and rhythmic chanting of vocalized or sub-vocalized sounds could facilitate the development of attention skills focused on the present moment. While there is currently no definitive empirical evidence supporting neural entrainment and differential learning curves in attention between mantra meditation and other forms of focused attention meditation, the findings from current studies can inform hypotheses for future research comparing the attentional learning trajectories of novices practicing mantra meditation versus focused attention meditation.

Furthermore, our findings diverge from those of previous studies on focused attention. This discrepancy can be attributed to several factors, including variations in experimental paradigms, sample sizes, and styles of meditation practice. Previous studies have also acknowledged these differences, noting that variations in experimental paradigms can significantly influence study outcomes (Fucci et al., 2022). A significant distinction between our paradigm and the prominent studies (Biedermann et al., 2016; Fucci et al., 2018) is that these studies replaced distractor tasks with meditation. Our study employs mantra meditation, where participants audibly chant and listen to mantras. Incorporating such a paradigm where participants meditate while simultaneously listening to background tones was deemed impractical for mantra meditators, as the dual auditory exposure could lead to increased auditory overload, potentially impacting the quality of meditation and sensitivity to background tones. This replacement of distractor task by meditation itself alters how the background tones are perceived and processed, potentially contributing to the observed differences. In our paradigm, subjects focus on a distractor task, inhibiting background stimuli, whereas in studies replacing distractor tasks with meditation, focused meditation might enhance monitoring and sensitivity to background stimuli, resulting in increased MMN, contrary to our findings. Consequently, we argue that trait effects inferred from such paradigms should consider if there is replacement of distractor task with meditation itself, the style of meditation practice and instructions given, and how these factors influence the processing of background stimuli.

To our knowledge, perhaps only one study (Srinivasan & Baijal, 2007) has examined trait effects of focused attention using a similar conventional experimental design to ours, allowing for a meaningful comparison of results. A comparison highlights trends in opposite directions, likely influenced by various factors such as small sample size, task instructions (passive or active), the type of load in the distractor task (perceptual vs. working memory load), and the interstimulus interval (constant or jittered). In our study, the distractor task included a working memory load. Previous research (Haroush, Hochstein, & Deouell, 2010; Zhang, Chen, Yuan, Zhang, & He, 2006) suggests that the direction of results would be opposite if the distractor task involved a perceptual load, such as reading a book, as used in Srinivasan and Baijal (2007). Additionally, our study utilized a jittered interstimulus interval, unlike the fixed inter-stimulus interval used in the study under comparison. This distinction might lead participants to anticipate background tones, introducing confounding effects in the event-related potential (Lang et al., 1995)and leading to divergent outcomes from our findings. Moreover,explicit instructions to ignore background tones during distractor tasks typically result in a lower MMN compared to passive listening (Erlbeck et al., 2014; Barnes et al., 2018). In our study, participants were explicitly instructed to focus on the task and disregard background tones. However, it remains unclear if similar instructions were provided in Srinivasan and Baijal (2007), raising the possibility of passive listening. In passive listening scenarios, an opposite trend to our findings would be expected, as experts tend to attend to tones more effectively than novices.

### Impact of intensity transitions on MMN

Previous MMN studies mainly used the frequency oddball paradigm, leaving an uncertainty about whether to interpret meditation effects on MMN to be result from higher-order cognitive processes or sensory adaptation (E. Sussman et al., 1999; O'Reilly & O'Reilly, 2021). Our study utilized an intensity mismatch negativity paradigm with quieter and louder deviant stimuli of the same frequency, aiming to discern if MMN modulation reflects sensory or cognitive components. The results revealed that both louder and quieter deviant stimuli elicited similar polarity and amplitude shifts compared to the standard stimulus. This observation is crucial because if MMN were solely an artifact of intensity transitions, a consistent unidirectional shift would not have been observed for both types of deviants. The significant differences from the standard stimulus for both louder and quieter deviants imply that they triggered a similar polarity of ERP responses, leading to the manifestation of louder and quieter MMN. These findings significantly contribute to dissociating MMN from a purely loudness-dependent explanation, supporting the idea of MMN as a mechanism for detecting deviance rather than a mere indicator of low-level sensory modulation. However, it's crucial to acknowledge the significant ERP differences found when the standards following quieter and louder deviants were tested. This significant effect cautions against a definitive interpretation, suggesting a potential overlapping role of sensory-level processes occurring in parallel and contributing to the observed MMN (Fitzgerald & Todd, 2020; May & Tiitinen, 2010).

## Conclusion

The findings from the present study on mantra meditation indicate a heightened ability of experts to resist background distractions when compared to novices. Consequently, there is a discernible trend towards a lower mismatch negativity response in experts compared to novices. The modest effect observed is attributed to novices' improved attention skills, possibly due to enhanced acquisition of attention skills facilitated by the repetitive speech and rhythmic nature inherent in mantra meditation, even from shorter and less frequent practice sessions. The contrary effect observed in this study, compared to a similar study with a comparable experimental design, could be attributed to several factors. These factors include a potentially smaller sample size, variations in the type of load used in the distractor task, differences in the interstimulus interval between tones, and specific variations in the instructions provided. These differences are anticipated to influence the outcomes in an opposing manner. Additionally, the consistent unidirectional polarity shift observed in response to both types of deviant stimuli (either louder or quieter) emphasizes that the impacts of meditation on mismatch negativity cannot be solely caused by loudness-dependence of auditory evoked potentials. We suggest that future studies with sufficient statistical power, investigating focused attention meditation and employing a paradigm similar to that used in the present study, will provide more conclusive insights into the debate surrounding the effects of focused attention meditation on MMN. These studies will also help clarify whether the effects of focused attention meditation differ from those of mantra meditation and will shed light on the magnitude and directionality of these effects.

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