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Meditation and auditory attention: An ERP study of meditators and non-meditators

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ABSTRACT

The findings of a study by Cahn and Polich (2009) suggests that there is an effect of a meditative state on three event-related potential (ERP) brain markers of "low-level" auditory attention (i.e., acoustic representations in sensory memory) in expert meditators: the N1, the P2, and the P3a. The current study built on these findings by examining trait and state effects of meditation on the passive auditory mismatch negativity (MMN), N1, and P2 ERPs. We found that the MMN was significantly larger in meditators than non-meditators regardless of whether they were meditating or not (a trait effect), and that N1 amplitude was significantly attenuated during meditation in non-meditators but not expert meditators (an interaction between trait and state). These outcomes suggest that low-level attention is superior in long-term meditators in general. In contrast, low-level attention is reduced in non-meditators when they are asked to meditate for the first time, possibly due to auditory fatigue or cognitive overload.

1. Introduction

Meditation has been described as the intentional regulation of attention (Kabat-Zinn, 1982), and specific instructions for the intentional regulation of attention form the basis of many styles of meditative practice (e.g., concentration on the breath; Tang & Posner, 2009; Tang et al., 2015). Given the central role that attention appears to play in meditation, it is interesting that a meta-analysis about the effects of meditation on behavioural variables concluded that meditation has only a moderate effect on measures of attention. However, this effect was measured across different meditation techniques (Sedlmeier et al., 2012), and the meta-analysis did not differentiate the effects of meditation on different "levels" of attention, such as early "low-level" processes of attention (e.g., the storage of stimulus features in the sensory memory) and "high-level" attention processes (e.g., complex attention skills, such as the ability to respond to multiple simultaneous streams of information). This raises the question of whether meditation has different effects on different types of attention that average together to produce a moderate effect on attention. The aim of the current study was to investigate the effect of meditation on one specific type of attention. We investigated low-level attention using event-related potentials (ERPs), which allows the measurement of attention during meditation without interrupting a meditator's practice.

An ERP is an average electrical potential generated by groups of neurons in response to a particular event or stimulus (e.g., a musical tone, a written word, a spoken word, a face). ERPs can be measured under "passive" conditions (i.e., an individual is not required to pay attention to a particular task or stimulus) or under active conditions (i.e., an individual is asked to attend to a stimulus or task). Passive and active ERPs are represented by waveforms that comprise a series of positive and negative peaks. These peaks are named according to their position in that series (e.g., P1 is the first positive peak and N1 is the first negative peak; see Fig. 1(a–d) for an example) or according to their timing (e.g., the N100 is a negative peak that occurs approximately 100 ms in the waveform, P200 is a positive peak that occurs at around 200 ms in the waveform).

Several studies have compared meditators' and non-meditators' passive and active ERPs to various stimuli after a period of meditation (e.g., Banquet & Lesévre, 1980; Sarang & Telles, 2006; Travis & Miskov, 1994). This includes two studies that focused on "low-level" auditory attention (i.e., storage of acoustic features in the sensory memory; Cahn et al., 2013; Delgado-Pastor et al., 2014). However, to our knowledge, only two studies have used ERPs to measure low-level attention in meditators during meditation (Cahn & Polich, 2009; Atchley et al., 2016).

Cahn and Polich (2009) tested 16 Vipassana meditators during meditation and non-meditation conditions for their passive auditory ERPs (N1, P2, P3a at midline frontal (Fz), central (Cz), and parietal (Pz)

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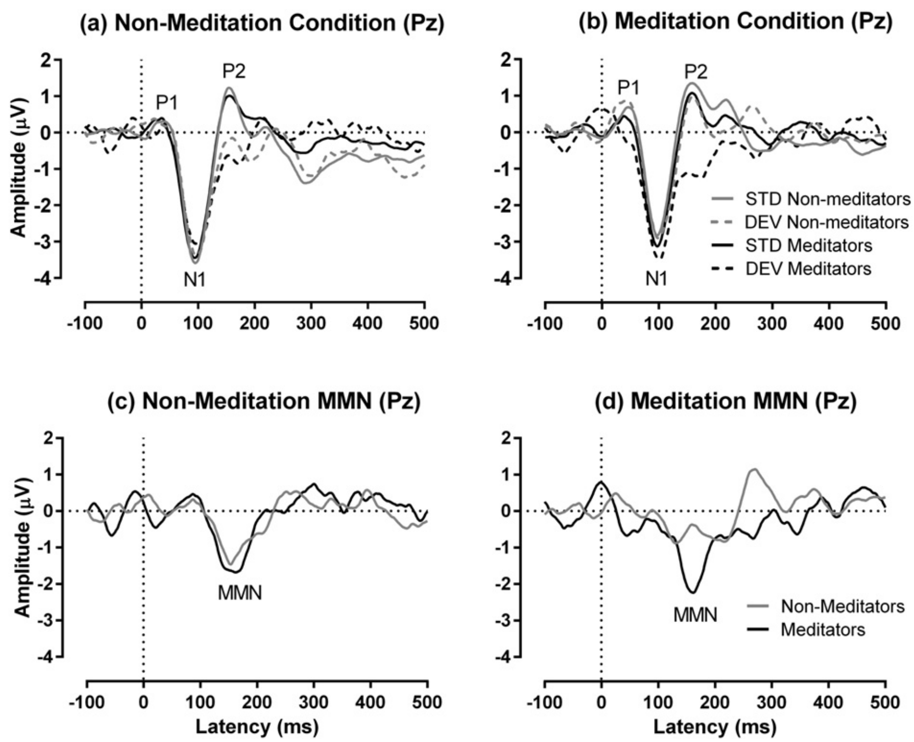

Fig. 1. a–d Examples and results for positive and negative peaks across conditions.

scalp sites) to three types of sounds: a frequent 500-Hz tone ("standard", 80% of tones), an infrequent 1000-Hz tone ("deviant", 10%) and an infrequent white noise ("distractor", 10%). The passive auditory N1 and P2 ERPs are thought to reflect the early processing of acoustic features of a stimulus and early automatic orienting of attention (Alcaini et al., 1994; Näätänen & Picton, 1987) while the P3a is thought to reflect attentional engagement (Polich, 2007). Cahn and Polich found that meditation reduced the N1, the P2, and the P3a to deviants and/or distractors - but not to standards. They concluded that meditation reduces automatic reactivity and processing of task-irrelevant attention-demanding stimuli.

The outcomes of Cahn and Polich's study are interesting because they suggest that meditation may have an effect on low-level auditory attention. However, the strength of this suggestion is obscured by two methodological factors. First, half of the participants were asked to meditate before the mind-wandering task, raising the possibility of meditation "after-effects" confounding the non-meditation control phase.[1] Second, there was no control group of non-meditators in the study, making it impossible to discern whether an effect of meditation on low-level attention-related reactivity was specific to expert meditators (i.e., an effect of "trait" that is only present in meditators), is specific to meditation (i.e., an effect of "state" that is present whenever anyone meditates), or resulted from an interaction between both trait and state (i.e., is only present in meditators during meditation).

A recent study by Atchley et al. (2016) addressed these two issues using three groups: non-meditators, novice meditators (under 1000 hours of practice within the last 2.5 years), and long-term meditators (over 4000 hours of practice). These groups were tested for their N2 and P3 ERPs firstly during a non-meditation condition (i.e., they were asked to count the deviant sounds in an oddball task) and then during a meditation condition (i.e., they were asked to ignore sounds in an oddball task in while breath counting). Compared to non-meditators, the meditators (i.e., novice and long-term meditators pooled together) had larger N2 and P3 responses during non-meditation (when the sounds were attended) and smaller N2 and P3 responses during meditation (when the sounds were ignored). In addition, there were greater differences in N2 and P3 amplitudes elicited by the meditation and non-mediation conditions compared to the non-meditators. The authors interpreted these findings as evidence for greater attention control in meditators.

The combined findings of Atchley et al. (2016) and Cahn and Polich (2009) support the idea that meditation may have trait and state effects on low-level auditory attention-related skills indexed by the N1, P2, and P2 ERPs. The aim of the current study was to expand build upon these findings by testing if meditation has trait or state effects on yet another ERP that indexes low-level auditory attention - the mismatch negativity (MMN). The auditory MMN is hypothesised to reflect an automatic auditory change detection mechanism that activates a shift in the focus of attention (Escera et al., 1998; Escera et al., 2003; though cf Garrido et al., 2009; Jääskeläinen et al., 2004). The MMN is calculated by subtracting a passive ERP to a frequent standard stimulus to a passive ERP to a rare deviant stimulus. The resulting "difference" waveform typically shows a negativity that peaks at around 200 ms in adults that is maximal at fronto-central scalp sites but is also observed at parietal scalp sites (for example see Näätänen et al., 2007). It is generally thought that the MMN is generated by neurons in temporal and pre-frontal brain regions (Garrido et al., 2009).

No study has compared the auditory MMN in meditators and non-meditators during meditation. However, one study has found that meditators had a larger average MMN after Sudarshan Kriya Yoga than non-meditators who did a relaxation session (Srinivasan & Baijal, 2007). While this study did include a control group of non-meditators, it confounded the comparison of meditators and non-meditators by applying different conditions to each group (yoga for the experimental group and relaxation for controls).

With the knowledge of the findings and limitations of the studies by Cahn and Polich (2009), Srinivasan and Baijal (2007), and Atchley et al. (2016) in mind, the current study aims to explore the effect of meditation on low-level attention by comparing the MMN ERP of expert

[1] For example, across different meditation traditions, breath counting is the fundamental basis but mind wandering is factored into the meditation (e.g., Zen). An integral part of the meditation practice is to notice 'the thought that arises' or the 'mind that is wondering', and to come back the breath or the koan.

meditators to non-meditators (i.e., controls) during meditation and non-meditation. Since the MMN requires the measurement of the N1 and P2 peaks to standard and deviant sounds, we also had the opportunity to test the reliability of Cahn and Polich's N1 and P2 effects. From the findings of Srinivasan and Baijal (2007), we tentatively predicted (1) a main effect of trait for the MMN (i.e., larger amplitude in meditators than non-meditators overall); (2) a main effect of state for the MMN (i.e., larger amplitude during meditation than non-meditation); and (3) an interaction between state and trait for the MMN (i.e., a larger MMN during meditation than non-meditation for meditators compared to non-meditators).

2. Method

2.1. Ethics

The study was approved by the Macquarie University Human Research Ethics Committee (reference number: 5201000950). All participants provided written informed consent.

2.2. Participants

Twelve expert meditators (seven males, five females, mean age: 55.83 years, SD = 13.59, 33–79 years) were recruited either from the Sydney Zen Centre, the Vajrayana Institute, Sydney, or through personal contacts. Each had over ten years of meditation practice and did at least 15 minutes of sitting practice on at least four days of the week (mean daily sitting practice = 20.67, SD = 8.89, 10–35 years, weekly hours ranged from 2 to 7 hours per week). Six of the expert meditators followed a Zen practice, two followed a Chan practice (one of whom was a fully ordained Chan monk), and five followed a Tibetan Mahayana practice. All three practices had breath meditation as an underlying technique.

The study also included 14 non-meditators who served as an age-matched control group (two males, twelve females, mean age: 52.55 years, SD = 15.77, minimum of 30–67 years). Non-meditators had no prior experience of any type of meditation or yoga. Participants from both groups had normal hearing bilaterally and did not report any significant neurological or psychological history. There was no statistical difference between the mean ages of the non-meditator and mediator groups, $t(24) = 1.60$, $p = 0.12$. There was a small difference between the mean ages of the non-meditator and mediator groups, but this was not statistically.

2.3. Experimental stimuli

The stimuli comprised two 13-min blocks - one during the meditation condition and one during the non-meditation condition - of 666 pure tones that were 175-ms in duration with 10-ms rise- and fall-times. Stimuli were presented binaurally via headphones at 80 dB SPL. Each block presented 566 1000-Hz “standard” tones (85% of trials) interspersed with 100 1200-Hz “deviant” tones (15% of trials). The randomization of the tones ensured that there were at least 2 standard tones presented before a deviant tone. A jittered inter-stimulus interval of 900 to 1100 ms was used to minimize the confounding effect of ERP artifacts related to anticipation of a stimulus (Lang et al., 1995).

2.4. Electroencephalogram (EEG) recording

Participants were seated in a comfortable chair for the EEG set up. To facilitate impedance reduction, each participant's scalp was combed prior to fitting the electrode cap (Mahajan & McArthur, 2010), which was an EasyCap with sintered Ag-AgCl electrodes placed at scalp sites positioned according to the International 10–20 system (Fz, Fp1, Fp2, F3, F4, FC3, FC4, FT7, FT8, F7, F8, C3, C4, CP3, CP4, Cz, Pz, FCz, O2, O1, Oz, P3, P4, P7, P8, T7, T8, TP7, TP8, M2). The left mastoid (M1) served as online reference and the right mastoid (M2) an offline reference. Vertical eye movements (VEOG) were measured with electrodes placed above and below the left eye. Horizontal eye movements (HEOG) were recorded using electrodes placed on the outer canthi of each eye. The ground electrode was positioned between FPz and Fz. The scalp-electrode impedance was kept below 5 kΩ. The EEG was sampled at each site using the Neuroscan system and Acquire software (version 4.3) using a 1000-Hz sampling rate and an online bandpass filter of 0.05–200 Hz. The raw EEG data was stored for offline processing.

2.5. Offline EEG processing

A standard ocular reduction algorithm (Semlitsch et al., 1986) was used to remove the VEOG activity from the EEG data. The EEG data was (1) re-referenced to both mastoids, which were mathematically linked, (2) bandpass filtered (0.1-Hz high pass and 30-Hz low pass; 12-dB-per-octave roll-off), and (3) divided into 600-ms epochs including a 100-ms pre-stimulus interval, which was used for baseline correction. Any epoch that contained a voltage change exceeding $\pm$ 150 μV was removed from further analysis. All epochs generated by the 1000-Hz standard and 1200-Hz deviant tones were averaged to produce a “standard ERP” and a “deviant ERP”, respectively. To calculate the “MMN ERP”, the 1000-Hz standard ERP was subtracted from 1200-Hz deviant ERP (i.e., a difference waveform).

2.6. Measurement of ERPs

In line with previous research, the N1, P2 and MMN ERPs were measured at frontal (Fz) and parietal (Pz) sites (Särkämö et al., 2010; Restuccia et al., 2005). It is noteworthy that, unlike Cahn and Polich (2009), we did not measure the P3 since one of our primary aims was to measure the MMN. The positivity associated with the P3 response can counteract the negativity associated with the MMN, effectively “neutralising” the MMN. Thus, the MMN must necessarily be generated under conditions that minimize the P3 response (i.e., in situations where attention is focused away from deviant auditory stimuli).

The N1 and P2 peaks were identified as the first clear negative and positive peaks in a participants' standard ERP. The MMN was identified as the first clear negative deflection in an individual's MMN ERP. All participants showed clear N1 peaks to standards and deviants tones in each condition, and so it was indexed using its peak amplitude between 75 and 125 ms. The P2 peak was distinct in both conditions to standard tones but not deviant tones. Thus, it was measured via its mean amplitude between 150 and 190 ms. As is typical, the MMN presented as a broad negativity rather than a distinct peak, and so it too was via its mean amplitude between 150 and 190 (Note: the P2 and MMN peaks occurred at similar times, hence the same time intervals; please see Fig. 1a–d). The use of different procedures to measure different ERPs was appropriate since (1) they best represented the morphology of the peaks (i.e., clear versus unclear), and (2) no analysis required a direct comparison of the three ERPs.

2.7. Procedure

A challenge for all current meditation research is establishing the generalisability (or not) of findings across specific styles of meditation practice. To date the most commonly accepted categorisation has been Lutz et al.'s (2008) distinction between practices involving focused attention and practices involving open monitoring. Focused attention meditation practices involve the deliberate focusing of attention on a specific target object (e.g., the breath, a particular body sensation or specific imagined image). Open monitoring meditation practices involve nonreactive monitoring of the contents of conscious experience as they arise. In the current study, in order to avoid any variability in participants' meditative practice, we gave all participants, regardless of their level of meditation experience or usual practice style, very specific, standardised instructions for a particular focused attention meditation (simple breath counts), a technique that is inherent to all meditation techniques named above.

Each participant's N1, P2, and MMN ERPs were measured in two conditions: a non-meditation (control) condition and a focused meditation condition. To avoid any after effects of the meditative state carrying over into the non-meditative condition, the non-meditation condition always preceded the meditation condition (i.e., conditions were not counter-balanced).

During the non-meditation condition, participants were administered the standard and deviants sounds through the headphones while they imagined building a tree house. This task was chosen as a control condition that matched all physical variables of the meditative condition (closed eyes, same body posture) while deliberating manipulating the level of mental activity. The instructions for this non-meditative task were as follows:

Please close your eyes. For the next 13 minutes, I would like you to think about how to build a tree house. Think about a suitable location (what type of tree, where does this tree stand? Is this a tree in Australia or somewhere else? What materials would you use? How would you start building the tree house, what are the steps involved from the beginning to the end?). While you are doing this, you are going to hear some beeps in the background. Please try to ignore these sounds and just focus on the tree house building. When we begin I will ask you to close your eyes, it is very important that you do not open your eyes until I tell you to. At the end of this task, I am going to ask you to draw or describe your tree house to me. Just keep your eyes closed and remember don't open them until I'll let you know.

During the meditation condition, individuals were presented the same standard and deviant sounds while they attempted to meditate. All expert meditators (and non-meditators) were asked to follow the same instructions, regardless of their typical style of meditation:

For the next 13 minutes, just sit comfortably with your back straight and relax. Concentrate now on your breath, slowly breathing in, slowly breathing out. With the first exhalation count 'one', with the second exhalation count 'two', with the third exhalation count 'three', and so forth. Continue counting your breath until the count of 10. Then start with 'one' again, come back to your breath. If you lose count, just start with the count of 1 with your next exhalation – after some time of counting your breath, some tones will arise in the background. Just notice them, do not attend to them. Gently let them go, and continue concentrating on your breath. If you forget your count or a thought arises, just start again with the count of 'one' on the next exhalation. Please do not open your eyes until we'll let you know, even if the tones stop.

These instructions are broadly compatible with the type of focused attention on breathing that all expert meditators should be familiar with. At the end of the meditation condition, participants were asked use a 7-point scale to rate: (1) their ability to concentrate on the breath, and (2) the percentage of time they were able to concentrate on the breath.

2.8. Statistical analyses

We tested datasets for equal variance using the Levene Test for Error Variance. Ten of the twelve datasets (N1, P2, and MMN for the meditators and non-meditators at Fz and Pz) did not differ significantly from normal ($F(1,24) = 4.02$, $p > 0.05$) while two did (P2 at Pz: $F(1, 24) = 4.37$, $p = 0.047$; Fz at N1: $F(1, 24) = 4.50$, $p = 0.04$). We tested the normality of each dataset using Kolmogorov-Smirnov Tests. These revealed that no data set differed significantly from a normal distribution ($KS = 0.09$ to 0.22; all ns).

Given that (1) most data sets passed tests for normality and equivariance (e.g., Levene Test for Error Variance, Kolmogorov-Smirnov Tests), and (2) parametric tests are robust to minor deviations in assumptions, we used parametric repeated-measures ANOVAs with two levels of group (meditators versus non-meditators) and two levels of condition (meditation versus non-meditation) to determine if the N1, P2, or MMN ERPs differed between meditators and non-meditators (a main effect of trait); meditation versus non-meditation (a main effect of state); or if there was a larger effect of state in meditators than non-meditators (a state-by-trait interaction). We used post-hoc *t*-tests to understand the effect underpinning any significant interactions between state and trait.

3. Results

Appendix 1 shows summary statistics (means (*M*) and standard deviation (*SD*)) for N1, P2, and MMN data at Pz and Fz, along with outcomes of the statistical analyses (main effects of group, stimulus, and condition, as well as interactions). These statistics indicated that while the pattern of outcomes were similar at Pz and Fz, data collected at Pz appeared to be more sensitive to meditation effects, possibly because of less variance (i.e., the SDs were generally smaller at Pz than Fz). Hence, Fig. 1(a–d) presents the mean ERP waveforms in each condition for meditators and non-meditators for standard and deviant sounds and the MMN measured at Pz. Similarly, Fig. 2(a–e) graphs the amplitudes of N1, P2, and the MMN for each groups to each stimulus in each condition at Pz. Below, we therefore report only Pz results but Appendix 1 also contains additional information on Fz results.

Regarding N1, the waveforms in Fig. 1 and the graphs in Fig. 2 suggest that there is a reliable group by condition interaction ($F(1, 24) = 9.67$, $p = 0.005$, $E = 0.29$) because the N1 amplitude was smaller (i.e., more positive) during meditation than non-mediation in non-meditators, but did not differ between these conditions in meditators (see also Appendix 1). The data also revealed a trend for a larger N1 amplitude to deviants than standards across the two stimuli groups - an effect that only just failed to reach statistical significance ($F(1, 24) = 3.71$, $p = 0.066$, $E = 0.13$).

Regarding P2, the data and figures revealed a reliable effect of stimulus because the P2 was smaller in amplitude to deviants (i.e., more negative) than to standards overall ($F(1, 24) = 46.47$, $p < 0.005$, $E = 0.66$). Since the same effect was observed for the N1 (i.e. more negative response to deviants than standards), it seems likely that the stimulus effect for the P2 and the N1 reflect the same process. This might also be the case for the significant group by condition interaction for the P2 that, similar to the N1, was more positive (hence, P2 was larger in amplitude while N1 was smaller in amplitude) in the meditation condition than the non-meditation condition in meditators but with little difference between conditions in meditators ($F(1, 24) = 9.23$, $p < 0.005$, $E = 0.28$). Unlike the N1, there was an additional group by stimulus interaction for P2 because the P2 amplitude was more negative (i.e., noticeably smaller) to deviants relative to standards in meditators than non-meditators – particularly in the meditation condition ($F(1, 24) = 6.97$, $p = 0.01$, $E = 0.22$).

With respect to the MMN, which is formed from the subtraction of the P2 of the standards from the deviant, our data supports a statistically reliable effect of group because meditators had a larger mean MMN amplitude across conditions than the non-meditators ($F(1, 24) = 5.94$, $p = 0.02$, $E = 0.19$). However, the interaction between condition and group only showed a trend. It seems therefore that a simple subtraction of the standards and deviants does not create a reliable MMN. Hence, the discussion below of the P2 component that allows for an analysis of brain potentials evoked by both the standard and the deviants rather than a simple subtraction of the two, and thus allows for the comparison of how the conditions may have differentially affected these brain responses.

4. Discussion

To recap, the aim of the current study was to measure the association between meditation and low-level auditory attention by comparing the MMN ERP of expert meditators to non-meditators (i.e., controls) during

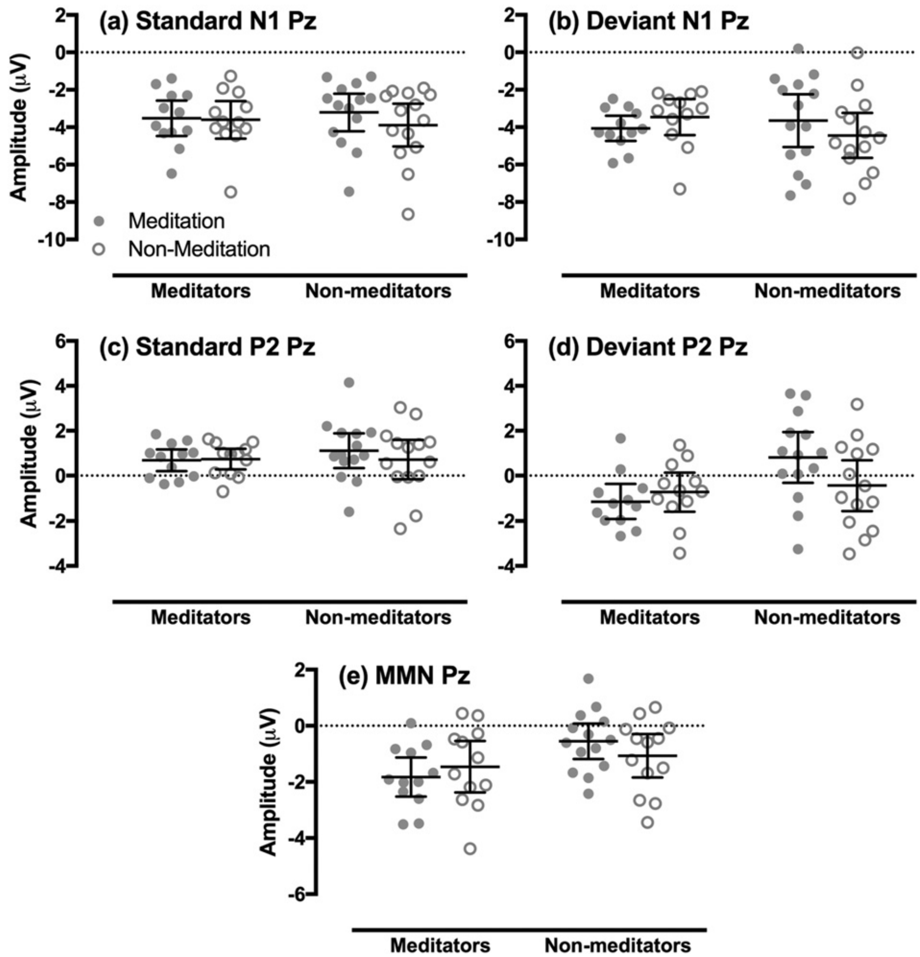

Fig. 2. a–e Amplitudes of N1, P2, and the MMN for each group to each stimulus in each condition at Pz.

meditation and non-meditation. Since the MMN requires the measurement of the N1 and P2 peaks to standard and deviant sounds, we also had the opportunity to replicate part of Cahn and Polich's (2009) findings relating to the effect of meditation on the N1 and P2 on meditators, which suggested that meditation reduces the N1 and P2 to deviant or distractor sounds (but not standards) in meditators. We tested 12 expert meditators and 14 non-meditators during periods of meditation and non-meditation for three passive auditory ERPs (the N1, the P2, and the MMN) generated by frequent standard and infrequent deviant tones. Below, we use the outcomes of the analysis of this data to discuss the MMN, P2, and N1, respectively.

From the results of Srinivasan and Baijal (2007), we predicted (1) a main effect of trait for the MMN (i.e., larger in meditators than non-meditators overall); (2) a main effect of state for the MMN (i.e., larger during meditation than non-meditation); and (3) an interaction between state and trait for the MMN (i.e., a larger MMN during meditation than non-meditation for meditators than non-meditators). The figures (Figs. 1a–d and 2a–e) and statistics (Appendix 1) supported the first of these predictions since our meditators had larger MMN ERPs than non-meditators overall (a trait effect). In contrast, our statistical analysis did not support the second prediction since the MMN, when averaged across groups, did not differ between meditation and non-meditation. However, the third prediction was somewhat supported since the waveforms of non-meditators clearly showed that the average MMN in non-meditators was markedly smaller in amplitude than the MMN of meditators in the meditation condition but not the non-meditation condition. Despite the clear suggestion of an interaction in the waveforms, the statistics for the MMN data showed that this interaction was not reliable, and only showed a trend.

The mismatch between the waveforms and the statistics could have occurred for at least two reasons. First, it is possible that there is no reliable relationship between meditation experience and meditative state, and that long-term meditators have a larger MMN than non-meditators regardless of whether they are meditating or not. Such a pattern would be interesting since it would suggest that a seemingly "high-level" activity like meditation can have an impact on - and indeed improve - a relatively low-level ability that relates to the detection of change in sounds that is done automatically without overt attention and generalises to more reliable low-level attention beyond the meditation condition.

A second explanation for the mismatch between the waveforms and the statistics relates to the reliability of the MMN ERP itself. Researchers have expressed concerns about the lesser reliability of the MMN under some conditions – including healthy adults (Badcock et al., 2013; Mahajan & McArthur, 2011). Of less concern is the reliability of the P2 in adults, which not only underpinned the MMN in this experiment (i.e., the MMN is based on the difference between the waveforms in the P2 region), but also showed an interaction between meditation experience and the meditative state. Additionally, the P2 allows for an analysis of brain potentials evoked by both the standard and the deviants rather than a simple subtraction of the two, and thus allows for the comparison of how the conditions may have differentially affected these brain responses. Thus, we discuss the P2 next.

In contrast to the MMN, both the waveforms and statistics for the P2 suggested a reliable interaction between the effect of meditation on trait (i.e., meditators versus non-meditators) and state (meditation versus non-meditation). Specifically, the P2 was clearly more positive (i.e., larger in amplitude) during meditation and then during non-meditation in non-meditators, but there was little difference between the meditators' P2 in these two conditions. In addition, there was an interaction between trait (i.e., meditators versus non-meditators) and stimulus (standard versus deviant tones), with a smaller difference between the P2 to standards and deviants in the non-meditators than in the meditators. The fact that (1) the P2 occurred at the same time as the MMN in this study, and (2) the statistically significant interactions in the P2 data supported the non-significant trends in the MMN data, suggest that the significant effects of state and trait on the P2 explained similar non-significant trends on the MMN, which failed to reach significance due to the poorer reliability of the MMN relative to the P2.

The P2 data also suggest that Cahn and Polich's (2009) finding that meditation reduces the P2 to deviant or distractor sounds (but not standards) in meditators is a reliable effect. Appendix 1 shows that in the current study, meditation had no effect on meditators' P2 to standard sounds (0.7 mV in both conditions), but it did increase the negativity of the P2 (i.e., made it smaller in amplitude) to deviants from −0.7 mV (non-meditation) to −1.1 mV (meditation). In contrast, in non-meditators, meditation increased the size of the P2 amplitude to standard sounds (from 0.7 mV in non-meditation to 1.1 mV in meditation) as well as deviant sounds (from −0.4 mV in non-meditation to 0.8 mV in meditation) – hence, the significant interaction between state and trait on the P2 in this study. The very different P2 effects found in the meditators (which support Cahn & Polich's, 2009 findings) and non-meditators emphasises the importance of examining the influence of meditation in non-meditators and meditators since the effects do not appear to be the same. This is an important addition to the Cahn and Polich (2009) study since this study did not incorporate a control group of non-meditators.

Cahn and Polich (2009) also examined the effect of meditation in meditators on the N1. Similar to the P2, they found that meditation reduced the N1 to deviants or distractors but not to standards. The current study partially supported this finding. It also found that, in meditators, the N1 to standards was similar during meditation and non-meditation. However, in contrast to Cahn and Polich, this study also found that the N1 in meditators to deviants was larger during meditation (−4.1 mV) than during non-meditation (−3.5 mV). Interestingly, this effect was reversed in non-meditators, whose N1 was smaller during meditation (−3.7 mV) than during non-meditation (−4.4 mV). Again, the difference between the effects in the meditators and non-meditators further support the conclusion that meditation may have different effects in people with different degrees of meditation experience, and that neurophysiological indices might be altered in non-meditators, but that this non-meditation pattern looks different to the long-term meditation pattern in the beginning of exposure to their meditation experience.

It is noteworthy that the opposing effects of meditation on the N1 in non-meditators compared to long-term meditators resulted in the same significant interaction between trait (meditators versus non-meditators) and state (meditation versus non-meditation) that we observed for the P2. Specifically, both the N1 and the P2 were less negative during meditation compared to non-meditation in non-meditators, making the N1 smaller and the P2 larger. The similarity of this interaction suggests that the effects of state and trait on the N1 and P2 ERPs in this study may reflect the same theoretical construct. Further, since the P2 appears to explain the MMN, it is possible that all the effects in this study may relate to the same construct. What might this theoretical construct be? The decreased negativity (and hence increased positivity) of non-meditators' N1, P2, and MMN ERPs during meditation – particularly to deviant sounds – suggests a kind of inhibition of a low-level attentional ability to detect a deviance in incoming sounds, manifesting in a decreased differentiation between the standard and deviant tones. This inhibition is best illustrated in Fig. 1(a–d) that shows that, unlike long-term meditators, non-meditators do not have a reduced P2 during meditation that is typically observed in an auditory oddball paradigm. We know that our non-meditators were capable of producing such a typical reduction in P2 because they clearly produced a reduced P2 in the non-meditation condition. However, in the meditation condition, their brain appears to be treating deviant sounds the same way as standard sounds.

A recent review by Fox et al. (2014) suggests that focused meditation practice is associated with changes in brain areas thought to be responsible for cognitive control, attention regulation, and mind wandering. Meta-analyses from Sedlmeier et al. (2012), Eberth and Sedlmeier (2012) and Goyal et al. (2014) have made similar conclusions based on behavioural measures and measures of psychological stress and well-being. The conclusions of these meta-analyses provide two possible explanations for why the brains of non-meditators during meditation appear to respond to deviant sounds in the same way as standard sounds. The first relates to *attention regulation or fatigue*. It is possible that meditating for the first time focuses a person's attention so completely on the breath that it inhibits even automatic low-level attentional capabilities that typically function under "passive" conditions that do not require a listener's overt attention (e.g., while a participant watches a movie), or cannot be attended to since the system is fatigued.

The second relates to *cognitive overload*. We are using the term 'cognitive overload' in this context as overextension of mental capacity when using the working memory. According to this explanation, the non-meditators were overwhelmed by the task and had no available working memory resources to attend to all instructions at the same time. In the current study, participants were asked to act upon a series of meditation instructions that are unfamiliar to non-meditators (please see Method). This included instructions about breath counting, what to do when thoughts arose, and what to do if sounds intruded into the breath counting. While a very familiar task to experienced meditators, carrying out such multi-layered instructions for the first time might place greater cognitive load on non-meditators. Cognitive overload may have also reduced the capacity of participants' automatic low-level attention system to detect a deviance in a stream of sounds, while being occupied with the difficult task of keeping count of the breath. A non-meditator's strategy might be to block out incoming sounds in order to more accurately track the breath. It is possible that extended meditation practice may lead to improved attention regulation capacities and a reduction/alleviation in a cognitive overload. This in turn would dissolve any inhibition or overload of low-level auditory attention, which would explain why experienced meditators do not show such inhibition or overload in the processing of deviant sounds during meditation. This possibility reinforces our previous point that it cannot be assumed that meditation has the same effect in non-meditators as meditators. These results suggest that in order to fully understand the effect of meditation on the brain and cognition, we require longitudinal studies that track the effects of meditation practice in non-meditators over time.

It is important to emphasise that although this experiment cannot provide a definitive explanation for the decreased negativity (and hence increased positivity) of non-meditators' N1, P2, and MMN ERPs during meditation, it is clear that expert meditators did not show this effect, in fact did not show a difference across the meditation and non-meditation condition. This suggests that expert meditators showed a trait effect of some kind that was not evident for non-meditators. The goal of our next study will therefore be to determine whether the decreased negativity of non- meditators' N1, P2, and MMN responses during meditation results from auditory fatigue (or some form of order effect) or cognitive overload.

5. Summary and conclusion

The difference of neurophysiological patterns between long-term meditators and non-meditators in the N1, MMN and P2 indices suggests that meditation alters brain responses after long-term meditation practice. The trait effect observed for long-term meditators suggests a greater sensitivity to sounds overall during meditation and non-meditation. Non-meditators did not show this pattern, and rather showed a state effect with reduced difference in the N1, P2 and MMN components evoked by tones during meditation. These findings highlight the need for longitudinal studies that track changes in the neurophysiological indices of attention in people as they progress from being a non-meditator to an experienced meditator.

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Appendix 1

Means (M) and standard deviations (SDs) for P1, N1, P2, and MMN data for meditators and non-meditators in each condition (meditation versus non-meditation) are shown in this table, along with outcomes of the statistical analyses (main effects and interactions). Grp = group; Stim = stimulus; Con = condition. Pz indicates parietal sites, Fz frontal sites.

Group	Meditators (N = 12)		Non-meditators (N = 14)		Group comparisons
Condition	Meditation	Non-meditation	Meditation	Non-meditation	
			Pz		
N1 standards	−3.5 (1.5)	−3.6 (1.6)	−3.2 (1.7)	−3.9 (2.0)	Grp: F(1,24) = 0.04, p = 0.84, E < 0.01
N1 deviants	−4.1 (1.1)	−3.5 (1.5)	−3.7 (2.4)	−4.4 (2.1)	Stim: F(1,24) = 3.71, p = 0.066*, E = 0.13
					Con: F(1,24) = 2.21, p = 0.15, E = 0.08
					Grp X Con: F(1,24) = 9.67, p = 0.005, E = 0.29 F1
					Grp X Stim: F(1,24) = 0.67, p = 0.42, E = 0.03
					Con X Stim: F(1,24) = 0.66, p = 0.42, E = 0.03
					Grp X Con X Stim: F(1,24) = 1.26, p = 0.27, E = 0.05
P2 standards	0.7 (0.8)	0.7 (0.7)	1.1 (1.3)	0.7 (1.5)	Grp: F(1,24) = 1.88, p = 0.18, E = 0.07
P2 deviants	−1.1 (1.2)	−0.7 (1.4)	0.8 (2.0)	−0.4 (1.9)	**Stim: F(1,24) = 46.47, p < 0.00, E = 0.66 F2**
					Con: F(1,24) = 2.87, p = 0.10, E = 0.11
					Grp X Con: F(1,24) = 9.23, p < 0.00, E = 0.28 F3
					Grp X Stim: F(1,24) = 6.97, p = 0.01, E = 0.22 F4
					Con X Stim: F(1,24) = 0.48, p = 0.49, E = 0.02
					Grp X Con X Stim: F(1,24) = 2.94, p = 0.099, E = 0.11
MMN	−1.8 (1.1)	−1.5 (1.4)	−0.6 (1.1)	−1.1 (1.2)	**Grp: F(1,24) = 5.94, p = 0.02, E = 0.19 F5**
					Con: F(1,24) = 0.07, p = 0.783, E < 0.01
					Grp X Con: F(1,24) = 1.78, p = 0.19, E = 0.07
			Fz		
N1 standards	−5.0 (2.1)	−6.2 (2.5)	−4.4 (1.6)	−5.3 (1.6)	Grp: F(1,24) = 1.05, p = 0.31, E = 0.04s
N1 deviants	−6.7 (1.9)	−7.0 (3.2)	−5.3 (2.0)	−6.8 (2.4)	**Stim: F(1,24) = 44.23, p < 0.00, E = 0.65 F6**
					Con: F(1,24) = 21.94, p < 0.00, E = 0.48 F7
					Grp X Med: F(1,24) = 1.41, p = 0.25, E = 0.06
					Grp X Stim: F(1,24) = 0.06, p = 0.81, E < 0.01
					Con X Stim: F(1,24) = 0.14, p = 0.72, E < 0.01
					Grp X Con X Stim: F(1,24) = 3.07, p = 0.093, E = 0.11
P2 standards	1.9 (1.2)	1.8 (1.4)	1.8 (2.2)	1.1 (2.7)	Grp: F(1,24) = 0.001, p = 0.98, E = 0.06
P2 deviants	−0.8 (2.0)	−0.9 (1.8)	0.1 (3.1)	−1.2 (2.8)	**Stim: F(1,24) = 90.3, p < 0.01, E = 0.79 F8**
					Con: F(1,24) = 7.13, p = 0.013, E = 0.23
					Grp X Con: F(1,24) = 5.54, p = 0.027, E = 0.19 F9
					Grp X Stim: F(1,24) = 2.05, p = 0.17, E = 0.08
					Con X Stim: F(1,24) = 76, p = 0.39, E = 0.31
					Grp X Con X Stim: F(1,24) = 51, p = 0.48, E = 0.02
MMN	−2.7 (1.8)	−2.8 (1.8)	−1.7 (1.5)	−2.3 (1.4)	Grp: F(1,24) = 2.1, p = 0.16, E = 0.08
					Con: F(1,24) = 0.62, p = 0.44, E = 0.02
					Grp X Con: F(1,24) = 0.34, p = 0.53, E = 0.02

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