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Research article

# Effect of long-term meditation on cognitive status and selected neurophysiological parameters

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ABSTRACT

Meditation is a self-entrainment of the mind impacting overall health. We evaluated the effect of long-term meditation on the cognitive status and selected neurophysiological parameters.

Thirty experienced long-term meditators (LTM) and thirty matched meditation naïve controls (MNC) were selected. A validated Sinhala-version of the repeatable battery for the assessment of neuropsychological status (RBANS) was used to assess the cognitive status. EEG with 10-20 system was recorded for 20 min. EEG frequencies were analysed from six regions. Latencies of N75, P100, N145 were measured on visual evoked potentials (VEP) while median and tibial nerve conduction velocities and amplitudes were recorded via nerve conduction study (NCS).

Sum of index scores of cognitive domains were higher among LTM (mean age 42.8; SD = 4.4 years) than MNC (mean age 42.6; SD = 4.4 years): immediate memory, LTM = 106.7 ± 12.4SD, MNC = 81.3 ± 17.9SD ($p < 0.001$); visuospatial, LTM = 116.2 ± 8.9SD, MNC = 78.3 ± 14.7SD ($p < 0.001$); language, LTM = 117 ± 9.35SD, MNC = 104 ± 8.5SD ($p < 0.001$); attention, LTM = 119.8 ± 16.8SD, MNC = 97.2 ± 17.2SD ($p < 0.001$); delayed memory, LTM = 112.5 ± 10.6SD, MNC = 81.5 ± 13.7SD ($p < 0.001$).

In EEG, significantly higher alpha activity was observed among LTM (mean rank 36.8) at rest in right temporal region compared to MNC (mean rank 24.2) ($p = 0.005$). During meditation bilateral frontopolar region had most significant changes with LTM having predominant higher frequency wave activity compared to MNC.

LTM had significantly higher conduction velocity (LTM 41.9 m/s, MNC 33.8 m/s, $p < 0.001$) and amplitude (LTM 6.7 mV, MNC 5.6 mV, $p = 0.007$) in tibial nerve NCS and significantly shorter latencies on VEP for all deflections.

Long-term meditation enhances cognitive domains and produces significant changes in EEG frequencies, VEP and NCS.

## 1. Introduction

Meditation is a self-regulated practice-based training of the mind that aims to transform mental processes from their usual default trajectories to greater volitional control. The effects of long-term meditation have been noted to have far reaching health benefits beyond the training of mindfulness. Studies have shown positive effects of meditation on both mental and physical disorders including

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irritable bowel disease [1], fibromyalgia [2], post-traumatic stress disorder [3], generalized anxiety disorders [4,5], depression associated with chronic pain syndromes [6], and chronic insomnia [7].

There is a growing interest to assess the effects of long-term meditation on neurological disorders. Migraine, functional neurological disorders and neurodegenerative diseases are some neurological conditions where mindfulness interventios were found to be beneficial [8]. Neurophysiological techniques such as EEG [9], functional neuroimaging [10] and visual evoked potentials (VEP) [10] have been utilized to objectively evaluate the central nervous system (CNS) effects of meditation. Specifically, EEG is utilized to investigate changes in the brain electrical activity and neural oscillations providing insights into functional brain connectivity modulations associated with meditation practice. Similarly, VEP assessed the functional integrity of the visual pathways. NCS assessed the peripheral nerve conduction which was a measure of peripheral nervous system function. However, these previous studies have yielded conflicting results [11–13]. Moreover, the literature on meditation research has been plagued by significant heterogeneity of study methodologies and by studying the effects of meditation on the CNS and peripheral nervous system (PNS) in separate cohorts rather than in the same cohort of patients. This study aimed to evaluate the impact of long-term meditation on both cognitive functioning and neurophysiological parameters of the central and peripheral nervous systems in healthy adults.

Studying how meditation influences both central and peripheral neuronal functions within a single cohort helps provide a more complete understanding of its overall effects on the nervous system. Thus, we aimed to objectively measure the effects of long-term meditation on both cognitive status and neurophysiological functions of central and peripheral neural networks in the same cohort of long-term meditators, and to compare these findings with meditation-naïve controls.

## 2. Methods

### 2.1. Study design, setting and participants

A case-control study of thirty (n = 30) healthy LTM and matched MNC (n = 30) was conducted at the Faculty of Medicine, University of Colombo, Sri Lanka. LTM were recruited by consecutive sampling of responders to advertisements in Buddhist monasteries and meditation centres according to inclusion and exclusion criteria. LTM were defined as those who have been practicing meditation in the last three years or more, participated in at least one week of formal session of meditation (retreat or temple-based) and has been engaging in regular self-practice of 6 h per week or more. In addition to the three selection criteria, a validated intake interview based on individual experiences during meditation was used to select participants for the study population [14].

As the study was designed as an exploratory case–control investigation of a specific population of experienced LTM it was therefore constrained by recruitment feasibility. A formal power assessment using G*Power (two-sample *t*-test, two-sided, $\alpha = 0.05$) indicates that with sample size of 30 (n = 30) participants per group, the study has 80% power to detect a standardized between-group effect size of approximately Cohen's d = .74 (i.e., a large effect). We therefore selected 30 participants per group to allow detection of large, clinically meaningful effects while remaining feasible. This approach is consistent with prior EEG and meditational neurophysiology studies that have used comparable sample sizes in exploratory work [13,15,16].

LTM in this study engaged in multiple established meditation practices. These included focused attention meditation (typically involving sustained awareness of the breath), loving-kindness meditation, open monitoring meditation (non-reactive monitoring of the content of experience from moment to moment), and general mindfulness practices aimed at cultivating present-moment awareness without judgment. These practices were not mutually exclusive and were often practiced interchangeably or sequentially by experienced meditators in the sample.

Age, gender, ethnicity, and educational level matched, healthy non-meditators were recruited as MNC via notices/advertisements displayed in public places. The MNC were either the ones who have never meditated or ones who meditate less than once in 3 months.

All the participants selected in both groups had a Montreal cognitive assessment (MoCA) score ≥26 and normal visual acuity in both eyes. Participants with a history of a neurological, ophthalmological, or psychiatric disease or those who were pregnant were excluded from the study.

At the time of recruitment, participants were well explained about the tests they had to undergo, and written information was also provided prior to obtaining informed consent.

### 2.2. Study procedure

We used RBANS (repeatable battery for the assessment of neuropsychological status), EEG, pattern reversal visual evoked potentials (PR-VEP) and nerve conduction study (NCS) parameters to objectively assess the central and peripheral neural functions, respectively. PR-VEP has not been previously used to measure the effects of meditation on the nervous system.

The RBANS questionnaire version in the participant's native language (Sinhala) [17] was administered in a quiet, comfortable room. RBANS contains 12 questions to assess five different cognitive domains including immediate memory, visuospatial/constructional skills, language, attention, and delayed memory.

EEG was recorded using a 10-20 system with 19 recording electrodes, one ground and one reference electrodes applied on the scalp. EEG signals were band-pass filtered from 1 to 50 Hz, which allowed inclusion of all major frequency bands (delta to low gamma) while minimizing high-frequency muscle artifacts and low-frequency drifts. For LTM, EEG recording commenced with an initial 1-min eyes closed state followed by 19 min of meditation. They were requested to practice their usual type of meditation. For the control group, EEG recording was obtained during a period of 20 min where the participants were requested to be in an eyes-closed relaxed state of mind and to concentrate on a recent engagement in a religious event which had neither been of extreme happiness nor extreme sorrow.

Prior to EEG recording participants were thoroughly explained on the procedure and they all had an initial brief period of trial recording to make them familiarise with the process of recording.

We used “recalling a neutral religious event” as it provided a culturally appropriate, emotionally non-arousing, and cognitively stable state for controls, minimizing mind-wandering and preventing drowsiness during the 20-min EEG recording. This approach allowed better standardization compared with a traditional resting state, in which variability and sleep onset are common.

VEP recordings were obtained according to the standard protocol recommended by the International Society for Clinicial Electrophysiology of Vision with the use of the machine X Calibre 1.4, XLTEX software version 1.4 [18]. It was recorded with pattern reversal stimuli (checkerboard with a red fixation point) using a mid-occipital electrode with the reference on the vertex and ground electrode placed on the mastoid. The recording (reversal rate was 2Hz with checkerboard stimuli 15′ and 60’ at 100% contrast) was obtained under binocular and monocular stimulation. The viewing distance used in this study was 100 cm. The main wave forms, N75, P100 and N145 were analysed for latencies in each eye.

The nerve conduction parameters were recorded using the machine X Caliber 1.4, XLTEX software version 1.4. The equipment contains an inbuilt amplifier with filters and an electrical stimulator. These filters can distinguish artifacts from the actual signal produced by an activated nerve. Peripheral nerve conduction was assessed at rest in the right median and tibial nerves. Nerve conduction velocity and amplitude of the compound motor action potentials were examined using standard procedure.

### 2.3. Data analysis

The RBANS assesses five cognitive domains, Immediate memory, visuospatial/constructional function, language, attention, and delayed memory. The test consists of 12 subtests and the score on each subtest contributes to one of the five cognitive domains [19]. The index scores of individual domains were compared between the two groups of LTM and MNCs.

The EEG data in this study was analysed with automated spectral analysis. Spectral analysis quantifies the amount of rhythmic activity of different frequencies in EEGs. It is a fundamental computational EEG analysis method that can provide information on power, spatial distribution, or event-related temporal change of a frequency of interest [20].

Upon completion of every real-time EEG recording, the EEGs were inspected offline for artifacts (e.g. eye, lips, and muscle movements etc) and such sections were excluded from analysis. Spectral analysis based on the epochs of 5 min before, during and after meditation were carried out. The percentage distribution of individual waveforms was analysed in epochs of 5 min in frontal, parietal, temporal and occipital brain areas both before and during meditation. In MNC, the percentage distribution was assessed before and during the relaxation activity.

Real-time averaged VEP waveforms were recorded offline for latency and peak-peak amplitudes. Latency of the wave forms were considered for analysis.

The peripheral nerve conduction parameters, amplitudes, latencies and conduction velocities, of the compound motor action potential of the right median and tibial nerves were assessed.

### 2.4. Statistical analysis

Data obtained for individual tests were analysed using IBM SPSS-23 statistical software for descriptive statistics using frequency distribution, mean etc. to demonstrate the distribution of data for each parameter. Non normal distribution of data was shown in normality assessment using Shapiro–Wilk normality test. Thus, Mann-Whitney *U* test was used as a non-parametric test to assess the statistical significance of data. A p value $\leq .05$ was statistically significant. Spearman's correlation test was used to assess the relationship between different cognitive domains and, meditational practice.

### 2.5. Ethical clearance

Ethical clearance was obtained from Ethics Review Committee, Faculty of Medicine, University of Colombo, Sri Lanka (EC-19-086).

**Table 1**
Socio demographic characteristics.

| | Long term meditators (n = 30) | Meditation naïve controls (n = 30) |
|---|---|---|
| Age in years (mean ± SD) | 42·83 ± 4·43 | 42·57 ± 4·38 |
| Gender (%) | | |
| Male | 19 (63·33%) | 19 (63·33%) |
| Female | 11 (36·67%) | 11 (36·67%) |
| Level of education (%) | | |
| Tertiary | 22 (73·33%) | 22 (73·33%) |
| Secondary | 8 (26·67%) | 8 (26·67%) |
| Civil status (%) | | |
| Married | 15 (50%) | 20 (66·67%) |
| Single | 15 (50%) | 10 (33·33%) |

*Role of the funding source*

The study was funded by the World Bank via the grant Accelerating Higher Education Expansion and Development (AHEAD) Operation of the Ministry of Higher Education funded by the World Bank [Grant No. 6026-LK/8743-LK].

The funders of the study had no role in the study design, study procedure, data analysis, data interpretation, or writing of the report.

## 3. Results

Socio-demographic and meditation practice of the study population.

Table 1 shows the sociodemographic characteristics of the study participants. One to one matching of age, gender and education level was done during recruitment of controls to minimize confounding factors.

In the cohort of LTM, meditation practice was quantified based on years of practice and hours of meditation per week. Mean years of meditation practice was 1273 (SD 7·11) while the mean hours of meditational practice per week was 6.28 (SD 1·19).

Cognitive assessment with RBANS.

Analysis of RBANS showed a higher total index score for LTM compared to MNC with a significantly higher score for all five domains tested (Table 2). Although a positive correlation was noted between the duration of meditation practice and the sum of index scores for each domain, these did not reach statistical significance (Table 3).

EEG.

The EEG wave form frequency percentages were analysed before and during meditation or focused thinking in the LTM and MNC groups (Figs. 1 and 2). At rest, prior to meditation/focused thinking, a difference was noted only in the right temporal region where LTM had a higher alpha activity than MNC ($p = 0{\cdot}005$). However, during meditation/focused thinking, compared to the MNC group, LTM had significantly higher alpha, theta and beta activity in both left and right frontopolar regions, higher alpha activity in in both left and right temporal regions and the right occipital region, and significantly lower delta activity in both frontopolar regions and lesser beta activity in the right occipital region (Fig. 2).

VEP latencies.

VEP recorded at rest is shown in Table 4. The VEP latencies of N75, P100 and N145 were significantly shorter in LTM than in MNC.

NCS.

NCS were performed on median and tibial nerves (Table 5). The amplitude and conduction velocity in the tibial nerve were significantly higher among LTM compared to MNC while there was no difference in the NCS parameters in the median nerve between the two groups.

## 4. Discussion

In the pursuit of understanding the effects of long-term meditation practice on the human nervous system, we conducted a study comparing 30 LTM with 30 MNC. This study delved into the realms of cognition, EEG activity, VEP latencies, and NCS to evaluate central and peripheral neural adaptations in response to long term meditation. In this study, we found that the cognitive function of LTM surpassed that of their non-meditating counterparts, marked by higher scores across various cognitive domains. EEG analysis found distinctive brainwave patterns, particularly during meditation, emphasizing increased alpha, theta, and beta activity. Furthermore, LTM individuals demonstrated accelerated visual information processing, as indicated by shorter VEP latencies. Peripheral nerve conduction, particularly in the tibial nerve, displayed enhancements among the meditators. These findings collectively underscore the transformative potential of long-term meditation on the nervous system.

Long-term meditation induced changes in the human body would span across many body systems starting at the cellular level where it has shown to be associated with longevity and longer telomere length due to modulations in epigenetic mechanisms [21].

Mechanistic insights behind these central and peripheral nervous system changes following long-term meditation could be multifaceted, including changes in the neurochemicals, structural brain components, and functional connectivity. These changes have been shown in multitude of studies. Considering modulations in neurochemicals, LTM have demonstrated to have higher levels of serotonin, melatonin and higher serum antioxidant levels [22]. These would possibly impact the neuronal and synaptic plasticity. Meditational research using Diffusion Tensor Imaging showed pronounced structural connectivity in brain pathways among long-term meditators [23] elucidating characteristic changes in brain white matter. Similarly functional modulations in large-scale brain networks have also been demonstrated [24] along with morphometric changes including grey matter volume [25].

**Table 2**
Mean comparisons of cognitive (RBANS) domains between meditators and non-mediators.

| | Mean index score for Meditators (n = 30) | Mean index score for non-meditators (n = 30) | *p value |
|---|---|---|---|
| Immediate memory | 106·7 (SD 12·4) | 81·3 (SD 17·8) | p < 0.001 |
| Visuospatial/constructional | 116·2 (SD 8·9) | 78·3 (SD 14·7) | p < 0.001 |
| Language | 117 (SD 9·3) | 104 (SD 8·5) | p < 0.001 |
| Attention | 119·8 (SD 16·8) | 97·2 (SD 17·2) | p < 0.001 |
| Delayed memory | 112·5 (SD 10·6) | 81·5 (SD 13·7) | p < 0.001 |
| Total score | 572·2 (SD 43·6) | 442·4 (SD 33·5) | p < 0.001 |

**Table 3**
Analysis of correlation of RBANS scores with meditational practice.

| Index scores of RBANS domains | Spearman's correlation coefficient (Significance 2-tailed) | |
|---|---|---|
| | Years of meditational practice | Hours of meditation per week |
| Immediate memory | 0·014 (.94) | 0·102 (.59) |
| Visuospatial/constructional | 0·011 (.95) | 0·265 (.16) |
| Language | −0·215 (.25) | −0·019 (.92) |
| Attention | 0·274 (.14) | 0·32 (.08) |
| Delayed memory | **0·399 (.03)** | 0·122 (.52) |
| Total score | .193 (.31) | .268 (.15) |

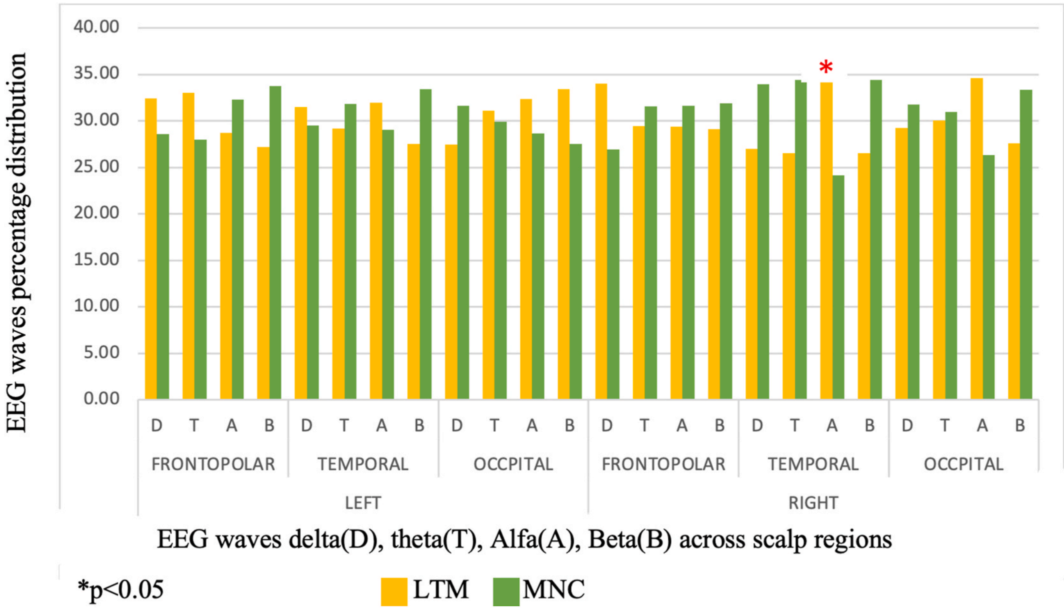


**Fig. 1.** EEG frequency analysis before meditation/focused thinking.

Although most of the above studies have focused on central nervous system, it is likely that the neuroplasticity which occurs there could also take place in the peripheral nerves too.

Cognition.

People who have entrained their minds on long term meditation have been shown to have improved cognitive skills [12]. Out of the six main cognitive domains of complex attention, executive function, learning and memory, language, perceptual–motor function, and social cognition [26], improvement in attention and visuospatial skills has been reported with varying meditational practices [27]. Although RBANS has been previously applied in short-term meditational research [28], our study is the first to comprehensively investigate all five cognitive domains, including short-term and long-term memory, visuospatial constructional abilities, attention, and language within a single cohort of healthy adults. The results of our investigation reveal a noteworthy trend, with individuals engaging in long term meditation exhibiting significantly higher scores across all these cognitive domains when compared to their meditation naïve counterparts.

The Spearman's correlation analysis explored the relationship between long-term meditation and various cognitive domains assessed by RBANS. Among the domains, delayed memory showed a statistically significant positive correlation with years of meditation practice ($\rho = .399$, $p = 0.03$), suggesting that longer-term meditators may have better preservation or enhancement of delayed memory. Other domains such as attention also showed moderate positive correlations with both years of practice ($\rho = .274$, $p = 0.14$) and weekly hours of practice ($\rho = .32$, $p = 0.08$), though these did not reach statistical significance.

Interestingly, language scores showed a weak negative correlation with years of meditation ($\rho = -.215$), although this was not significant ($p = 0.25$), indicating potential variability in this domain unrelated to meditation exposure. Immediate memory and visuospatial construction showed minimal correlations, with coefficients close to zero. The total RBANS score showed modest positive correlations with both meditation duration ($\rho = .193$) and weekly intensity ($\rho = .268$), yet again not statistically significant. Overall, these findings tentatively support a positive association between long-term meditation and specific cognitive functions, particularly delayed memory.

EEG.

EEG is a non-invasive measure of electro-cortical activity which has been in used in meditational research for over 50 years [29].

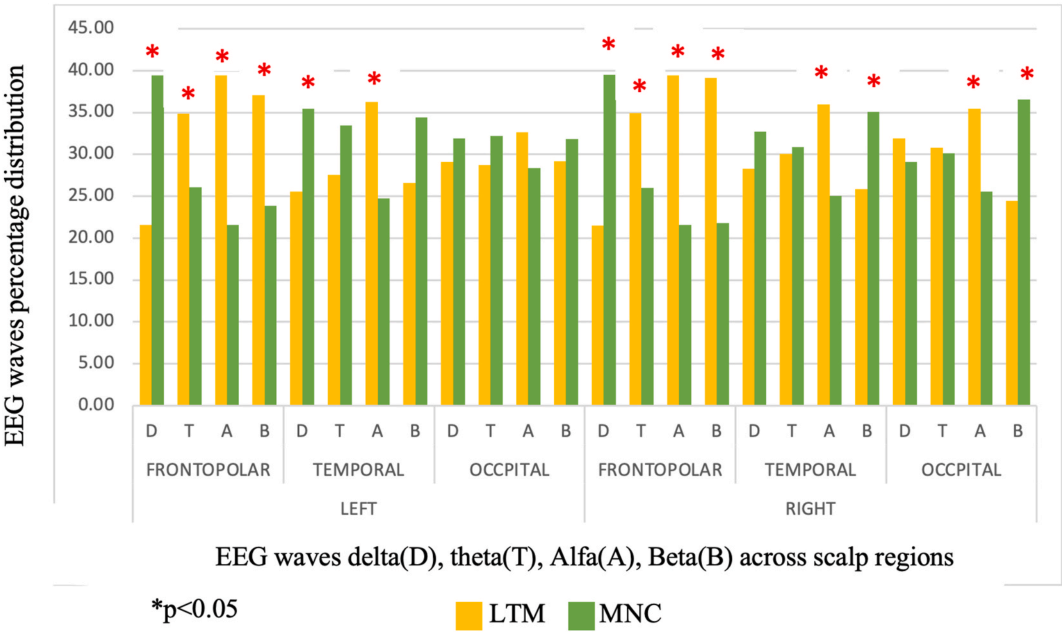


**Fig. 2.** EEG frequency analysis during meditation/focused thinking.

When examining individuals involved in LTM in comparison to the MNC group, notable differences emerged in the delta, alpha, and beta frequencies observed during meditation. Particularly noteworthy were the significant alterations identified in the alpha wave activity in the right temporal region during resting states. Specifically, participants engaged in LTM displayed substantially elevated levels of alpha activity in this region. Like previous observations, we found an augmentation in the distribution of alpha frequencies during meditation in the frontopolar region bilaterally [13].

The long-term meditators who participated in this study, as stated earlier were practicing different types of Buddhist mediational techniques belonging to both Samatha and Vipassana. The predominant alpha waves during meditation in the frontopolar regions in this group could be explained by increased concentration and reduced cortical excitatory effect [29] which are key prerequisites in any meditation.

EEG has been stated as a functional neural correlate of various aspects of cognition including cognitive reserve [30]. Although we have not directly assessed cognitive reserve as a parameter in our study, resting state EEG changes may resemble the distinction in cognitive reserve because of long-term meditation.

VEP.

For the first time in long-term meditational research, pattern reversal visual evoked potentials (PR-VEP) were employed as a measurement tool in our study. We found that all three wave forms: N74, p100 and N145, had significantly shorter latencies among LTM compared to MNC suggesting that long term meditation entrains faster neural processing. Previously, similar findings have been reported using neuroimaging techniques to demonstrate heightened visual cortical responsivity following a visual recognition memory task in a cohort of mindfulness meditation practitioners [31]. Our work, in concert with these earlier findings, underscores the profound impact that meditation can have on neural processing.

NCS.

Although modulations of CNS functions have been extensively researched, PNS has so far received minimal attention in meditational research. Few studies have demonstrated subjective symptom improvement in varying disease related states following a trial of meditation although the findings have not been supported by objective measurements of PNS functions [32,33]. Ours is the first long-term mediational research to have used NCS as an objective measurement.

We found significantly faster NCV in the tibial nerve among LTM compared to MNC. Although, faster NCV have been reported in patients with diabetes who engaged in yoga practice [34], our findings were related to healthy individuals and were not influenced by physical nerve stretching that may occur during yoga practice.

There were few limitations in our study. LTM in our study were engaged in diverse forms of Buddhist meditation, encompassing both Samatha and Vipassana practices. Notably, the scientific literature lacks clear and definitive criteria for distinguishing between these two types of meditation, making it challenging to analyse outcomes separately for each. Furthermore, our study chose to focus on specific cognitive domains due to the limited availability of validated tools for cognitive assessment within our community. This decision was made to ensure a more accurate and relevant evaluation of cognitive parameters within the constraints of available resources. We have not considered the stage of the menstrual cycle when matching female controls although this may have had an emotional component and there by influencing the cognitive assessment. Furthermore, it may be argued that the changes we observed may reflect a trait in persons biased to meditation rather than the effects of meditation *per se*. Although this assumption cannot be

**Table 4**
VEP latencies.

| | Right side | | | | | Left side | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Long term Meditators | | Non-meditators | | Independent sample test (Sig 2-tailed) | Long term Meditators | | Non-meditators | | Independent sample test (Sig 2-tailed) |
| | Mean latency (ms) | SD | Mean latency (ms) | SD | | Mean latency (ms) | SD | Mean latency (ms) | SD | |
| N 75 | 70·62 | 7·87 | 76·09 | 6·74 | ·006 | 70·3 | 7·64 | 78·08 | 7·71 | <·001 |
| P 100 | 99·88 | 10·65 | 104·2 | 3·27 | ·044 | 98·77 | 10·23 | 106·14 | 3·23 | <·001 |
| N 145 | 129·3 | 16·1 | 137·24 | 10·16 | ·035 | 129·73 | 14·24 | 139·78 | 6·74 | <·001 |

**Table 5**
Peripheral nerve conduction studies.

| Peripheral nerve | Parameter | Long term Meditators | | Non- Meditators | | Independent sample test (Sig 2-tailed) |
|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | |
| Median nerve | Amplitude (μV) | 5·46 | 1·57 | 7·65 | 1·5 | 0·657 |
| | Conduction velocity (m/s) | 54·95 | 3·8 | 53·81 | 3 | 0·249 |
| Tibial Nerve | Amplitude (μV) | 6·72 | 1·77 | 5·61 | 1·56 | <0·001 |
| | Conduction velocity (m/s) | 41·88 | 5·58 | 33·8 | 5·46 | 0·007 |

completely ruled out, we believe that it may be largely mitigated by comparing the LTM with an equal number of MNC who were carefully matched one on one for age, sex and educational status. Another limitation of the study is the imbalance in civil status between the two groups, with a higher proportion of married individuals in the control group. Marital status has been associated with differences in psychological wellbeing, stress levels, social support, and cognitive performance, which may indirectly influence neurophysiological measures. Although the groups were matched for age, sex, and educational level, this difference in civil status could represent a potential confounding factor.

These findings suggest that long-term meditation may contribute to enhanced neural efficiency and cognitive functioning in healthy individuals, and warrant further investigation through interventional studies, particularly in populations with neurological disorders.

In conclusion, our study has demonstrated measurable outcomes among LTM in relation to cognition, EEG and VEP dynamics, and NCS parameters compared to MNC. These findings suggest that LTM may contribute to enhanced neural efficiency and cognitive functioning in healthy individuals, and warrant further investigation through interventional studies, particularly in populations with neurological disorders.

## CRediT authorship contribution statement

**Kumarangie Vithanage:** Writing – original draft, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Dilshani WN. Dissanayake:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Thashi Chang:** Writing – review & editing, Supervision, Conceptualization, Data curation, Formal analysis, Investigation, Methodology.

## Data sharing

Data will be made available on request. For requesting data, please write to the corresponding author.

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgement of Sources

We acknowledge the original sources of MOCA (Nasreddine et al., 2005) and RBANS (Randolph C, 1998) and the validated sinhala versions of MOCA (Karunaratne, S et al., 2011) and RBANS (Suraweera C et al., 2016).

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