

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

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23 A recent meta-analysis emphasises that meditation can improve attention in healthy adults
24 (Sedlmeier et al., 2012). The findings of a study by Cahn and Polich (2009) suggests that there is an
25 effect of a meditative state on three event-related potential (ERP) brain markers of low-level
26 auditory attention in expert meditators: the N1, the P2, and the P3a. The current study built on these
27 findings by examining the trait and state effects of meditation on the passive auditory mismatch
28 negativity (MMN), N1, and P2 ERPs. We found that the MMN was significantly larger in
29 meditators than non-meditators regardless of whether they were meditating or not (a trait effect),
30 and that the N1 was significantly attenuated during meditation in non-meditators but not meditators
31 (an interaction between trait and state). These outcomes suggest that low-level attention is superior
32 in long-term meditators in general. In contrast, low-level attention is reduced in non-meditators
33 when they are asked to meditate for the first time, possibly due to cognitive overload.

Attention is a critical component of meditation. Meditation has been described as the intentional regulation of attention (Kabat-Zinn, 1982), and control over attention is the focus of many types of meditative practice, particularly in early stages of meditation training (e.g., Tang & Posner, 2009; Tang, Hölzel, & Posner, 2015). Given the central role that attention appears to play in meditation, it is interesting to note that a meta-analysis of the effects of meditation on cognitive and psychological variables concluded that meditation has only a moderate effect on behavioural measures of attention (Sedlmeier et al., 2012). It is also interesting to note that this meta-analysis did not differentiate the effects of meditation on different "levels" of attention, such as early "low-level" processes of attention (e.g., awareness of a sound) versus to "high-level" attention processes (e.g., sound is interpreted as a meaningful word). 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 overall. To answer this question, we need a better understanding of the strength of the associations that exist between meditation and different types of attention.

The aim of the current study was to contribute to this understanding by measuring the strength of the association between meditation and low-level attention using event-related potentials (ERPs), which allow the measurement of low-level 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 Figure 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).

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), including two studies that focused on low-level auditory attention (Cahn, Delmore, & Polich, 2013; Delgado-Pastor et al, 2014). However, to our knowledge, only one study has used ERPs to measure low-level attention in meditators *during* meditation. Cahn and Polich (2009) tested 16 Vipassana meditators during meditation and non-meditation conditions for their passive ERPs (N1, P2, P3a at midline frontal (Fz), central (Cz), and parietal (Pz) 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 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 in suggesting that meditation may have an effect on low-level auditory attention. However, the strength of this suggestion is mitigated by the absence of a control group of non-meditators (novices) in the study. Further, the non-meditative control condition consisted of a mind-wandering task that resembled in part a meditation according to some meditative practices¹. Additionally, half of the participants were asked to meditate before the mind-wandering task, raising the possibility of meditation "after-effects" confounding measures made during non-meditation control phase. Thus, while the results of Cahn and Polich are important and encouraging, they leave us wondering whether an effect of meditation on low-level attention-related reactivity is 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

¹ For example, across different meditation traditions, 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.

86 whenever anyone meditates), or results from an interaction between both trait and state (i.e., is only
87 present in meditators during meditation).

88 We also wonder whether there might be state or trait effects of meditation on the auditory
89 mismatch negativity (MMN) ERP component, as well as the N1, P2, and P3a ERPs. The auditory
90 MMN is hypothesised to reflect an automatic auditory change detection mechanism that activates a
91 shift in the focus of attention (Escera, Alho, Winkler, & Näätänen, 1998; Escera, Yago, Corral,
92 Corbera, & Nuñez, 2003; though *cf* Garrido, Kilner, Stephan, & Friston, 2009; Jääskeläinen et al.,
93 2004). The MMN is calculated by subtracting a passive ERP to a frequent standard stimulus to a
94 passive ERP to a rare deviant stimulus. The resulting "difference" waveform typically shows a
95 negativity that peaks at around 200 ms in adults that is maximal at fronto-central scalp sites but is
96 also observed at parietal scalp sites (for example see Näätänen, Paavilainen, Rinne, & Alho, 2007).
97 It is generally thought that the MMN is generated by neurons in temporal and pre-frontal brain
98 regions (Garrido et al., 2009).

99 No study has compared the auditory MMN in meditators and non-meditators *during*
100 meditation. However, one study has found that meditators had a larger average MMN after
101 Sudarshan Kriya Yoga than non-meditators, who did a relaxation session (Srinivasan & Baijal,
102 2007). While this study did well to include a control group of non-meditators, it confounded the
103 comparison of meditators and non-meditators by applying different conditions to each group (yoga
104 for the experimental group and relaxation for controls).

105 With both the findings and limitations of the studies by Srinivasan and Baijal (2007) and
106 Cahn and Polich (2009) in mind, the aim of the current study was to measure the association
107 between meditation and low-level attention by comparing the MMN ERP of expert meditators to
108 novice non-meditators (i.e., controls) during meditation and non-meditation. Since the MMN
109 requires the measurement of the N1 and P2 peaks to standard and deviant sounds, we also had the
110 opportunity to test the reliability of Cahn and Polich's N1 and P2 effects. From the findings of
111 Srinivasan and Baijal (2007), *we tentatively 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 compared to non-meditators).

2. Method

2.1 Ethics

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

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 per day (M= 20.67, SD = 8.89, 10-35 years). 14 non-meditators (two males, twelve females, mean age: 52.55 years, SD = 15.77, minimum of 30-67 years) formed the control group. The small difference between the mean ages of the two groups was not statistically significant, $t(24) = 1.60, p = .12$. 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.

2.3 Experimental stimuli

The stimuli comprised two 13-minute 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). Deviant tones were presented after a sequence of successive standard tones (randomized), on average 5.5. Tones were separated by a jittered stimulus-onset asynchrony (SOA)

138 of a stimulus (Lang et al., 1995).

139 **2.4 Electroencephalogram (EEG) recording**

140 Participants were seated in a comfortable chair for the EEG set up. To facilitate impedance
141 reduction, each participant’s scalp was combed prior to fitting the electrode cap (Mahajan &
142 McArthur, 2010), which was an EasyCap with sintered Ag-AgCl electrodes placed at scalp sites
143 positioned according to the International 10-20 system (Fz, Fp1, Fp2, F3, F4, FC3, FC4, FT7, FT8,
144 F7, F8, C3, C4, CP3, CP4, Cz, Pz, FCz, O2, O1, Oz, P3, P4, P7, P8, T7, T8, TP7, TP8, M2). The
145 left mastoid (M1) served as online reference and the right mastoid (M2) an offline reference.
146 Vertical eye movements (VEOG) were measured with electrodes placed above and below the left
147 eye. Horizontal eye movements (HEOG) were recorded using electrodes placed on the outer canthi
148 of each eye. The ground electrode was positioned between FPz and Fz. The scalp-electrode
149 impedance was kept below 5kΩ. The EEG was sampled at each site using the Neuroscan system
150 and Acquire software (version 4.3) using a 1000-Hz sampling rate and an online bandpass filter of
151 0.05-200 Hz. The raw EEG data was stored for offline processing.

152 **2.5 Offline EEG processing**

153 A standard ocular reduction algorithm (Semlitsch et al., 1986) was used to remove the VEOG
154 activity from the EEG data. The EEG data was (1) re-referenced to both mastoids, which were
155 mathematically linked, (2) bandpass filtered (0.1-Hz high pass and 30-Hz low pass; 12-dB-per-
156 octave roll-off), and (3) divided into 600-ms epochs including a 100-ms pre-stimulus interval,
157 which was used for baseline correction. Any epoch that contained a voltage change exceeding ±
158 150 µV was removed from further analysis. All epochs generated by the 1000-Hz standard and
159 1200-Hz deviant tones were averaged to produce a “standard ERP” and a “deviant ERP”,
160 respectively. To calculate the “MMN ERP”, the 1000-Hz standard ERP was subtracted from 1200-
161 Hz deviant ERP (i.e., a difference waveform).

163 In line with previous research, the N1, P2 and MMN ERPs were measured at frontal (Fz) and
164 parietal (Pz) sites (Särkämö et al., 2010; Restuccia, Della, Marra, Rubino, & Valeriani, 2005). It is
165 noteworthy that, unlike Cahn and Polich (2009), we did not measure the P3 since this peak is
166 inhibited under conditions used to generate the MMN (i.e., where attention is focused away from
167 auditory stimuli).

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

179 2.7 Procedure

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

184 During the non-meditation condition, participants were administered the standard and
185 deviants sounds through the headphones whilst they imagined building a tree house. The
186 instructions for this non-meditative task were as follows:

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

196 During the meditation condition, individuals were presented the same standard and deviant
 197 sounds whilst they attempted to meditate. The instructions were as follows:

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

207 At the end of the meditation condition, participants were asked use a 7-point scale to rate: (1)
 208 their ability to concentrate on the breath, and (2) the percentage of time they were able to
 209 concentrate on the breath.

210 **2.8 Statistical Analyses**

211 We tested datasets for equal variance using the Levene Test for Error Variance. Ten of the
 212 twelve datasets (N1, P2, and MMN for the expert and novice meditators at Fz and Pz) did not differ

significantly from normal ($F = 0.16 - 4.02$, $p > .05$) while two did (P2 at Pz: $F(1, 24) = 4.37$, $.047$; Fz at N1: $F(1, 24) = 4.50$, $p = .04$). 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, Figure 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, Figure 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 Figure 1 and the graphs in Figure 2 suggest that there is a reliable group by condition interaction ($F(1, 24) = 9.67$, $p = .005$, $E = .29$) because the N1 was smaller

(i.e., more positive) during meditation than non-mediation in non-meditators, but did not differ

much between these conditions in meditators (see also Appendix 1). The data also revealed a trend for a larger N1 to deviants than standards across the two stimuli groups - an effect that only just failed to reach statistical significance ($F(1, 24) = 3.71, p = .066, E = .13$).

Regarding P2, the data and figures revealed a reliable effect of stimulus because the P2 was smaller to deviants (i.e., more negative) than to standards overall ($F(1, 24) = 46.47, p < .005, E = .66$). 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 (i.e., P2 was larger) in the meditation condition than the non-meditation condition in meditators but with little difference between conditions in meditators ($F(1, 24) = 9.23, p < .005, E = .28$). Unlike the N1, there was an additional group by stimulus interaction for P2 because the P2 was more negative (i.e., noticeably smaller) to deviants relative to standards in meditators than non-meditators – particularly in the meditation condition ($F(1, 24) = 6.97, p = .01, E = .22$).

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 across conditions than the non-meditators ($F(1, 24) = 5.94, p = .02, E = .19$). 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.

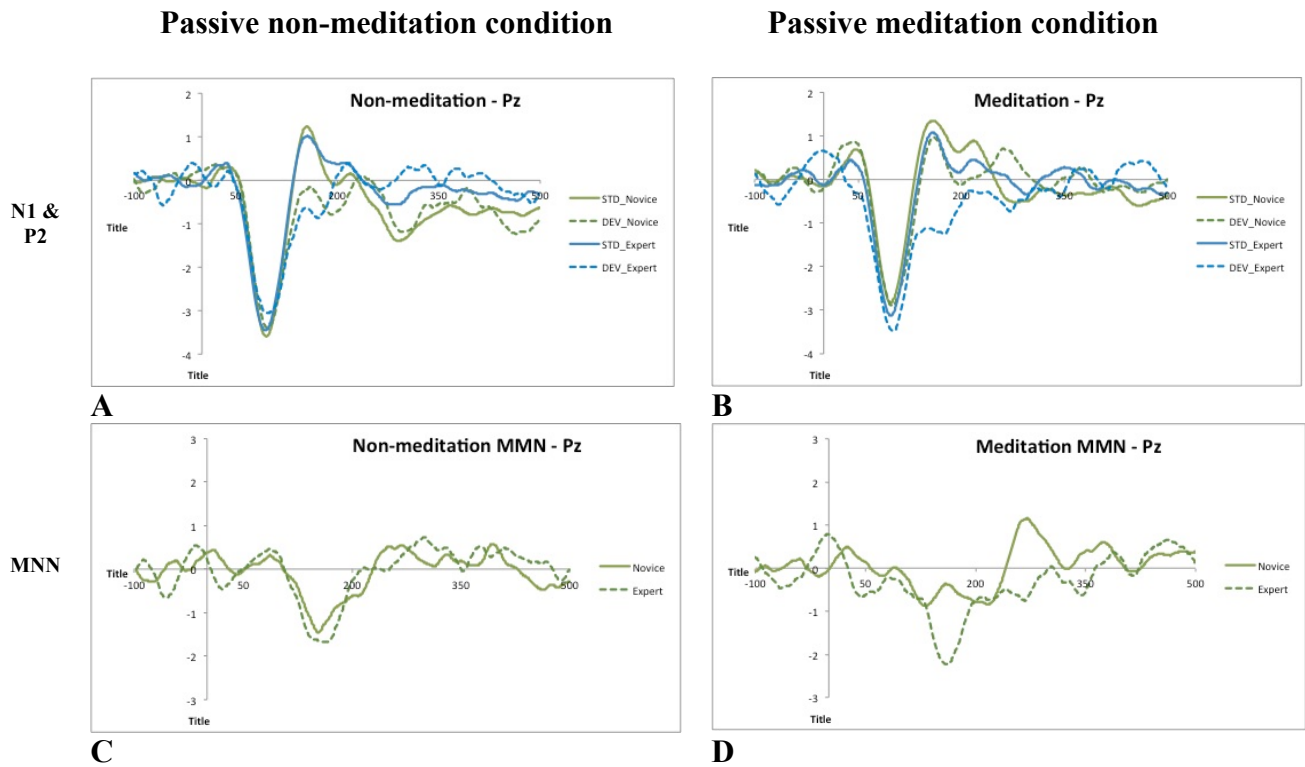


Figure 1: Examples and results for positive and negative peaks across conditions.

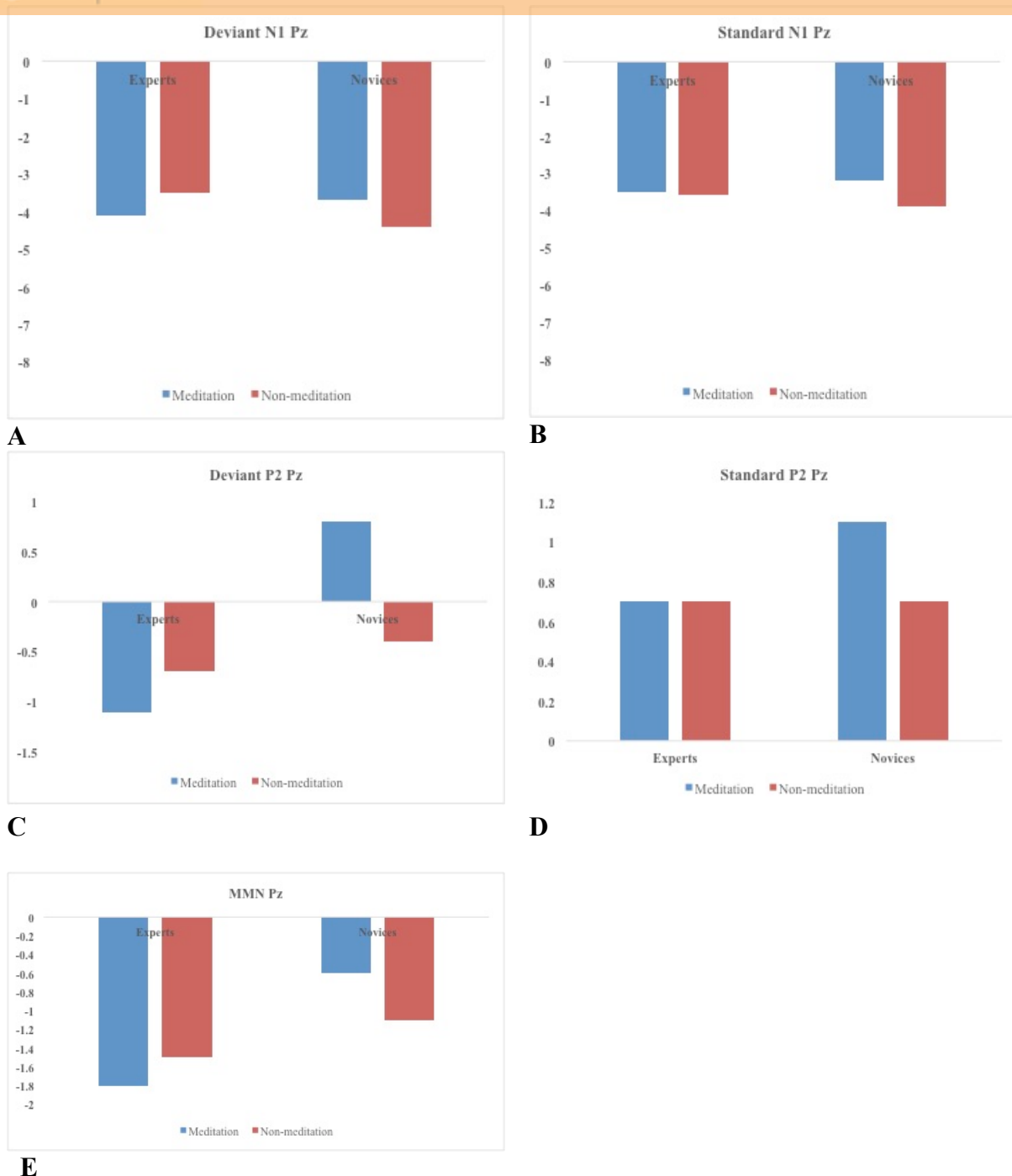


Figure 2: Amplitudes of N1, P2, and the MMN for each groups to each stimulus in each condition at Pz.

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 novice non-meditators (i.e., controls) during meditation and non-meditation. Since the MMN requires the

274 measurement of the N1 and P2 peaks to standard and deviant sounds, we also had the opportunity to
275 test the reliability of Cahn and Polich's (2009) findings relating to the effect of meditation on the N1
276 and P2 on meditators which suggested that meditation reduces the N1 and P2 to deviant or
277 distractor sounds (but not standards) in meditators. We tested 12 expert meditators and 14 novice
278 meditators during periods of meditation and non-meditation for three passive auditory ERPs (the
279 N1, the P2, and the MMN) generated by frequent standard and infrequent deviant tones. Below, we
280 use the outcomes of the analysis of this data to discuss the MMN, P2, and N1. We then consider
281 some methodological challenges and considerations for future studies of the effect of meditation.

282 4.1 The MMN

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

296 The mismatch between the waveforms and the statistics could have occurred for at least two
297 reasons: First, it is possible that there is no reliable relationship between meditation experience and
298 meditative state, and that long-term meditators have a larger MMN than non-meditators regardless
299 of whether they are meditating or not. Such a pattern would be interesting, as it suggests that a

300 seemingly "high-level" activity like meditation can have an impact on - and indeed improve - a

301 relatively low-level ability that relates to the detection of change in sounds that is done
302 automatically without overt attention and generalises to more reliable low-level attention beyond
303 the meditation condition.

304 A second explanation for the mismatch between the waveforms and the statistics relates to
305 the reliability of the MMN ERP itself. Researchers have expressed concerns about the lesser
306 reliability of the MMN under some conditions – here in healthy adults (Badcock, Mousikou,
307 Mahajan, de Lissa, Thie, & McArthur, 2013; Mahajan & McArthur, 2001). Of less concern is the
308 reliability of the P2 in adults, which not only underpinned the MMN in this experiment (i.e., the
309 MMN is based on the difference between the waveforms in the P2 region), but showed an
310 interaction between meditation experience and the meditative state. Additionally, the P2 allows for
311 an analysis of brain potentials evoked by both the standard and the deviants rather than a simple
312 subtraction of the two, and thus allows for the comparison of how the conditions may have
313 differentially affected these brain responses. Thus, we discuss the P2 next.

314 4.2 The P2

315 In contrast to the MMN, both the waveforms and statistics for the P2 supported a reliable
316 interaction between the effect of meditation on trait (i.e., meditators versus non-meditators) and
317 state (meditation versus non-meditation). Specifically, the P2 was clearly more positive (i.e., larger)
318 during meditation and then during non-meditation in non-meditators, but there was little difference
319 between the meditators' P2 in these two conditions. In addition, there was an interaction between
320 trait (i.e., meditators versus non-meditators) and stimulus (standard versus deviant tones) because
321 there was a smaller difference between the P2 to standards and deviants in the non-meditators than
322 in the meditators. The fact that (1) the P2 occurred at the same time as the MMN in this study, and
323 (2) the statistically significant interactions in the P2 data supported the non-significant trends in the
324 MMN data, suggest that the significant effects of state and trait on the P2 explained similar non-

325 significant trends on the MMN, which failed to reach significance due to the poorer reliability of the
326 MMN relative to the P2.

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

339 4.3 The N1

340 Cahn and Polich (2009) also examined the effect of meditation in meditators on the N1.
341 Similar to the P2, they found that meditation reduced the N1 to deviants or distractors but not to
342 standards. The current study partially supported this finding. It also found that, in meditators, the
343 N1 to standards was similar during meditation and non-meditation. However, in contrast to Cahn
344 and Polich, it also found that the N1 in meditators to deviants was larger during meditation (-4.1)
345 than during non-meditation (-3.5). Interestingly, this effect was reversed in non-meditators, whose
346 N1 was smaller during meditation (-3.7) than during non-meditation (-4.4). Again, the difference
347 between the effects in the meditators and non-meditators further support the conclusion that
348 meditation may have different effects in people with different degrees of meditation experience, and
349 that neurophysiological indices might be altered in non-meditators, but that this non-meditation

350 pattern looks different to the long-term meditation pattern in the beginning of exposure to their
351 meditation experience.

352 It is noteworthy that the opposing effects of meditation on the N1 in non-meditators
353 compared to long-term meditators resulted in the same significant interaction between trait
354 (meditators versus non-meditators) and state (meditation versus non-meditation) that we observed
355 for the P2. Specifically, both the N1 and the P2 were less negative during meditation compared to
356 non-meditation in non-meditators, making the N1 smaller and the P2 larger. The similarity of this
357 interaction suggests that the effects of state and trait on the N1 and P2 ERPs in this study may
358 reflect the same theoretical construct. Further, since the P2 appears to explain the MMN, it is
359 possible that all the effects in this study may relate to the same construct. What might this
360 theoretical construct be?

361 4.4 Theory

362 The decreased negativity (and hence increased positivity) of non-meditators' N1, P2, and
363 MMN ERPs during meditation – particularly to deviant sounds – suggests a kind of inhibition of a
364 low-level attentional ability to detect a deviance in incoming sounds, manifesting in a decreased
365 differentiation between the standard and deviant tones. This inhibition is best illustrated in Figure
366 1(a-d) that shows that, unlike long-term meditators, non-meditators do *not* have a reduced P2 during
367 meditation that is typically observed in an auditory oddball paradigm. We know that our non-
368 meditators were capable of producing such a typical reduction in P2 because they clearly produced
369 a reduced P2 in the non-meditation condition. However, in the meditation condition, their brain
370 appears to be treating deviant sounds the same way as standard sounds. Why might this be the case?

371 A recent review by Fox et al. (2014) suggests that focussed meditation practice is associated
372 with changes in brain areas thought to be responsible for cognitive control, attention regulation, and
373 mind wandering. Meta-analyses from Sedlmeier et al. (2012), Ebert and Sedlmeier (2012) and
374 Goyal et al. (2014) have made similar conclusions based on behavioural measures and measures of
375 psychological stress and well-being. The conclusions of these meta-analyses provide two possible

376 explanations for why the brain's of non-meditators during meditation appear to respond to deviant
 377 sounds in the same way as standard sounds. The first relates to *attention regulation*. It is possible
 378 that meditating for the first time focuses a person's attention so completely on the breath that it
 379 inhibits even automatic low-level attentional capabilities that typically function under "passive"
 380 conditions that do not require a listener's overt attention (e.g., while a participant watches a movie).
 381 The second relates to *cognitive overload*. In the current study, participants were asked to act upon a
 382 series of meditation instructions that are unfamiliar to non-meditators (please see Methods). This
 383 included instructions about breath counting, what to do when thoughts arose, and what to do if
 384 sounds intruded into the breath counting. While a very familiar task to experienced meditators,
 385 carrying out such multi-layered instructions for the first time might place greater cognitive load on
 386 non-meditators compared to long-term meditators. A cognitive overload also reduces the capacity
 387 of an automatic low-level attention system to detect a deviance in a stream of sounds, while being
 388 occupied with the difficult task to keep count of the breath. A non-meditator's strategy might be to
 389 block out incoming sounds to not lose track of the breath. It is possible that with extended
 390 meditation practice, the effect of meditation might free up resources needed to alleviate attention
 391 regulation or a cognitive overload. This in turn will dissolve any inhibition or overload of low-level
 392 auditory attention, which would explain why experienced meditators do not show such inhibition or
 393 overload in the processing of deviant sounds during meditation. This possibility, which we offer
 394 tentatively, reinforces our previous point that it *cannot* be assumed that meditation has the same
 395 effect in non-meditators as meditators, and further suggests that in order to fully understand the
 396 effect of meditation on the brain and cognition requires longitudinal studies that track the effects of
 397 meditation practice in novice meditators over time.

398 5. Summary and Conclusion

399 The difference of neurophysiological patterns between long-term meditators and non-
 400 meditators in the MMN and P2 indices suggests that meditation indeed alters brain responses after
 401 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 P2 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 the each group (experienced versus novice meditators) in each condition (meditation versus non-meditation [Non-med.]) are shown in Table 1, 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-med.	Meditation	Non-med.	
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=.84, E<.01 Stim: F(1,24)=3.71, p=.066*, E=.13 Con: F(1,24)=2.21, p=.15, E=.08 Grp X Con: F(1,24)=9.67, p=.005, E=.29 F1
N1 deviants	-4.1 (1.1)	-3.5 (1.5)	-3.7 (2.4)	-4.4 (2.1)	Grp X Stim: F(1,24)=.67, p=.42, E=.03 Con X Stim: F(1,24)=.66, p=.42, E=.03 Grp X Con X Stim: F(1,24)=1.26, p=.27, E=.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=.18, E=.07 Stim: F(1,24)=46.47, p<.00, E=.66 F2 Con: F(1,24)=2.87, p=.10, E=.11 Grp X Con: F(1,24)=9.23, p<.00, E=.28 F3
P2 deviants	-1.1 (1.2)	-0.7 (1.4)	0.8 (2.0)	-0.4 (1.9)	Grp X Stim: F(1,24)=6.97, p=.01, E=.22 F4 Con X Stim: F(1,24)=.48, p=.49, E=.02 Grp X Con X Stim: F(1,24)=2.94, p=.099, E=.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=.02, E=.19 F5 Con: F(1,24)=.07, p=.783, E<.01 Grp X Con: F(1,24)=1.78, p=.19, E=.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=.31, E=.04s Stim: F(1,24)=44.23, p<.00, E=.65 F6 Con: F(1,24)=21.94, p<.00, E=.48 F7 Grp X Med: F(1,24)=1.41, p=.25, E=.06 Grp X Stim: F(1,24)=.06, p=.81, E<.01 Con X Stim: F(1,24)=.14, p=.72, E<.01 Grp X Con X Stim: F(1,24)=3.07, p=.093, E=.11
N1 deviants	-6.7 (1.9)	-7.0 (3.2)	-5.3 (2.0)	-6.8 (2.4)	
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=.98, E=.06 Stim: F(1,24)=90.3, p<.01, E=.79 F8 Con: F(1,24)=7.13, p=.013, E=.23 Grp X Con: F(1,24)=5.54, p=.027, E=.19 F9
P2 deviants	-0.8 (2.0)	-0.9 (1.8)	0.1 (3.1)	-1.2 (2.8)	Grp X Stim: F(1,24)=2.05, p=.17, E=.08 Con X Stim: F(1,24)=76, p=.39, E=.31 Grp X Con X Stim: F(1,24)=51, p=.48, E=.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=.16, E=.08 Con: F(1,24)=.62, p=.44, E=.02 Grp X Con: F(1,24)=.34, p=.53, E=.02