Chapter 3

Attention

3.1 Introduction

Attention has been investigated by psychologists since the late nineteenth century and much more recently by neuroscientists, yet the majority of research has focused on individuals with normal or impaired attention (Wallace 2006). Concentrative meditation offers an opportunity to study the potential for training attention and how this faculty, developed through one activity, might be applied to another. Notwithstanding over five decades of electroencephalographic (EEG) studies of meditative states, accord about the neurophysiological processes involved in meditation has yet to be reached (Cahn & Polich 2006). Studies examining changes in sensory evoked potential (EP) and cognitive event-related potential (ERP) recordings are beginning to reveal the ability of different meditation practices to influence sensory processing (Barwood et al. 1978; Liu et al. 1990; McEvoy et al. 1980; Panjwani et al. 2000; Slagter et al. 2007; Srinivasan & Baijal 2007; Telles et al. 1999; Zhang et al. 1993) and attentional resource allocation (Banquet & Lesèvre 1980; Cahn & Polich 2008; Cranson et al. 1990; Goddard 1989, 1992; Lutz et al. 2009). Although evoked potentials and event-related potentials can be obtained with different modalities (Picton 1992; Picton & Hillyard 1974; Polich 2003), differences between stimulus modalities during meditation have not yet been systematically investigated (Cahn & Polich 2006). In 1980, Banquet and Lesèvre reported larger P2 amplitudes in meditators before and after meditation, relative to controls in a go/no-go visual task. Meditators also demonstrated greater accuracy and shorter behavioural response latencies before and after meditation compared to controls. In addition, P3 amplitude increased in meditators after meditation and decreased in controls after rest. This experiment extends Banquet and Lesèvre's work by examining the auditory modality and investigating divided attention in addition to selective attention.

That meditation is an attentive and vigilant mental state has already been supported by evidence of increased alpha and theta EEG frequency power (Banquet 1972; Corby et al. 1978; Herbert & Lehmann; Hirai 1974; Kasamatsu & Hirai 1966; Kasamatsu et al. 1957) as well as EEG coherence (Aftanas & Golocheikine 2005; Travis et al. 2002). There are very few controlled neuroimaging studies on meditation, however Newberg et al. (2001) revealed loci of activation in frontal and prefrontal areas using fMRI, suggested to index increased attentional demand during meditation.

Considering the neuroscientific and Buddhist models of consciousness, evoked and event-related brain potentials are speculatively postulated to correspond to stages or aggregates of perception (Table 1.1). Brainstem potentials reflecting initial sensory processing within the first 10 ms of the onset of a stimulus (Luck 2005) correspond to the first aggregate called form or matter (viz. physical sense organs interacting with the external world). Middle latency potentials reflect initial cortical processing occuring between 10 and 50 ms (Luck 2005) and correspond to the second aggregate called sensation or feeling (that is, the resulting experience from object or stimulus interaction). Longer latency potentials such as the P1, N1, P2 and N2 reflect primary cortical activation and can be influenced by attention. The third aggregate, perception or discrimination, would be represented by these later components indicating the basic conscious registration of objects, such as sounds and shapes. Finally, the P3 component reflects conscious mentation, such as target recognition in an oddball paradigm (Nunez & Srinivasan 2006) and corresponds to the fourth aggregate called mental formations or impulses which includes thoughts and decisions evoked by an object (Guenther

1976).

The present study aimed to assess acute and long-term effects of concentrative meditation on attentional processing in experienced practitioners. Subjects were asked to respond to target stimuli randomly interspersed among non-target and distractor stimuli during audiovisual continuous performance attention tasks. Event-related potentials were used to assess attentional resource allocation and were correlated with behavioural performance measures (viz. response accuracy and latency).

It is quickly becoming apparent from recent evidence that meditation practice can result in improved attentional performance (sustainment and flexibility), modified attentional subsystems (alerting and orientating) and activated cortical regions involved in attention (Cahn & Polich 2006).

A number of psychological studies have reported changes in attentional performance in meditators. Significant improvements in stimulus detection and orientating in meditators during a stimulus detection task was suggested to imply more highly developed receptive attention skills, as well as improved abilities to endogenously orientate attention (Jha et al. 2007). Meditators have also demonstrated increased attentional flexibility and sustainment during a divided-attention task as measured by response times and readiness to shift attention (Rutschman 2004). In addition to this, increased control over the distribution of brain resources via the enhanced ability to stabilise the mind during concentrative meditation is substantiated by evidence of greater attention-related perceptual stability in meditators during a perceptual binocular rivalry task (Carter et al. 2005).

These findings are also supported by results from neuroelectric and neuroimaging studies. Activation of brain regions involved in sustained attention and self-monitoring (Brefczynski-Lewis et al. 2007; Newberg et al. 2001) and changes in brain potentials over dorsal posterior electrode sites during an attentional-blink task (Slagter et al. 2007) suggest an ability in meditators to modify brain resource allocation and effectively control cognitive processes involved in concentration.

3.2 Hypotheses

Here will be outlined hypotheses relating to behavioural trait and state effects as well as event-related potentials.

3.2.1 Trait and state effects (behavioural)

Based on the aforementioned findings, MEDITATORS [1] are hypothesied to perform better (greater response accuracy and shorter response latencies) on all attention tasks *before* the meditation condition, relative to *controls*. Increases in performance are expected to demonstrate a *trait* effect of meditation on attentional ability, that is, increased ability to remain focused on the task at hand with reduced distractor interference. MEDITATORS are also hypothesised to perform better on all attention tasks *after* the meditation condition, relative to *controls*, demonstrating an acute *state* effect of meditation on attentional ability. These effects are hypothesised to result from the activation of attentional networks during meditation, allowing MEDITATORS to more effectively focus during the task (again with reduced distractor interference). In other words, meditating before performing the attention task will improve behavioural responses by enhancing attentional functioning. *Controls* are hypothesised to demonstrate a minor improvement in performance after the meditation condition due to a practise effect which will also be present in MEDITATORS.

3.2.2 Event-related potentials

Based on previous literature and postulated correlations between the Buddhist model of perception and brain potentials, MEDITATORS are hypothesised to exhibit shorter latencies and larger amplitudes in P1, N1 and P2 components reflecting augmented attention to stimuli and less task interference from internal and external distraction. MEDITATORS are also hypothesised to exhibit increases in P300 amplitudes and decreases in P300 latencies during the attention task,

[1] To facilitate the reading of hypotheses, results and discussion the word "meditators" will be written in SMALL CAPS and the word "controls" in *italics*.

relative to controls. This P3 effect is expected to be greater after the meditation condition and will reflect MEDITATORS' increased control over the allocation of brain resources in regard to attention (Polich 2003). During a more focused state, the detection of targets and the ability to ignore non-targets and distractors is expected to be facilitated.

3.3 Methods

The study was approved by the Clinical Research Ethics Committee of Flinders University and Flinders Medical Centre (application reference 109/067). The meditation technique practised at Lifeflow is derived from Theravadin and Vajrayana Buddhist traditions and encompasses both the concentrative and insight aspects of meditation (see §1.3). However, only concentrative meditation was investigated in this study. The methods in this chapter include information relevant to all chapters, for example, ethics approval and EEG aquisition.

3.3.1 Experimental sequence

The attention experiment here was the first experiment that subjects undertook. By ordering the attention experiment before the meditation experiment, we aimed to avoid any effects meditation might have on attention task performance, thereby allowing us to more accurately assess the trait effects of long-term meditation on attentional performance. The meditation and perception experiments which followed the attention experiment were counterbalanced between subjects and groups to avoid any order effects. The sensory processing experiment (§6) was always presented subsequent to the perception experiment (§5) to reduce the impact that continuous exposure to bright light (during sensory processing experiment) would have on the detection of faint flashes of light (perception experiment). All subjects arrived at the lab in the morning and overall the experiment required approximately 4–5 hours, including around an hour to set up equipment and electrodes.

3.3.2 Attentional processes

The two attentional sub-processes examined here were 1) selective or focused attention to a particular stimulus and 2) divided attention between two or more different stimuli. More specifically, focused attention is described as the short-term ability to voluntarily attend to a given task or object, that is, the *selection of* an object. Focused attention is specifically relevant to concentration meditation and refers here to attending to one sense while ignoring another sense, during the presentation of bimodal (audiovisual) stimuli. Divided attention on the other hand describes the ability to shift attention between stimuli and stimulus modalities, that is, the *division* of attention *between* objects. The definition of divided attention here refers to simultaneously attending to two senses during the presentation of bimodal (audiovisual) stimuli. It should be noted that in other research experiments in the past, divided attention has been defined and examined within one sensory modality, as when a subject is asked to focus on audio stimuli in one ear while ignoring stimuli in the other ear (Luck 2005; Picton & Hillyard 1974). However, as one reported quality of meditation is the ability to maintain awareness of multiple sensory objects, how attention is divided among sensory modalities is of particular interest. Psychological interest in divided attention has focused on how well people can perform two simultaneous tasks and how much, if any, performance decrement in one task occurs due to performing the other task.

3.3.3 Subjects

Although a total of thirteen MEDITATORS and thirteen non-meditator *controls* were recruited for the project, not all twenty-six subjects were included in all four experiments due to subject and equipment complications. The subject table below (Table 3.1) provides the details of included subjects. Details in each chapter's relevant section are also given regarding those subjects which were excluded.

Out of the twenty-six subjects recruited for the project, three MEDITATORS were excluded from the attention experiment due to one subject misunderstanding

Pair no.	Gender	Handedness	Education level	Age of meditator	Age of control
01	F	Right	Secondary	35	34
02	F	Right	Tertiary	33	32
03	F	Right	Tertiary	46	47
04	F	Right	Tertiary	55	53
05	F	Right	Tertiary	59	57
06	F	Right	Tertiary	64	59
07	F	Left	Tertiary	40	41
08	M	Right	Tertiary	30	26
09	M	Right	Tertiary	53	57
10	M	Right	Tertiary	62	63
11	M	Left	Tertiary	29	29
12	M	Left	Tertiary	39	34
13	M	Left	Tertiary	62	62

Table 3.1: **Subject pairs used in experiments.**

the instructions, one subject being unable to complete the experiment and one subject's data missing due to equipment malfunction. *Controls* paired to these subjects also had to be excluded to ensure that only pair-matched subjects were included in analyses. Therefore, ten MEDITATORS (♀ 4, ♂ 6, age $\overline{x}$=45.2 years, range 29–64 years) with 3–30 years meditation experience ($\overline{x}$=14 years) from the Lifeflow Meditation Centre in Adelaide, South Australia participated in the attention experiment and all MEDITATORS were pair-matched with non-meditator *controls* for age (± 6 years), gender, handedness and education level (§2.7.2.2).

3.3.4 Neurological evaluation

Before participating in the experiment, all subjects underwent a neurological evaluation by our neurologist colleague to determine if any subjects had any serious neurological illnesses, in which case they were omitted from the study. All subjects were also subjected to a National Adult Reading Test (NART) (Nelson 1982) which gave a relatively accurate measure of intellectual function (that is, intelligence quotient, IQ) by assessing the ability to read non-phonetic words. This test also helped to ensure cognitive functioning was not impaired.

3.3.5 Pre-study respite

The day preceding the experiments, meditators spent time at an isolated location (meditation retreat) where they practised meditation and relaxed. This period of respite was designed to optimise the maintenance of meditative states during the experiment. *Controls* also spent the day before the experiment in relaxation and general passivity, i.e., not working or over-exerting themselves. Although all subjects were required to undertake their normal routine (for example, basic exercise and activities) and dietary intake (for example, coffee and alcohol), this pre-study remission restricted subjects from taking illicit drugs as this behaviour may have significant neurophysiological effects for the following day.

3.3.6 Phenomenological reports

Meditative competency questionnaire

All participating meditators were asked to complete a *meditation competency questionnaire* (see Appendix A) designed by the author. This enabled us to gather details about each practitioner's meditative history and experience so that it could be confirmed that all subjects met the inclusion criteria (viz. sufficiently experienced and able to reach all meditative states).

Pre-study report

Prior to beginning any experiments on the day, all subjects were asked to fill out a *pre-study report* (see Appendix B) designed by the author. This was to record pre-study respite activities, including the amount of recent meditation practise for meditators in order to ensure that all subjects' mental and physiological states were normal before the experiment.

Post-study report

In order to correlate the experiences during the experiments with neurophysiological data, subjects were finally asked to fill out a *post-study questionnaire* (see

Appendix C) designed by the author. This report assessed the subjects' physical, mental and emotional experiences during the experiments by asking them to describe their experiences in terms of focus, levels of drowsiness or relaxation, degree of thought occurrence, etc. The reports were used to assess if each state had been successfully achieved (see Table 4.1).

3.3.7 Stimuli

The attention task used in this experiment was derived from one used by Degerman et al. (2007). The experiment consisted of three different attention tasks, during which audiovisual stimuli were presented. Each stimulus was a combination of a harmonic tone (high or low pitch) and a coloured circle (red or blue), with the stimuli components (tone and circle) being either long or short in duration (viz. 200 ms and 50 ms, respectively). Tones were presented binaurally via pneumatic headphones through foam earplugs at a comfortably loud volume and the frequencies of the high and low tones were 1000 Hz and 500 Hz, respectively. Visual stimuli were solid red and blue circles appearing approximately 7 cm in diameter in the centre of a computer screen displaying a black background. During all tasks, a white cross was presented continuously in the centre of the screen, on which subjects were asked to fixate. All possible combinations of circles and tones (red-high, red-low, blue-high, blue-low) were presented randomly, but in such a way that prevented two targets from occurring consecutively. A total number of 360 stimuli were presented per task and each stimulus had a randomly varying offset-to-onset interval (or interstimulus interval, ISI) of 500–700 ms (Figure 3.1). A short ISI was chosen in order to include a sufficient number of trials required for ERP averaging in the limited experimental timeframe (see below).

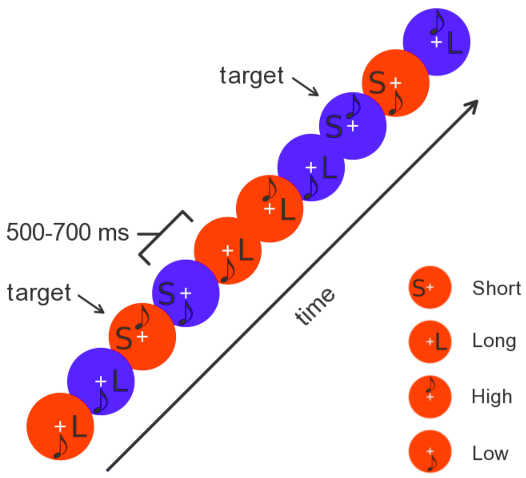

Figure 3.1: **Example of the audio attention task.** Targets are high tones presented for a short time (50 ms) and are interspersed between distractors and non-targets (50 or 200 ms, respectively). Letters within the circles indicate whether the stimulus was presented for a long time (L) or a short time (S) and the position of the musical notes indicates if the tone was high or low.

3.3.8 Experimental protocol

The experiment consisted of two audio tasks, two visual tasks and two audiovisual tasks (Figure 3.2) and was preceded by an eyes-open and an eyes-closed baseline which were both 30 seconds in duration.

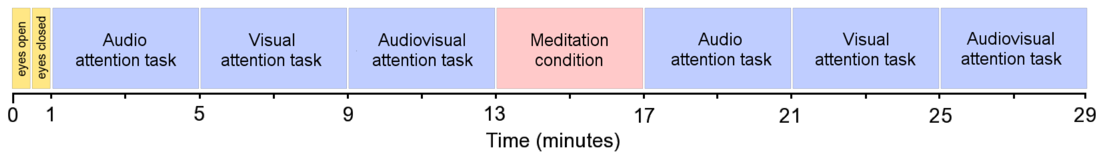

Figure 3.2: **Protocol for the attention experiment.** Eyes-open and eyes-closed baselines were performed first. Three attention tasks (viz. audio, visual and audiovisual) were followed by a four minute meditation condition and then another three attention tasks, in the same order. Each task lasted approximately four minutes.

After preparatory instructions, three attention tasks (one audio, one visual and one audiovisual) were presented. These tasks were followed by a four minute meditation condition, which was then followed by a repetition of the three attention tasks (one for each modality). During the meditation condition, all subjects were asked to follow instructions for the second absorption as closely as possible (§1.3.5). The instructions were to follow the breath down through the centre of the body as they breathed in and up though the centre of their body as they breathed out. The order of the three attention tasks was counterbalanced between subjects to avoid any task-order effects, however, within each subject, the task order was identical before and after the meditation condition. Each task lasted approximately four minutes in duration and the total experiment time was approximately 29 minutes.

Audio and visual tasks

During the audio and visual tasks, subjects were requested to selectively attend to either high tones or red circles, respectively, and respond with a button press when any stimuli of a short duration (50 ms) were detected (Tables 3.2 and 3.3).

Audio task	Target	Distractor	Non-target
1. High tone (50 ms) + red circle (200 ms)	10%		
2. High tone (50 ms) + blue circle (200 ms)	10%		
3. Low tone (50 ms) + red circle (200 ms)		10%	
4. Low tone (50 ms) + blue circle (200 ms)		10%	
5. High tone (200 ms) + red circle (200 ms)			15%
6. High tone (200 ms) + blue circle (200 ms)			15%
7. Low tone (200 ms) + red circle (200 ms)			15%
8. Low tone (200 ms) + blue circle (200 ms)			15%

Table 3.2: **Audio attention task stimuli.** Note the durations of the audio (tones) and visual (circles) stimuli for the audio task. Combinations determine whether a stimulus is a target, distractor or a non-target. The percentages in the target, distractor and non-target columns represent the proportions of stimulus presentations.

Visual task	Target	Distractor	Non-target
1. Red circle (50 ms) + high tone (200 ms)	10%		
2. Blue circle (50 ms) + high tone (200 ms)		10%	
3. Red circle (50 ms) + low tone (200 ms)	10%		
4. Blue circle (50 ms) + low tone (200 ms)		10%	
5. Red circle (200 ms) + high tone (200 ms)			15%
6. Blue circle (200 ms) + high tone (200 ms)			15%
7. Red circle (200 ms) + low tone (200 ms)			15%
8. Blue circle (200 ms) + low tone (200 ms)			15%

Table 3.3: **Visual attention task stimuli.** Note the durations of the visual (circles) and audio (tones) stimuli for the visual task. Combinations determine whether a stimulus is a target, distractor or a non-target. The percentages in the target, distractor and non-target columns represent the proportions of stimulus presentations.

These infrequent stimuli were defined as targets and comprised 20% (72 targets) of the total 360 stimuli in each of the audio and visual tasks. 20% of stimuli also had shorter durations within the attended modality, but were the wrong pitch or colour, for example, low tones in the audio task or blue circles in the visual task. These stimuli were defined as distractors. The remaining stimuli (60%) were defined as non-targets. All visual components (circles) of the stimuli in the audio task were presented for 200 ms to avoid the visual stimulus containing any information regarding the duration of audio stimuli (Table 3.2). This convention was the same for audio components (tones) of the stimuli in the visual task (Table 3.3).

Audiovisual task

During the audiovisual task, subjects were requested to selectively attend to the combination of red circles and high tones and respond when they detected red-high combinations with shorter durations (50 ms) (Table 3.4).

Audiovisual task	Target	Distractor	Non-target
1. Red circle (50 ms) + high tone (50 ms)	10%		
2. Blue circle (50 ms) + high tone (50 ms)		10%	
3. Red circle (50 ms) + low tone (50 ms)		10%	
4. Blue circle (50 ms) + low tone (50 ms)		10%	
5. Red circle (200 ms) + high tone (200 ms)			15%
6. Blue circle (200 ms) + high tone (200 ms)			15%
7. Red circle (200 ms) + low tone (200 ms)			15%
8. Blue circle (200 ms) + low tone (200 ms)			15%

Table 3.4: **Audiovisual attention task stimuli.** Note the durations of the visual (circles) and audio (tones) stimuli for the audiovisual task. Combinations determine whether a stimulus is a target, distractor or a non-target. The percentages in the target, distractor and non-target columns represent the proportions of stimulus presentations.

These infrequent short red-high combinations were defined as targets and comprised 10% (36 targets) of the total 360 stimuli. 30% of the stimuli also had shorter durations within the attended modalities but were red-low, blue-high or blue-low combinations and were defined as distractors. The remaining stimuli (60%) were red-high, blue-high, red-low or blue-low combinations with both components presented for 200 ms and defined as non-targets.

3.3.9 Behavioural response analysis

Attentional performance was assessed by calculating response accuracies via an evaluation algorithm called the Bookmaker (Powers 2003). The Bookmaker provides a single measure of fitness which better takes into account the negative effect of an incorrect result, compared to other evaluation formulas such as Recall and Precision, Weighted Average and Receiver-Operator Curve (ROC) (Powers 2006).

A subject's response to a stimulus may be sufficiently slow that the next stimulus may occur before the button response occurs. Hence a response cannot be presumed to be in response to the stimulus that most clearly precedes it. To account for this, a window of 250 ms preceding the response was defined, and any stimulus in this window was ignored for the purposes of associating responses and stimuli. A response was therefore associated with the stimulus that precedes the response by the smallest time not less than 250 ms.

Stimulus classification

As the Bookmaker works off a two-way confusion matrix, distractors were treated as non-targets. Based on these classifications, a confusion matrix (Table 3.5) was generated by calculating the numbers of true positives (responses to targets), false positives (non-responses to targets), false negatives (responses to non-targets) and true negatives (non-responses to non-targets), which were then used to calculate the Bookmaker score. Response latencies were also calculated for responses to targets (true positives). Both Bookmaker scores and response latencies were analysed using linear model repeated measures ANOVA with group (MEDITATORS and *controls*), modality (audio, visual and audiovisual) and intervention (pre- and post-meditation condition) as factors.

	+R	-R	
+P Targets presented	TRUE POSITIVE or Response to target	FALSE POSITIVE or No response to target	Total number of targets presented
-P Non-targets presented	FALSE NEGATIVE or Response to non-target	TRUE NEGATIVE or No response to non-target	Total number of non-targets presented
	Total number of responses	Total number of no responses	Total number of presentations

Table 3.5: **Bookmaker confusion matrix.** The +R and -R columns in this confusion matrix include responses and non-responses, respectively; the +P (positive) and -P (negative) rows indicate whether a target was or was not presented, respectively. Totals can be calculated by summing down columns and across rows. True and false labels reflect whether or not a response is correct, for example, a false negative is an incorrect response to a distractor or non-target.

3.3.10 EEG acquisition and analysis

Subjects were seated comfortably in a dimly lit Faraday cage (R.F.I. Industries, Bayswater, Vic., Australia) to minimise contamination from electromagnetic fields and were observed via an Axis 2420 infrared network camera (Melbourne, Vic., Australia). Instructions were displayed on a Trinitron Multiscan G520 colour monitor (Sony, Tokyo, Japan).

One hundred and sixteen channels of EEG were recorded continuously using Neuroscan hardware (El Paso, TX, USA) connected to an IBM IntelliStation M Pro computer, running Neuroscan software (El Paso, TX, USA). EEG was amplified and digitised at 2000 Hz. The low pass cut-off was set at 500 Hz for all electrodes. ECG and respiration electrodes were set at 40 Hz low pass and DC high pass. All other electrodes were set at 500 Hz low pass and DC high pass. Data files were saved in Neuroscan continuous (.cnt) file format. A 128-channel electrode cap with Ag-AgCl electrodes (Easy Cap Falk Minnow, Germany) was used to provide uniform scalp coverage. The electrode distribution relative to the 10-20 system is illustrated at http://www.easycap.de/easycap/e/electrodes/11_M15.htm. Electrode impedances were kept below 5 kOhm. 12 electrodes were removed from the EEG cap for use in recording electro-oculography (EOG)[2], electrocardiography (ECG), respiration, temperature, electrodermal levels and peripheral blood oxygen saturation. One electrode was used for an ear reference. As autonomic measures were only analysed from the meditation experiment, these methods will be expanded on in §4.3.

3.3.11 ERP processing

12 electrodes from the International 10-20 reference system were selected for analysis (Figure 3.3).

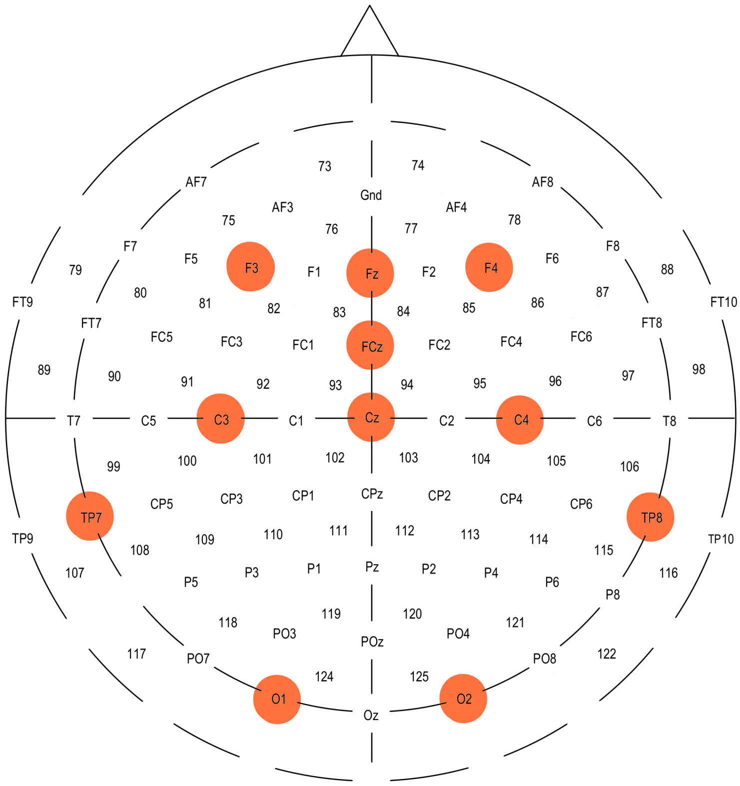

Figure 3.3: **Electrode selection for ERP analysis.** 11 electrodes from the International 10-20 reference system were selected to represent attentional networks (F3, Fz, F4, C3, Cz, C4), auditory brain regions (TP7, TP8) and visual regions (O1, O2). In addition, FCz was included to improve resolution of midline attentional networks (Luck 2005).

[2]Two cap electrodes, positioned beside the outer canthi of each eye, monitored horizontal EOG. One cap electrode, positioned supraorbital to the left eye, and one removed electrode attached to the infraorbital region of left eye, monitored vertical EOG.

Electrodes F3, Fz, F4, C3, Cz and C4 were selected to assess neural activity in the prefrontal and cingulate cortices related to attentional processing. TP7 and TP8 were selected to assess processing in the primary auditory cortex and electrodes O1 and O2 were selected to assess visual processing. In addition, FCz was included to improve resolution of midline attentional networks (Luck 2005).

All of the following processing was looped over each subject, task and channel, ignoring any invalid data. Recorded data were initially resampled at 250 Hz to expedite data processing. Selected epochs -200 ms to 500 ms from stimulus presentation were baselined using the average voltage in the preceding 200 ms (Luck 2005) and filtered with a 20 Hz low-pass filter to remove high-frequency noise, which also facilitates peak-picking (see below). Epochs were then separated based on targets responded to and non-targets ignored and separately averaged, resulting in individual ERPs for true positives and true negatives, respectively.

The latencies of component peaks necessarily vary between scalp electrode sites due to multiple generator sources (Niedermeyer & Lopes da Silva 1999). Therefore, based on pre-grand averages (Figure 3.4) of both groups, stimulus types, interventions and all task modalities for each of the aforementioned electrodes, P1, N1 and P2 peaks were automatically located as deflections in a search window. Based on latency variation in component peaks between conditions and recommendations by Luck (2005), the search window was elected to be 80 ms (peak $\pm$ 40 ms). ERP waveforms are plotted with positive voltages upward in accordance with the same positive-up convention as the rest of the scientific world (Luck 2005). Search windows were centred on peaks' grand average ERP waveforms of combined groups, stimulus types, interventions and task modalities (Figure 3.5).

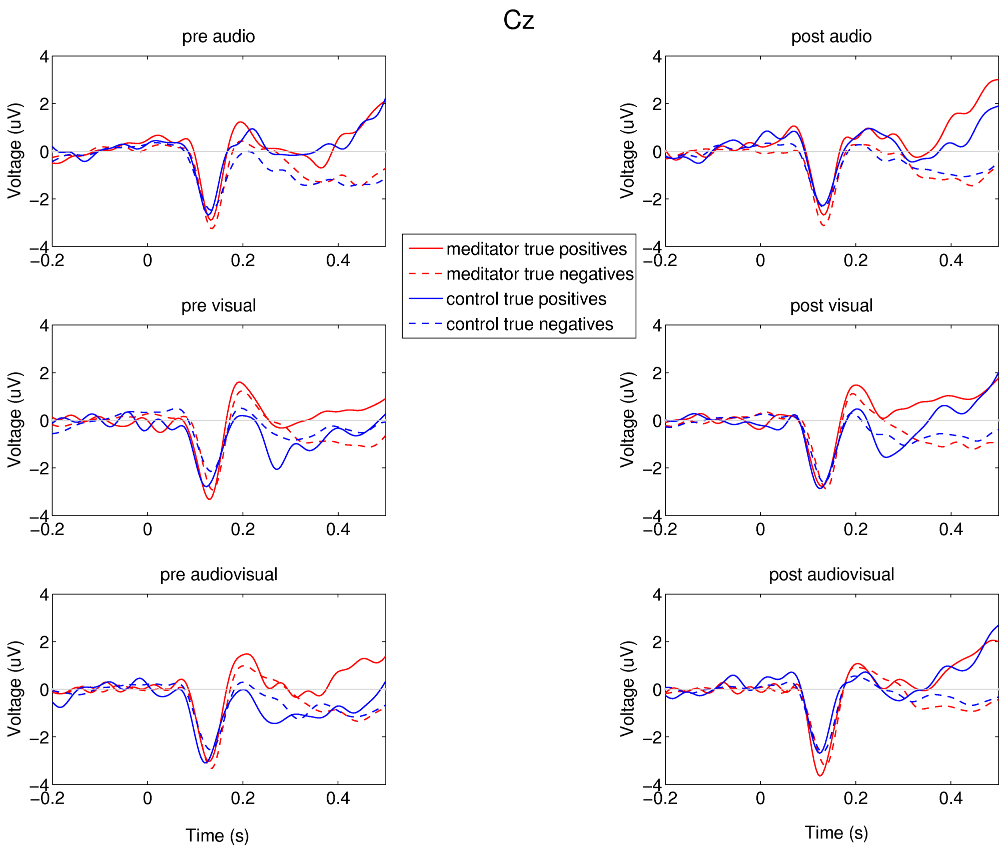

Figure 3.4: **ERP pre-grand averages.** These event-related potentials are examples of a pre-grand averages used to determine the span of the peak latency search windows. The electrode site shown is Cz. Positive is plotted upward.

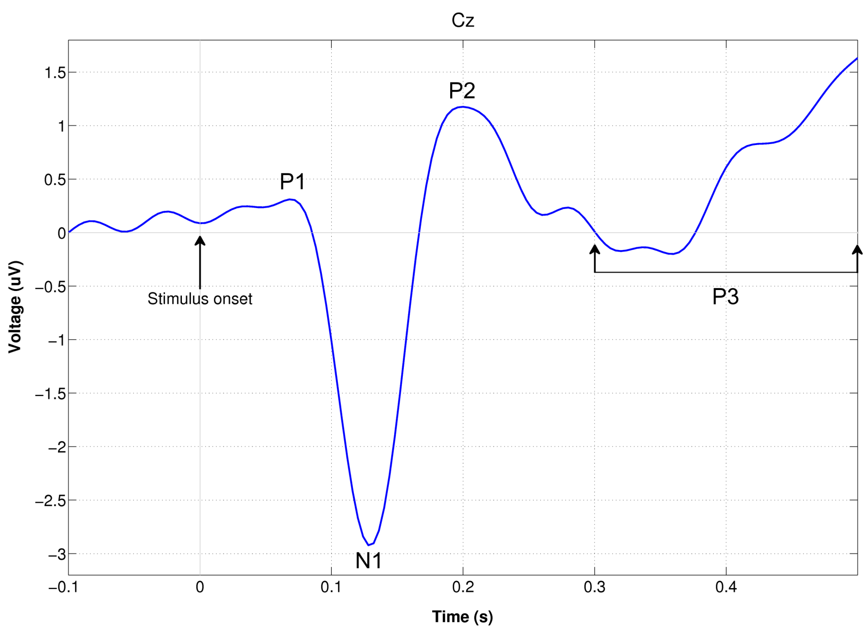

Figure 3.5: **ERP grand average.** This event-related potential is an example of a grand average used to determine the centre of the peak latency search windows for P1, N1 and P2 peaks. The electrode site shown is Cz. Positive is plotted upward.

3.3.12 ERP analysis

Analysis of ERPs was undertaken using code written in Matlab (Matlab, The Mathworks, Natick, Massachusetts, USA). Descriptive statistics were stored (see Appendix E on cd).

Mean amplitude and peak latency

In measuring ERP component amplitudes, mean amplitude (the mean voltages calculated within defined time windows) was chosen over peak amplitude (the maximum amplitude within a time window) for two reasons as suggested by Luck (2005). Firstly, compared to peak amplitude, mean amplitude is less sensitive to noise. Mean amplitude measures are not biased when noise levels or measurement windows are increased, which legitimises mean amplitude comparisons of waveforms based on different numbers of trials, which was the case here. Secondly, mean amplitude is a linear measure. This means that the average of the mean amplitudes from a component measured in each subject will be equal to the mean amplitude of the component from the grand-average waveform (Luck 2005).

To gather mean amplitude measures, three transparent coloured patches representing P1, N1 and P2 peak latency search windows were presented onto each subjects averaged ERP waveform for each task modality, stimulus type and intervention (Figure 3.6). A fourth patch representing the area of the P3 component was also presented for additional waveform definition. The mean voltages for the P3 were collected automatically (see below).

Within the respective search windows, the *local peak amplitude* was automatcially selected using a custom-built function in Matlab, defined as the largest point within the search window that is surrounded on both sides by smaller points (Luck 2005). This peak selection method differs from what is called the *simple peak amplitude*, which simply takes the largest point within the measurement window. The simple peak amplitude approach can be problematic, as the maximum voltage measured in the measurement window may occur on the border of the window and in fact be the rising or falling edge of an overlapping compo-

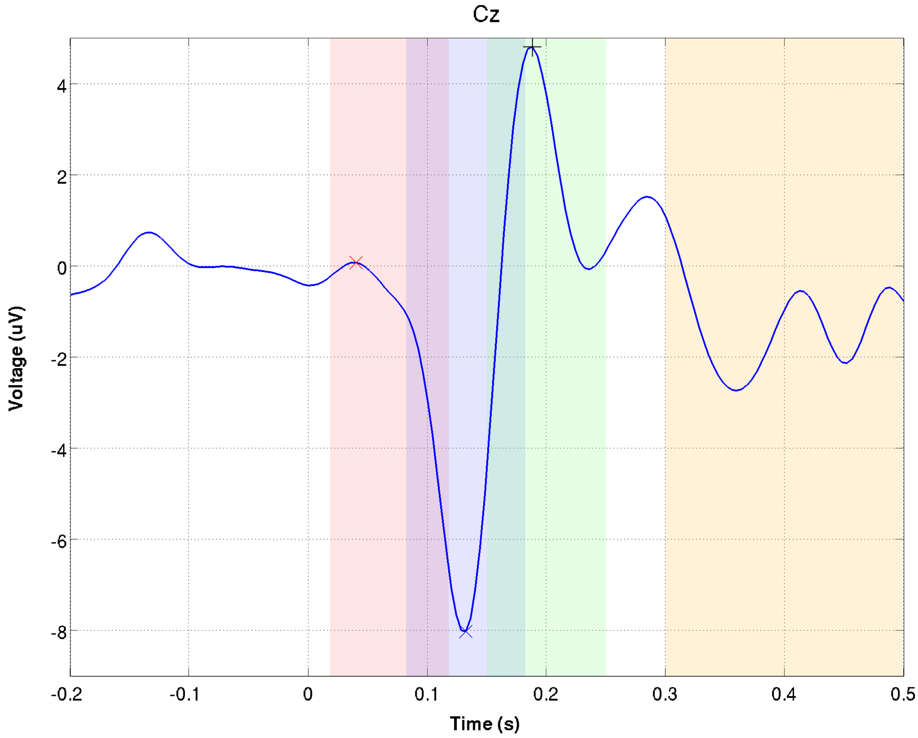

Figure 3.6: **ERP peak picking example.** This example shows four transparent coloured patches to guide peak selection: pink for P1, blue for N1, green for P2 and orange for P3. The first three patches show slight overlap. The electrode site shown is Cz. Positive is plotted upward.

nent, rather than the desired peak. However, if a component peaked just outside the measurement window, the largest amplitude value found within that window was selected.

The integrity of each waveform was manually verified and a number of waveforms were discarded due to insufficiently defined configurations and lack of distinguishable ERP components (Figure 3.7). Once an automatically selected peak was accepted, the mean voltage from a 50 ms window centred on the peak was calculated and stored. Latencies from each selected peak were also stored. If no local peak was located within a search window, no data for that peak component was stored in order to avoid data bias. For the P3 component, a 300-499 ms measurement window was chosen, the duration being limited by the ISI of 500-700 ms.

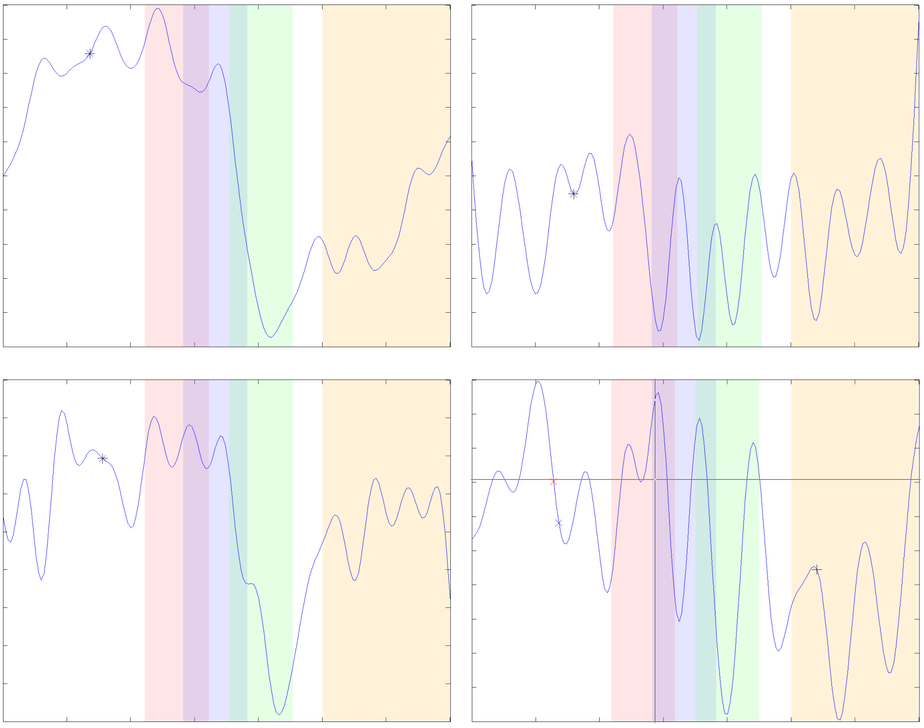

Figure 3.7: **Examples of discarded ERP waveforms.** These ERP examples were considered unacceptable and discarded due to insufficiently defined configurations and lack of distinguishable ERP components. Positive is plotted upward.

Statistical analysis

Due to the number of ANOVAs performed on 11 electrodes, a modifed Bonferroni correction was employed. This procedure involves arranging p-values from lowest to highest, then calculating the alpha at each position by dividing the number of tests minus the position in the sequence plus one and finally, ignoring p-values which exceeds the adjusted alpha. An analysis of the residuals confirmed reasonable normality in their distribution. An $\alpha = 0.05$ was chosen for the critical level of significance.

3.4 Results

All subjects reported the experiment to be difficult and taxing, however, they were able to comply with all task instructions.

3.4.1 Behavioural data

Bookmaker scores

Both groups demonstrated a significant improvement in response accuracy ($p = 0.029$) for all modalities after the meditation condition. Post-intervention Bookmaker scores (0.779 ± 0.033) were revealed to be significantly larger than pre-intervention scores (0.675 ± 0.034).

Analyses on group and modality failed to reveal any significant effects.

Response latencies

Both groups reponded to targets significantly faster after the meditation condition ($p < 0.001$). Post-intervention response latencies (0.489 s $\pm$ 0.0022) were found to be approximately 21 ms faster compared to pre-intervention (0.510 s $\pm$ 0.0022).

In addition, all subjects responded more quickly ($p < 0.001$) during the audio task (0.470 s $\pm$ 0.0026) in comparison to visual (0.523 s $\pm$ 0.0026) and audiovisual tasks (0.505 s $\pm$ 0.0034).

3.4.2 Event-related potentials

Grand means of modes (audio, visual and audiovisual) and times (pre and post) for all 11 electrodes were plotted and directly compared with means from statistical analyses (Luck 2005) (Figures 3.8 to 3.18).

P1

The continuous performance attention task evoked larger P1 mean amplitudes ($p = 0.0028$) in MEDITATORS (0.724 µV $\pm$ 0.084) at electrode TP7 (Figure 3.15) compared to *controls* (0.358 µV $\pm$ 0.087) across all conditions (Table 3.6). Larger P1 mean amplitude ($p = 0.0128$) was also found during pre-intervention and post-intervention audio tasks (0.587 µV $\pm$ 0.099) in comparison to pre-intervention and post-intervention audiovisual tasks (0.177 µV $\pm$ 0.096) for both groups at electrode TP8 (Figure 3.16).

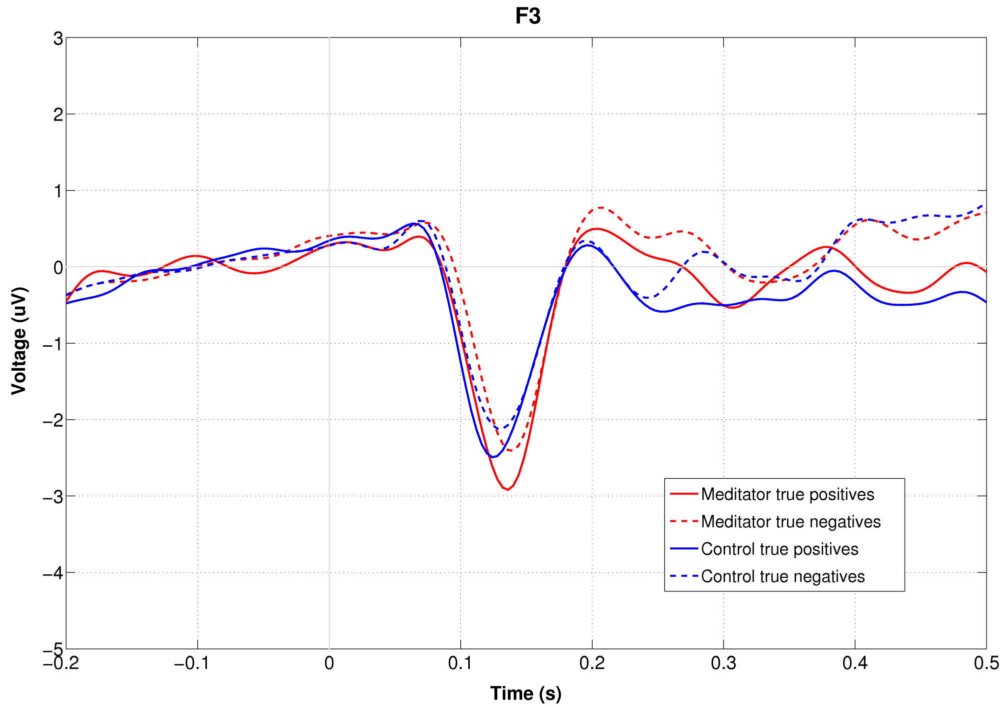

Figure 3.8: **Electrode F3** showing ERPs evoked by true positives (solid line) and true negatives (broken line) in MEDITATORS (red) and *controls* (blue). Positive is plotted upward.

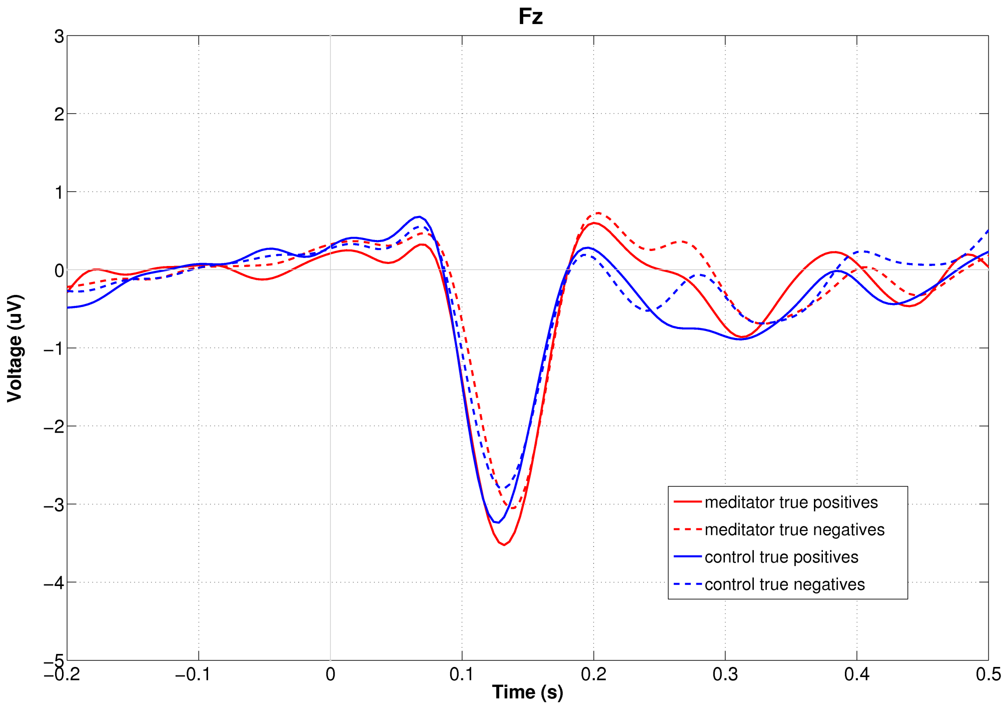

Figure 3.9: **Electrode Fz** showing ERPs evoked by true positives (solid line) and true negatives (broken line) in MEDITATORS (red) and *controls* (blue). Positive is plotted upward.

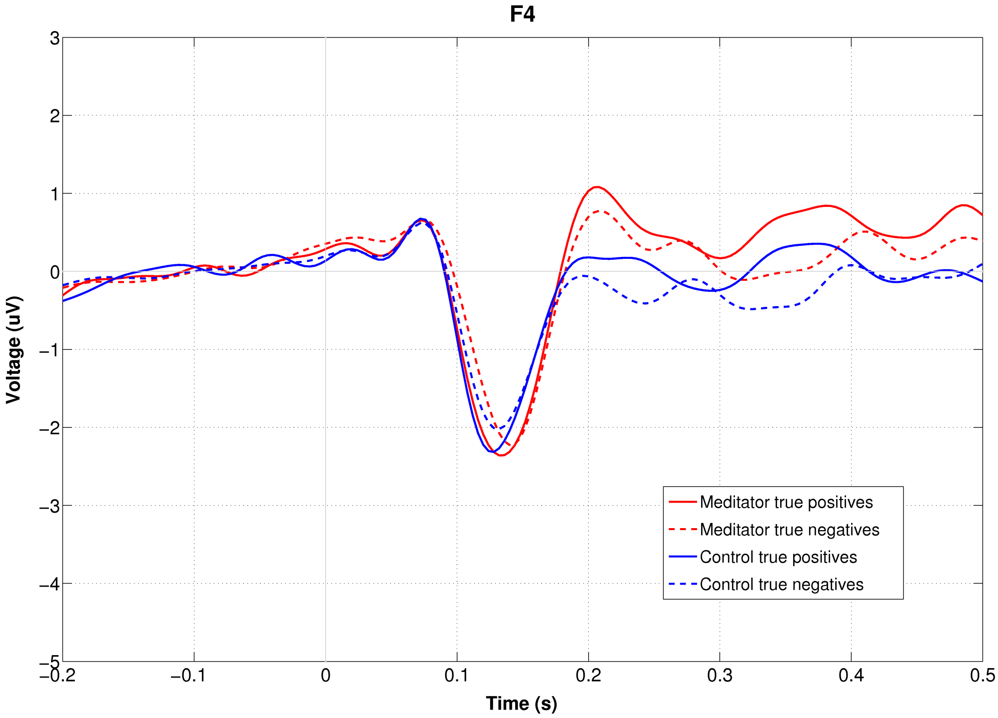

Figure 3.10: **Electrode F4** showing ERPs evoked by true positives (solid line) and true negatives (broken line) in MEDITATORS (red) and *controls* (blue). Positive is plotted upward.

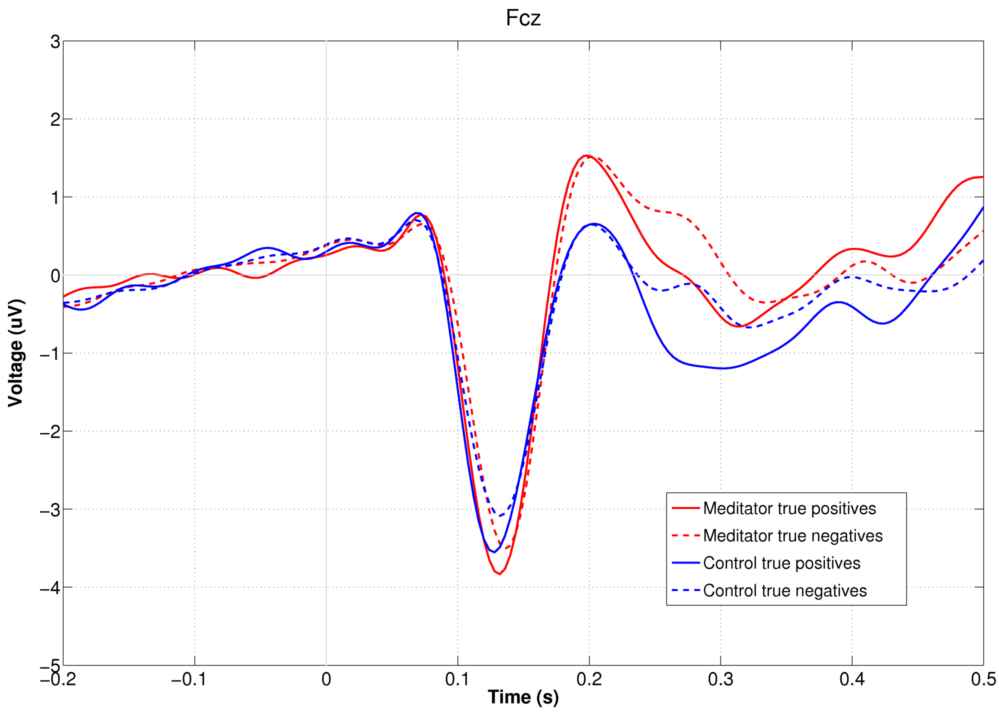

Figure 3.11: **Electrode FCz** showing ERPs evoked by true positives (solid line) and true negatives (broken line) in MEDITATORS (red) and *controls* (blue). Positive is plotted upward.

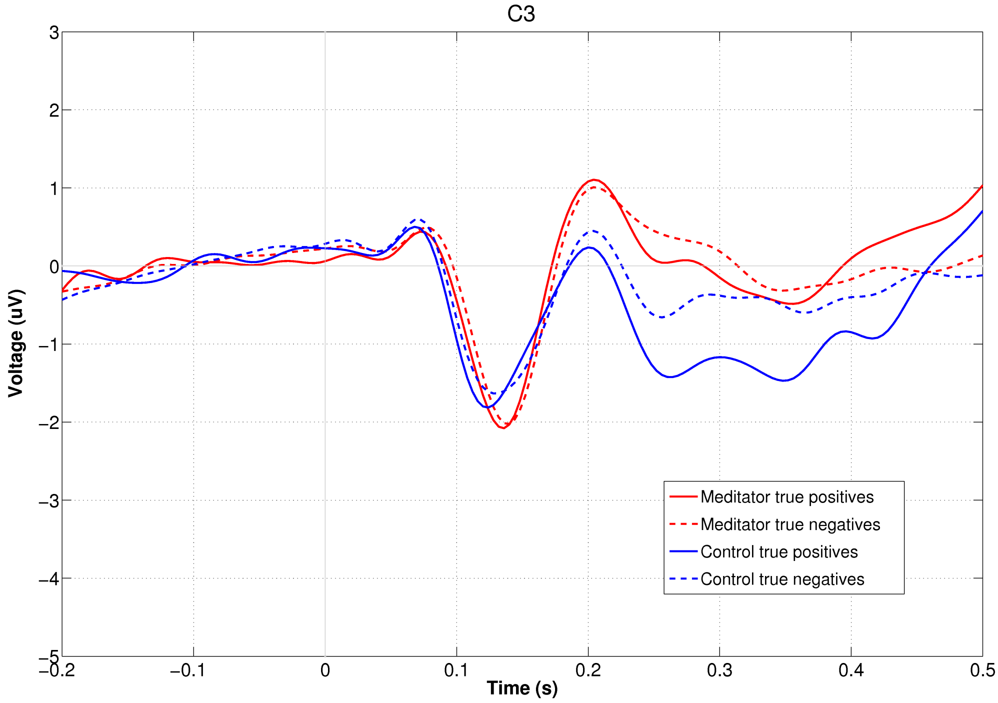

Figure 3.12: **Electrode C3** showing ERPs evoked by true positives (solid line) and true negatives (broken line) in MEDITATORS (red) and *controls* (blue). Positive is plotted upward.

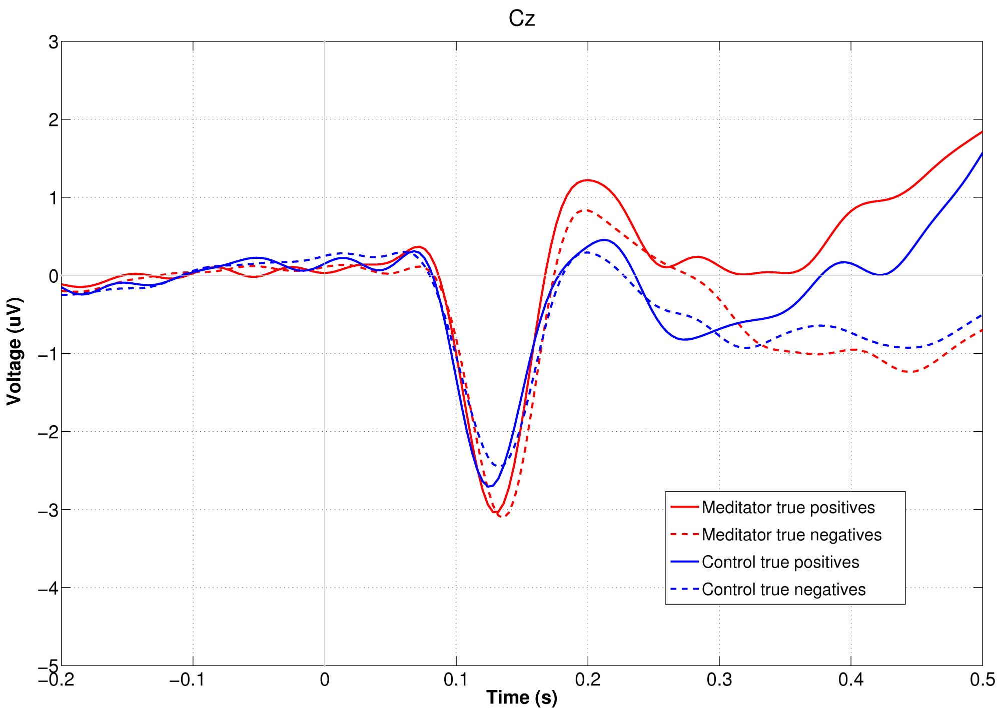

Figure 3.13: **Electrode Cz** showing ERPs evoked by true positives (solid line) and true negatives (broken line) in MEDITATORS (red) and *controls* (blue). Positive is plotted upward.

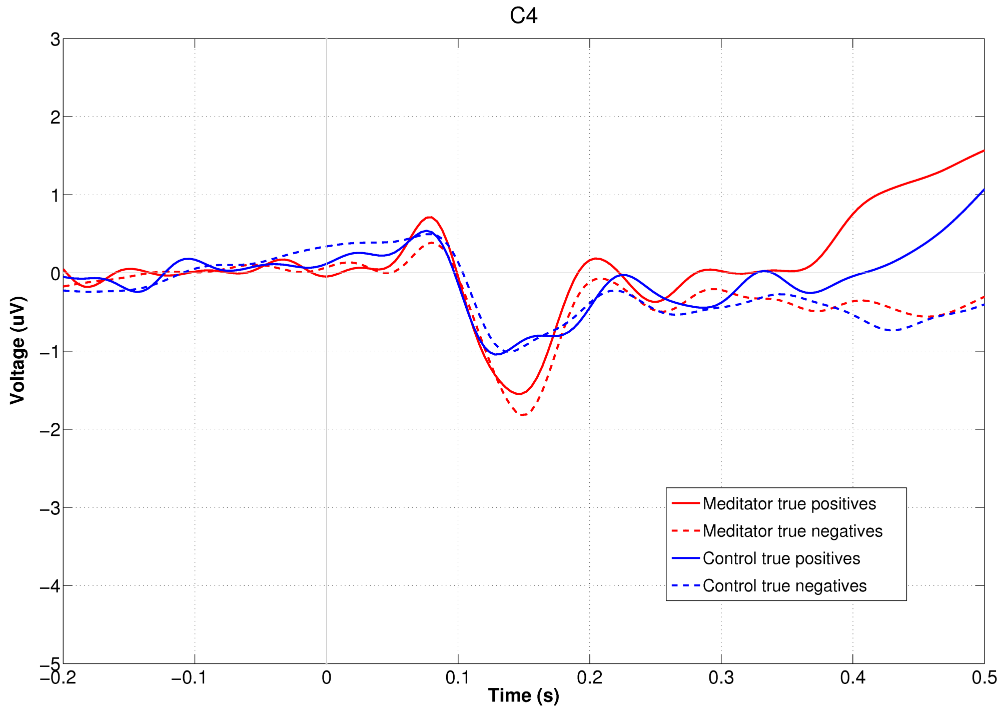

Figure 3.14: **Electrode C4** showing ERPs evoked by true positives (solid line) and true negatives (broken line) in MEDITATORS (red) and *controls* (blue). Positive is plotted upward.

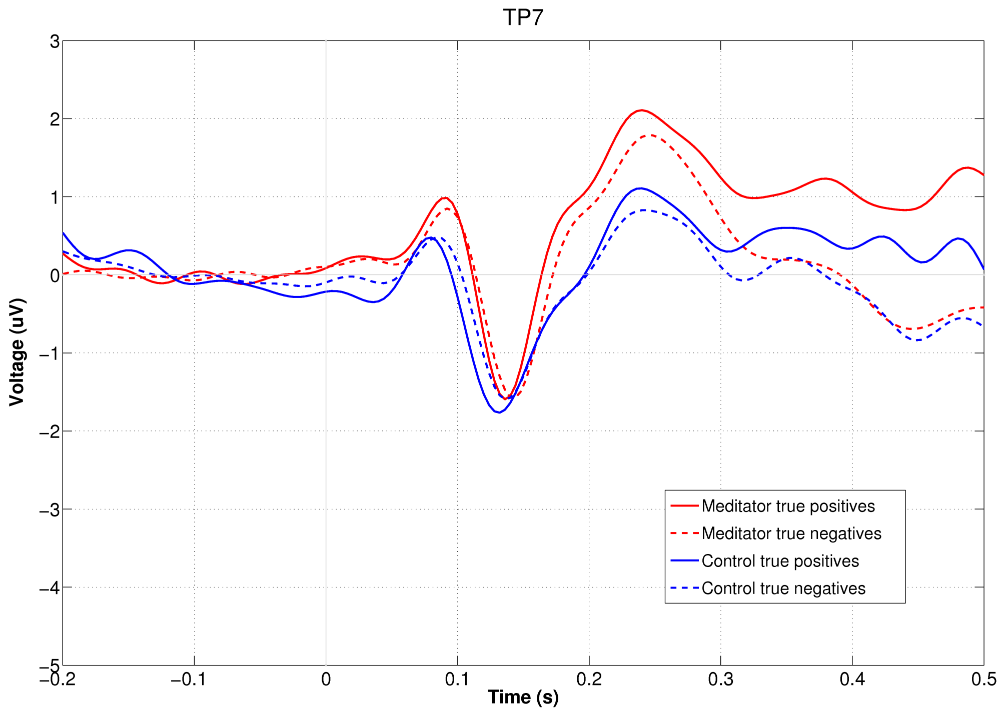

Figure 3.15: **Electrode TP7** showing ERPs evoked by true positives (solid line) and true negatives (broken line) in MEDITATORS (red) and *controls* (blue). Positive is plotted upward.

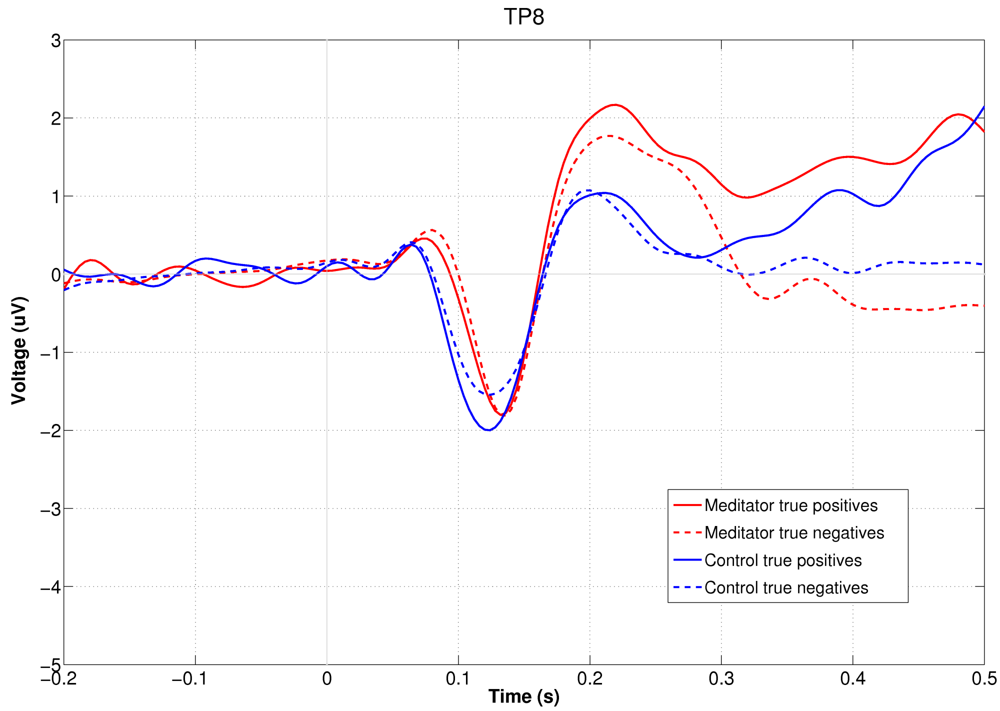

Figure 3.16: **Electrode TP8** showing ERPs evoked by true positives (solid line) and true negatives (broken line) in MEDITATORS (red) and *controls* (blue). Positive is plotted upward.

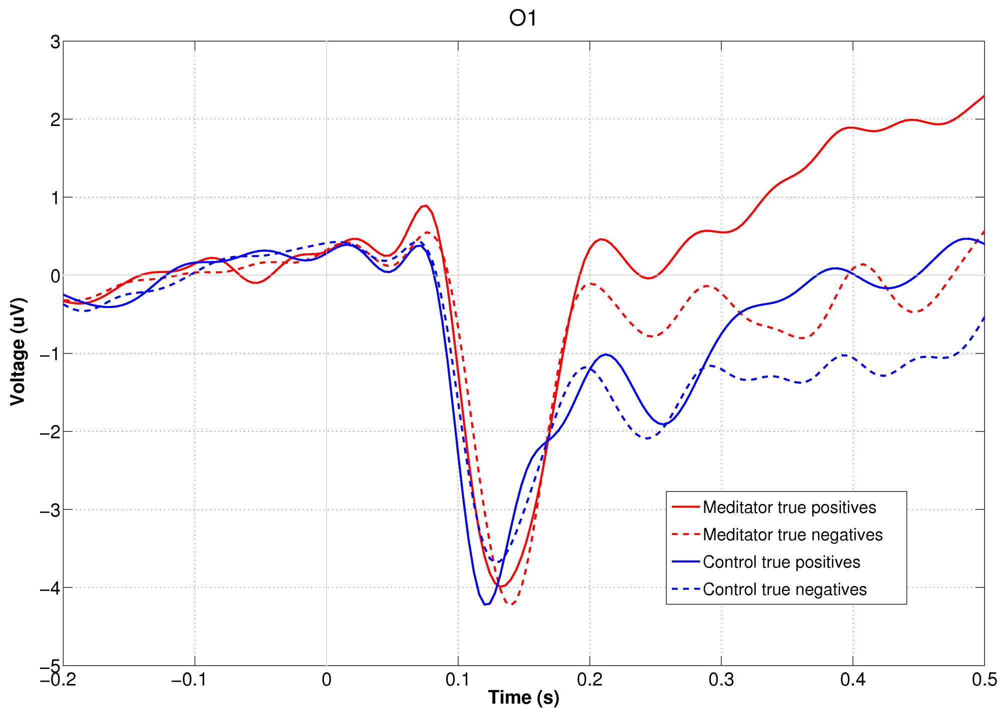

Figure 3.17: **Electrode O1** showing ERPs evoked by true positives (solid line) and true negatives (broken line) in MEDITATORS (red) and *controls* (blue). Positive is plotted upward.

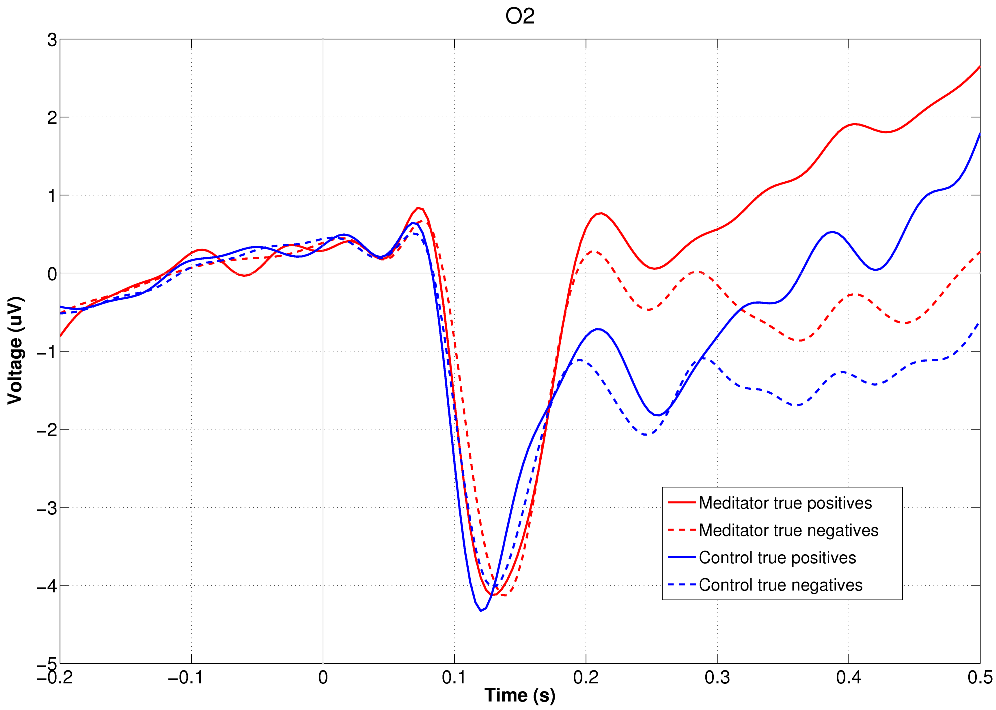

Figure 3.18: **Electrode O2** showing ERPs evoked by true positives (solid line) and true negatives (broken line) in MEDITATORS (red) and *controls* (blue). Positive is plotted upward.

Controls exhibited shorter P1 peak latencies (0.084 s ± 0.001) at electrode O2 (Figure 3.18) in combined conditions ($p = 0.013$) compared to MEDITATORS (0.089 s ± 0.001) (Table 3.7). Analyses on electrode TP7 (Figure 3.15) revealed shorter P1 peak latencies in both groups ($p = 0.0196$) for pre-intervention and post-intervention audiovisual tasks (0.083 s ± 0.002) compared with pre-intervention and post-intervention visual tasks (0.091 s ± 0.002).

No intervention effects were found for P1 mean amplitude or peak latency.

N1

MEDITATORS were found to have larger N1 mean amplitude (-2.542 µV ± 0.129) in electrode F3 ($p = 0.0012$) (Figure 3.8) for combined interventions and modalities compared to *controls* (-1.931 µV ± 0.135).

Electrode	P1 mean amplitude	N1 mean amplitude	P2 mean amplitude	P3 mean amplitude
F3	–	Meditators > *controls* ($p = 0.0012$)	–	Targets > non-targets ($p = 0.0045$)
Fz	–	–	–	–
F4	–	–	Meditators > *controls* ($p = 0.0021$)	–
FCz	–	–	Meditators > *controls* ($p = 0.0006$)	–
C3	–	–	Meditators > *controls* ($p < 0.0001$)	–
Cz	–	–	Meditators > *controls* ($p = 0.0001$)	Targets > non-targets ($p < 0.0001$)
C4	–	–	–	Targets > non-targets ($p < 0.0001$)
TP7	Meditators > *controls* ($p = 0.0028$)	–	Meditators > *controls* ($p < 0.0001$)	Targets > non-targets ($p = 0.0002$)
TP8	Audio > audiovisual ($p = 0.0128$)	–	Meditators > *controls* ($p < 0.0001$)	–
O1	–	–	Meditators > *controls* ($p = 0.0021$)	Targets > non-targets ($p < 0.0001$) Meditators > *controls* ($p < 0.0001$)
O2	–	–	–	Targets > non-targets ($p < 0.0001$) Meditators > *controls* ($p < 0.0001$)

Table 3.6: **Summary of mean amplitudes for P1, N1, P2 and P3 ERP components.** The symbol “>” represents “mean amplitude larger than” and “–” indicates no significance was found.

Electrode	P1 peak latency	N1 peak latency	P2 peak latency
F3	–	–	–
Fz	–	–	–
F4	–	–	*Controls* visual < *controls* audiovisual (p = 0.0104)
FCz	–	–	MEDITATORS < *controls* (p = 0.0101)
C3	–	–	–
Cz	–	Targets < non-targets (p < 0.0121)	–
C4	–	–	–
TP7	Audiovisual < visual (p = 0.0196)	–	–
TP8	–	–	–
O1	–	–	–
O2	*Controls* < MEDITATORS (p = 0.0013)	–	Targets < non-targets (p < 0.0109)

Table 3.7: **Summary of peak latencies for P1, N1, P2 and P3 ERP components.** The symbol "<" represents "peak latency shorter than" and "–" indicates no significance was found.

N1 peak latency was shorter for targets in both groups (0.131 s ± 0.001), across all modalities (p = 0.0121) at electrode Cz (Figure 3.13), compared to non-targets (0.134 s ± 0.001).

No intervention effects were found for N1 mean amplitude or peak latency.

P2

The continuous performance attention task evoked significantly larger P2 mean amplitude in MEDITATORS compared to *controls* across seven of the eleven electrodes. Highly significant groups effects, with larger P2 amplitude in meditators, were found at electrodes F4 (p = 0.0021, 1.28 µV ± 0.18), FCz (p = 0.006, 1.46

µV ± 0.20), C3 ($p < 0.0001$, 1.20 µV ± 0.11), Cz ($p = 0.0001$, 1.33 µV ± 0.13), TP7 ($p < 0.0001$, 2.21 µV ± 0.16), TP8 ($p < 0.0001$, 2.31 µV ± 0.12) and O1 ($p = 0.0021$, 0.82 µV ± 0.24) (see Figures 3.10, 3.11, 3.12, 3.13, 3.15, 3.16 and 3.17, respectively), compared to controls (0.51 µV ± 0.17 [F4], 0.70 µV ± 0.19 [FCz], 0.37 µV ± 0.11 [C3], 0.59 µV ± 0.13 [Cz], 1.19 µV ± 0.16 [TP7], 1.42 µV ± 0.13 [TP8] and -0.23 µV ± 0.23 [O1]).

Only three electrodes were found to have changes in P2 peak latencies. Meditators exhibited shorter P2 peak latencies (0.199 s ± 0.002) for combined conditions at electrode FCz ($p = 0.0101$) in comparison with *controls* (0.205 s ± 0.002). Non-targets evoked shorter P2 latencies (0.204 s ± 0.002) in comparison to targets (0.211 s ± 0.002) in both groups for combined conditions at electrode O2 ($p = 0.0109$). Controls exhibited shorter P2 latencies during the visual task (0.199 s ± 0.004) compared with the audiovisual task (0.219 s ± 0.004) at electrode F4 ($p = 0.0104$).

No intervention effects were found for P2 mean amplitude or peak latency.

P3

As expected from a multitude of previous studies on ERPs and oddball tasks, targets evoked significantly larger P3 mean amplitude, compared to non-targets across 6 of the eleven electrodes. Highly significant effects for stimulus, with larger P3 mean amplitude for targets compared with non-targets, were found at electrodes Cz ($p < 0.0001$, 0.424 µV ± 0.203 [targets], -0.867 µV ± 0.203 [non-targets]), C4 ($p < 0.0001$, 0.401 µV ± 0.138 [targets], -0.449 µV ± 0.138 [non-targets]), TP7 ($p = 0.0002$, 0.7366 µV ± 0.179 [targets], -0.214 µV ± 0.179 [non-targets]), O1 ($p < 0.0001$, 0.757 µV ± 0.178 [targets], -0.731 µV ± 0.178 [non-targets]) and O2 ($p < 0.0001$, 0.963 µV ± 0.178 [targets], -0.881 µV ± 0.178 [non-targets]). Meditators also exhibited significantly larger P3 amplitudes in comparison to controls at electrodes O1 ($p < 0.0001$, 0.636 µV ± 0.179 [meditators], -0.610 µV ± 0.176 [controls]) and O2 ($p < 0.0001$, 0.587 µV ± 0.175 [meditators], -0.504 µV ± 0.172 [controls]). P3 mean amplitude was larger in non-targets (0.296 µV ± 0.135) compared to targets (-0.254 µV ± 0.135) at electrode F3 ($p = 0.0045$).

No intervention effects were found for P3 mean amplitude.

3.5 Discussion

Both groups improved response accuracy as well as responded more quickly after the meditation condition. Several explanations may apply. Firstly, a number of reasons suggest that *controls* were also able enter the first or second absorptions during the meditation condition between tasks. All non-meditator *controls* used in this experiment were pair-matched to MEDITATORS for education-level, of which all had completed at a tertiary level. Due to biological variability and non-meditative mental training (academia or sports), certain individuals of a particular mental constitution might well be able to concentrate at higher-than-average levels. This fact is especially relevant for those who have studied at a level which requires a degree of intensive concentration for sustained durations. Also, as discussed in §4.5, non-significant frontal/central theta power increases in controls during the first absorption (Figure 4.16) is likely to reflect focused attention. *Controls* potentially entered the first absorption in the meditation experiment, although this state may not have been held with the same stability and clarity as MEDITATORS and it may have been interrupted by internal and external distractions. Nevertheless, the ability to meditate somewhat successfully in lighter states may also explain the increased performance here in attention tasks even in controls after the meditation condition. This said however, this improvement post-intervention was not reflected in any intervention effect in the ERPs, that is, ERP brain potentials did not significantly change after meditation. The findings by Banquet and Lesèvre (1980) that meditators demonstrated greater accuracy and shorter behavioural response latencies before and after meditation compared to controls was not supported in this study.

Both groups responded faster during the audio task both before and after the meditation condition. This performance difference in the audio task was reflected by larger P1 amplitudes compared to audiovisual tasks and shorter P1 peak latencies in audiovisual tasks compared to visual tasks in electrode TP7. This augmentation of performance and brain potentials may reflect the potential for meditation to influence the audio modality more than the visual modality. This is further supported by possible long-term effects of meditation on the audio modality, suggested by larger P2 mean amplitude in MEDITATORS at both audio electrodes and larger P1 mean amplitude at electrode TP7. However, no statistical effects for modality were found during analyses of mean amplitudes.

Larger N1 amplitude in electrode F3 in MEDITATORS was not found in electrode F4 or other electrodes. The frontocentral N1 component appears to be generated in the auditory cortex (Naatanen & Picton 1987) and is sensitive to attention (Hillyard et al. 1998; Luck 2005). The augmentation of N1 amplitude in meditators has been reported previously (Banquet & Lesèvre 1980) during performance of a visual oddball task, relative to controls. The finding of a frontocentral N1 increase in the left hemisphere of MEDITATORS may be related to the evidence suggesting that the left auditory cortex is tuned to process fast sound changes (Zatorre & Belin 2001). In other words, the enhanced attention resulting from the practice of meditation may facilitate the processing of audio stimuli in the left cortex, particularly rapidly presented sounds.

MEDITATORS consistently exhibited highly significant increases in P2 mean amplitudes compared to non-meditator *controls*. As P2 components are largely influenced by stimuli containing target features, the augmented P2 amplitude in MEDITATORS may reflect more accurate detection and subsequent recognition of targets, facilitated by increased selective attention capacity. The augmentation of the P2 has been reported during attended versus unattended condition (Luck & Hillyard 1994) and also in meditators after meditation (Banquet & Lesèvre 1980).

Increases in the N1 amplitude and more importantly P2 amplitude in MEDITATORS reflect primary cortical activation and correspond to the third aggregate (viz. perception or discrimination). These changes are thought to represent a modification of basic conscious object registration, for example sounds and shapes, or in this case tones and circles. With an augmented state of vigilance and concentration, as well as reduced internal and non-task-related external distractions, MEDITATORS are more able to detect attended-to stimuli.

MEDITATORS also exhibited significantly larger P3 mean amplitudes in both electodes O1 and O2, in comparison to *controls*, supporting reports by Banquet and Lesèvre (1980) of P3 amplitude increases in MEDITATORS after meditation and decreased P3 amplitude in *controls* after rest. Task efficacy of this experiment was validated by consistently larger P3 mean amplitudes evoked in targets compared to non-targets. P3 waveforms depend on state-dependent brain processing of the stimulus (Nunez & Srinivasan 2006) which is generally recorded at longer latencies from the stimuli due to multiple feedback interactions required for conscious mentation. Accordingly, increases in P3 amplitude during target detection is a very commonly reported phenomenon. It is proposed that due to less distraction and more intense attention (indicated by larger P2 amplitudes), MEDITATORS demonstrate more clarity in relation to the fourth aggregate in the model of perception (viz. mental formations or impulses) which includes thoughts and decisions evoked by an object.

By utilising an audiovisual continuous performance task, this experiment extended Banquet and Lesèvre's (1980) findings by including the audio modality and investigating divided attention in addition to selective attention. Although no differences between pre and post-condition effects were found, the above findings show that both audio and visual modalities are sensitive to the influence of meditation on improved vigilance and increased selective attention capacity, as indexed by N1, P2 and P3 ERP components.