Concentrative meditation enhances preattentive processing: a mismatch negativity study

Narayanan Srinivasan and Shruti Baijal

Centre for Behavioural and Cognitive Sciences, University of Allahabad, Allahabad, India

Correspondence to Dr Narayanan Srinivasan, Centre for Behavioural and Cognitive Sciences, University of Allahabad, Allahabad 211002, India
Tel: +915322460738; fax: +915322460738; e-mail: ammuns@yahoo.com

Received 18 July 2007; accepted 6 August 2007

The mismatch negativity (MMN) paradigm that is an indicator of preattentive processing was used to study the effects of concentrative meditation. Sudarshan Kriya Yoga meditation is a yogic exercise practiced in an ordered sequence beginning with breathing exercises and ending with concentrative (Sahaj Samadhi) meditation. Auditory MMN waveforms were recorded at the beginning and after each of these practices for meditators and equivalently after relaxation sessions for the nonmeditators. Overall meditators were found to have larger MMN amplitudes than nonmeditators. The meditators also exhibited significantly increased MMN amplitudes immediately after meditation suggesting transient state changes owing to meditation. The results indicate that concentrative meditation practice enhances preattentive perceptual processes enabling better change detection in auditory sensory memory. *NeuroReport* 00:000–000 © 2007 Lippincott Williams & Wilkins.

Keywords: brain, event-related potentials, meditation, mismatch negativity, preattentive processing, Sudarshan Kriya Yoga

Introduction

The processes involved in automatic detection of changes in the environment are of great relevance to understanding human perception. Such automatic and preattentive mechanisms of auditory change detection are represented by the event-related potential (ERP) waveform called mismatch negativity (MMN) [1]. MMN appears as negativity in the difference waveforms that begins around 100 ms from stimulus onset and lasts until about 250 ms poststimulus. The negative wave is observed as ERP topographies, maximally over the frontocentral sites when a mismatching, infrequent stimulus appears in a stream of frequent stimuli. The underlying neural generators of the waveform lying in and around the primary auditory cortex and the frontal cortex are linked to change detection and involuntary attentional switching mechanisms respectively that follow the elicitation of MMN [2]. MMN can be elicited by a variety of changes in the stimulus-driven factors (tonal frequency, intensity, frequency, interstimulus interval) or the analysis of semantic information and has been found to be relatively independent of the effects of attention [1].

The changes in preattentive processing with different levels of arousal or consciousness such as sleep, anesthesia, coma, vegetative state and hypnosis have been studied using MMN [3–5]. Most sleep studies have failed to show MMN changes during sleep but MMN changes have been observed to some extent in rapid eye movement sleep, coma and vegetative state [3]. Interestingly, significant change in MMN amplitude was shown with hypnosis [4,5]. These studies point to the possibility of differences in change detection ability due to other manipulations that affect consciousness like meditation.

Despite the increasing number of studies on meditation including ERP studies, the effects of meditation on preattentive processing as indexed by MMN have not been studied. Given the observed changes in MMN owing to changes in consciousness, the research on meditation will inform us about the mechanisms that get altered due to mental training. It is important to distinguish between state and trait changes due to the practice of meditation. Trait changes refer to changes in brain activity or behavior due to long-term practice of meditation that can be observed even when the person is not meditating. State changes refer to immediate, transient changes during or immediately after a meditation session. In this study, we investigated the state as well as trait effects on MMN due to concentrative meditation. For the purpose of studying the effects of concentrative meditation on MMN, Sudarshan Kriya Yoga was chosen. Sudarshan Kriya is a unique breathing technique that involves specific rhythms of breath that has immediate and tangible effects in alleviation of stress, anxiety and depressive symptoms [6]. Normally, this practice of controlled breathing is associated with Mudra pranayam and Sahaj Samadhi meditation that are typically performed in a particular order. These forms of yogic meditation focus on specific body rhythms and a mantra that brings the mind to a peaceful centered state. Mudra pranayam involves formation of mudras (finger positions) and concentration on breath. Sudarshan Kriya on the other hand comprises of cycles of breathing that repeats itself. Sahaj Samadhi is a concentrative form of meditation where attention is focused on breath and mantra.

With different types of meditation, a number of studies have observed changes in brain activity owing to long-term practice [7–10]. These changes include changes in θ power or α power especially in the frontal areas [7,8]. For example, the deep meditative ecstatic state has been found to be correlated with increased frontal θ coherence [7]. Differences in contingent negative variation have been shown with the practice of transcendental meditation [9]. Like other types of yoga and meditation, studies with sudarshan kriya meditators have shown increased frontocentral coherence in the β band and posterior coherence in the α band during the practice of sudarshan kriya for meditators suggesting increased connectivity and efficient information processing in the brain. Sudarshan kriya has also been used as intervention for persons with dysthymia resulting in increase of P300 amplitude among patients to match those from the control group [11].

In addition to changes in electroencephalogram (EEG), extensive practice of meditation leads to certain long-lasting perceptual changes [12]. For example, Tibetan Buddhist meditators were found to show large increases in duration of perceptual dominance compared with nonmeditators after one-point meditation compared with compassion meditation and controls [12]. Although these findings strongly suggest that perceptual processing is affected, it is not clear at what stage (attentive or preattentive) these changes are bound to occur. In this study, we explored the neurocognitive changes in preattentive processing owing to the practice of meditation. When the MMN task was given after every subpractice, we were especially interested in comparing (i) any earlier difference in change detection ability and (ii) transient cognitive changes owing to the final meditation portion. We were also interested in whether concentrative meditation primarily affects response to standards or deviants in the MMN paradigm. Given the fact that MMN effects are most prominent at the frontal sites that exhibit differential activity during meditation [13], it is a well-suited task to study changes owing to yoga and meditation. The MMN paradigm does not require the participant to perform a task making it ideal to study changes in cognitive processing immediately after meditation.

Materials and methods

The study was carried out with 10 meditators (mean age=39 years, SD=5) and 10 nonmeditator controls (mean age=36 years, SD=6). All the voluntary participants were right-handed, had no history of neurological illness and were blind to the experimental hypotheses. The meditators consisted of teachers at the Art of Living Foundation with rigorous mental training in Sudarshan Kriya Yoga and have been practicing it daily for a period ranging from 3 to 7 years. The participants in the control group had no yoga or meditation training. A verbal and written consent was obtained from the participants before the study. EEG data were recorded and analyzed with 64-channel Neuroscan system with a sampling frequency of 1000 Hz. The electrodes were fixed using a gel (silver chloride compound) and setup at appropriate impedance (2–15 kΩ) before beginning the recording. For the purpose of analysis the raw EEG/ERP data were filtered with zero-phase shift, band pass filtering from 1 to 30 Hz at 12 dB/oct. EEG segments with eye movement and muscular artifacts were manually removed from the data.

The experiment was carried out in a soundproof, dimly lit room, conditions that were conducive for the participants to meditate. Normally, Sudharshan Kriya Yoga is practiced in a specific chronological order of events beginning with Mudra pranayam (5–7 min) followed by Sudarshan Kriya (10–12 min) and lastly by Sahaj Samadhi meditation (6–8 min). The meditators followed the same order during the recording. Correspondingly, nonmeditators were asked to relax for durations that approximately matched with those of meditators.

During the recording session, the MMN tones were played binaurally through a pair of speakers. The auditory pure tones comprised of frequent ‘standard’ tones (500 Hz, 70 dB) that were presented 80% of the times and infrequent ‘deviant’ tones (540 Hz, 70 dB) presented 20% of the times out of 300 trials. The duration of the tone presentations were 100 ms with an intertone interval of 400 ms. The MMN was recorded at the beginning (MMNPre) and after each of the three stages of yoga meditation, that is, Mudra pranayam (MMN1), Sudarshan Kriya (MMN2) and Sahaj Samadhi Meditation (MMN3) within a few seconds after completion of a particular stage. The participants were instructed to send an auditory signal to indicate to the experimenter when they had finished each stage of kriya yoga. The experimenter would then come in and play the MMN tones. A similar procedure was carried out for the control group where MMN was recorded before (MMNPre) and after each session of relaxation (MMN1, MMN2 and MMN3) during which they performed a secondary task of reading a book provided to them by the experimenter. The meditators were not asked to perform any secondary task, as it would disrupt the yoga and meditation practice.

Results

Analysis was performed with artifact-free EEG data with an epoch length of 1 s (500 ms prestimulus and 500 ms poststimulus) for both the standard and the deviant tones. The noisy sweeps from the epoched file were rejected and the epochs were averaged to obtain ERP components for every participant. A difference waveform or MMN obtained by subtracting ERP of standard stimulus from the ERP of deviant stimulus was used to compute peak amplitudes. The grand peak amplitudes of the two groups were compared across the four times when MMN was recorded that is, MMNPre, MMN1, MMN2 and MMN3.

Figure 1 presents averaged amplitudes of MMN waveforms for all the four conditions for the meditators and nonmeditators at the Fz electrode location. As can be seen in Fig. 1, the MMN amplitudes remained constant for the nonmeditators across all the conditions. For the meditators, the MMN amplitudes remained approximately the same for MMNPre, MMN1, and MMN2 but increased for MMN3. The data were analyzed using two-way mixed analysis of variance of the MMN amplitudes [group (2) × conditions (4)]. The two groups were found to be significantly different from each other as shown by a main effect for group [$F(1,18)=4.862$, $P<0.05$] with meditators having higher overall MMN amplitude than nonmeditators. The interaction was not significant given the fact that the two graphs show similar patterns of change for MMNPre to MMN2 and the divergence within meditators occur only for MMN3.

Given our specific interest in the state-related changes owing to meditation, we performed planned comparisons to

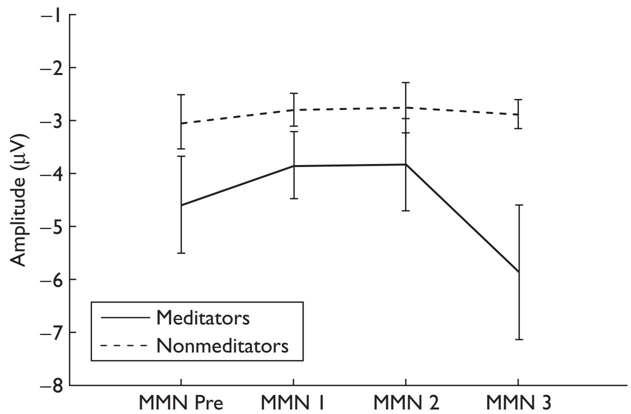

Fig. 1 Grand averaged mismatch negativity peak amplitudes for meditator and nonmeditators.

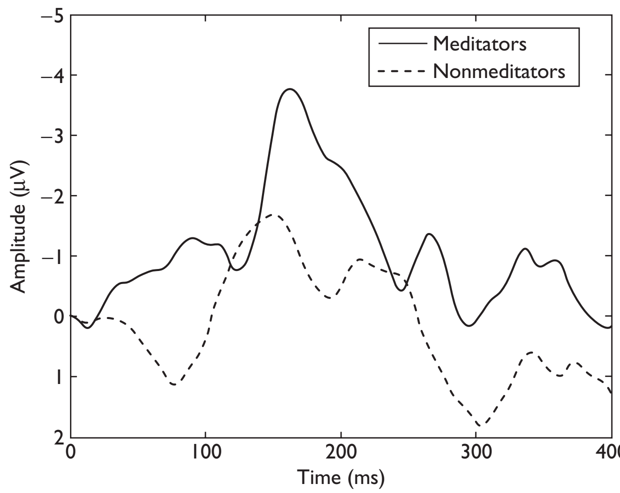

Fig. 2 Grand averaged mismatch negativity waveform of meditators and nonmeditators for the sahaj samadhi meditation (MMN3) condition at frontocentral sites.

see whether concentrative meditation affects MMN amplitudes. For the meditators, the amplitudes for MMN3 were found to be significantly higher compared with MMN2 indicating that the MMN amplitude increased immediately after meditation [F(1,54)=3.598, $P<0.05$]. No difference was observed between MMNPre and MMN2 amplitudes indicating that the MMN was not affected by breathing practice. For the controls, the MMN amplitudes did not significantly change for all the conditions. Comparing the controls and meditators, the MMNPre amplitudes were not significant but close [F(1,54)=2.751, $P=0.057$]. The MMN3 amplitudes, however, were significantly higher for meditators compared with the nonmeditators as in Fig. 2 [F(1,54)=5.256, $P<0.01$].

To analyze specific change in standard and deviant tone ERPs, a three-way mixed analysis of variance [group (2) × conditions (4) × tone (2)] was performed with peak amplitudes of the negative peak in the 100–250 ms range. The results (see Table 1) showed the MMN effect with an overall larger amplitudes for infrequent tones compared

Table 1 Peak amplitudes (in μV) of negative peak (with SEM in brackets) in frequent and infrequent ERPs for meditators and nonmeditators

	Frequent	Infrequent
Meditators	−1.67 (0.33)	−4.08 (0.62)
Nonmeditators	−1.20 (0.22)	−2.33 (0.42)

ERP, event-related potential.

with frequent tones [F(1,18)=51.778, $P<0.001$]. The frequent and infrequent ERPs changed differently for both the groups [F(1,18)=6.671, $P<0.05$]. The post hoc tests revealed that although there was no difference in the frequent tone ERPs between the two groups, the infrequent tone ERPs showed much higher amplitudes for meditators [F(1,18)=6.891, $P<0.01$] compared with controls.

Discussion

Although other studies have used ERP paradigms, our study is probably the first to use the MMN paradigm to investigate changes in preattentive processing, specifically automatic change detection, owing to the practice of meditation. The results show that the meditators have larger MMN amplitude than nonmeditators, particularly those for the deviant tones. The MMN amplitudes did not change immediately after the breathing exercises or kriyas (MMN1 and MMN2) for the meditators. The meditators, however, showed increased amplitudes specifically after Sahaj Samadhi meditation (MMN3) indicating state changes due to the practice of meditation. It is worthwhile to note that the larger MMN amplitudes present for meditators were obtained under conditions that may result in the reduction of MMN that is, without a secondary task. The pattern with MMN amplitudes before yoga and meditation in the beginning of the experiment suggests that preattentive processing gets altered indicating a possible trait change due to the practice of meditation. Further studies, especially with a larger number of meditators, may show significant and long-lasting changes in processing abilities. The findings extend strong support for the claim that the practice of meditation induces distinct 'state' [14] as well as 'trait' [4,5,15,16] changes.

It is to be noted that the present result provides unique evidence suggesting that the MMN generators in frontal midline or temporal areas get affected during meditational trance showing altered preattentive level of processing immediately after performing meditation. Furthermore, the study is consistent with the proposals linking the frontal lobe and modification of attentional mechanisms owing to meditation [17,18]. The larger amplitude at the frontal electrode can be interpreted as better ability of the meditators to make involuntary shifts of attention or alternatively, enhancing the mechanisms of deviance detection processes. The results are consistent with other studies on meditation that show a significant difference in cognitive processing [14] including decreases in P1, N1, P2, N2 amplitudes of auditory brain potentials during transcendental meditation.

How can concentrative meditation enhance preattentive perceptual processing? Meditators learn to focus their attention on a specific object during concentrative meditation and extensive practice leads to better control of attention. It has been shown that attention plays a critical role in enabling the formation of better sensory representations that improve preattentive detection of deviant tones as indicated by MMN [19]. It has been hypothesized that MMN amplitude can be changed by training by possibly increasing temporal coherence or response synchronization of cortical neural activity [19]. Meditative practice has been found to enhance long-range synchronization of brain activity with meditators [20]. Another possibility is through the arousal burst mechanism in adaptive resonance networks [21]. Adaptive resonance networks consist of an attentional subsystem and an orienting subsystem. A mismatch generated by the deviant tone may lead to the activation of an arousal burst by the orienting subsystem, related to MMN and change detection. The practice of concentrative meditation may result in a self-organization of brain processes with increased efficiency in the arousal burst mechanism, leading to enhanced MMN amplitudes and change detection. The MMN results are also in agreement with studies on hypnosis demonstrating increased frontal MMN amplitudes during hypnosis [4,5]. It is to be noted that the significant change in MMN amplitude is present when the meditators are actually not meditating but immediately after finishing their meditation.

Although a number of studies have observed changes in attentional processing in the brain [20], this study particularly shows changes in sensory perception that typically occurs before the shifting of attention. The results show that the detection of violations of regularities in sensory stimuli as indexed by MMN can be improved with mental training indicating the plasticity of preattentive automatic processing. Given the MMN reductions demonstrated in certain clinical conditions, such as schizophrenia [22], depression [23], and social withdrawal [24], meditation may be useful as a noninvasive therapeutic measure to improve the cognitive abilities of those patients by enhancing their perceptual processing.

The results also suggest that MMN could be a suitable paradigm to compare the cognitive changes owing to different types of meditation. This study focuses on a specific type of concentrative meditation and it would be interesting to see whether the findings from this study will extend to other forms of concentrative meditation (e.g. Buddhist Samatha meditation). In addition, the effects of mindfulness meditation (which uses more distributed attention) on MMN can be explored in a further study.

Conclusion

The meditative state of consciousness leads to restructuring of the perception that induces definitive state changes and possibly trait changes in frontal lobe function. Meditation thus results in enhanced perceptual and preattentive processing.

Acknowledgements

The authors thank the teachers of the Art of Living Organization who agreed to participate in the study and for Mr and Mrs Saigal for their efforts in helping us get in touch with meditators. The authors also thank Antonino Raffone for providing valuable comments.

References

1. Naatanen R, Paavilainen P, Tiitinen H, Jiang D, Alho K. Attention and mismatch negativity. *Psychophysiology* 1993; **30**:436–450.
2. Molholm S, Martinez A, Ritter W, Javitt DC, Foxe JJ. The neural circuitry of pre-attentive auditory change-detection: an fMRI study of pitch and duration mismatch negativity generators. *Cereb Cortex* 2005; **15**:545–551.
3. Kotchoubey B. Event-related potential measures of consciousness: two equations with three unknowns. *Prog Brain Res* 2005; **150**:427–442.
4. Kallio S, Revonsuo A, Lauerma H, Hamalainen H, Lang H. The MMN amplitude increases in hypnosis: a case study. *NeuroReport* 1999; **10**:3579–3582.
5. Graham A, Jamieson GA, Dwivedi P, Gruzelier JH. Changes in mismatch negativity across pre-hypnosis, hypnosis and post-hypnosis conditions distinguish high from low hypnotic susceptibility groups. *Brain Res Bull* 2005; **67**:298–303.
6. Brown RP, Gerbarg PL. Sudarshan Kriya yogic breathing in the treatment of stress, anxiety and depression: part II—clinical applications and guidelines. *J Altern Complement Med* 2005; **11**:711–717.
7. Aftanas LI, Golocheikine SA. Human anterior and frontal midline theta and lower alpha reflect emotionally positive state and internalized attention: high resolution EEG investigation of meditation. *Neurosci Lett* 2001; **310**:57–60.
8. Travis F, Wallace RK. Autonomic and EEG patterns during eyes closed rest and transcendental meditation (TM) practice: the basis for a neural model of TM practice. *Cons Cogn* 1999; **8**:302–318.
9. Travis F, Tecce J, Arenander A, Wallace RK. Patterns of EEG coherence, power and contingent negative variation characterize the integration of transcendental and waking states. *Biol Psych* 2001; **61**:293–319.
10. Bhatia M. EEG during Sudarshan Kriya: a quantitative analysis in science of breath. International Symposium on Sudarshan Kriya, Pranayam & Consciousness, New Delhi, India: All India Institute of Medical Sciences; 2002.
11. Naga Venkatesha Murthy PJ, Janakiramaiah N, Gangadhar BN, Subbukrishna DK. P300 amplitude and antidepressant response to Sudarshan Kriya Yoga (SKY). *J Affect Disorders* 1998; **50**:45–48.
12. Carter OL, Presti DE, Callistemon C, Ungerer Y, Liu GB, Pettigrew GD. Meditation alters perceptual rivalry in Tibetan Buddhist monks. *Current Biol* 2005; **15**:412–413.
13. Narayanan S, Baijal S. Meditation: brain activity and cognitive changes. In: Menon S, editor. *Consciousness, experience and ways of knowing*. Bangalore, India: National Institute of Advanced Studies; 2006. pp. 155–183.
14. Banquet JP, Lesévre N. Event-related potentials in altered states of consciousness. *Prog Brain Res* 1980; **54**:447–453.
15. Goddard PH. Transcendental meditation as an intervention in the aging of neurocognitive function: reduced age-related declines of P300 latencies in elderly practitioners [U S A. Dissertation Abstracts Internatl]. 1992.
16. Slagter HA, Lutz A, Greischar LL, Francis AD, Nieuwenhuis S, Davis JM, Davidson RJ. Mental training affects distribution of limited brain resources. *PLOS Biol* 2007; **5**:1–8.
17. Dietrich A. Functional neuroanatomy of altered states of consciousness: the transient hypofrontality hypothesis. *Consc Cogn* 2002; **12**:231–256.
18. Cahn BR, Polich J. Meditation states and traits: EEG, ERP and neuroimaging studies. *Psychol Bull* 2005; **132**:180–211.
19. Atienza M, Cantero JL, Dominguez-Marin E. The time course of neural changes underlying auditory perceptual learning. *Learn Mem* 2002; **9**:138–150.
20. Lutz A, Greischar LL, Rawlings NB, Ricard M, Davidson RL. Long-term meditators self-induce high-amplitude gamma synchrony during mental practice. *Proc Natl Acad Sci U S A* 2004; **101**:16369–16373.
21. Banquet J, Grossberg S. Probing cognitive processes through the structure of event-related potentials during learning: an experimental and theoretical analysis. *Appl Optics* 1987; **26**:4931–4946.
22. Michie PT, Budd TW, Todd J, Rock D, Wichmann H, Box J, Jablensky AV. Duration and frequency mismatch negativity in schizophrenia. *Clin Neurophysiol* 2000; **111**:1054–1065.
23. Ogura C, Nageishi Y, Omura F, Fukao K, Ohta H, Kishimoto A, Matsubayashi M. N200 component of event-related potentials in depression. *Biol Psychiat* 1993; **33**:720–726.
24. Yair BH, Peter JM, Nathan AF, Efrat AS, Sandra GS. Mismatch negativity in socially withdrawn children. *Biol Psychiat* 2003; **54**:17–24.