Asian Journal of Psychiatry 44 (2019) 112–118

Contents lists available at ScienceDirect

Asian Journal of Psychiatry

journal homepage: www.elsevier.com/locate/ajp

Mindfulness and hemodynamics in asians: a literature review

Carol C. Choo[a,*], John J.W. Lee[a], Jonathan H.L. Kuek[a], Kai Keng Ang[b,c], Juan Hong Yu[b], Cyrus S. Ho[d], Roger C. Ho[d,e,f,g]

[a] Department of Psychology, College of Healthcare Sciences, James Cook University, 387380, Singapore
[b] Institute for Infocomm Research, Agency for Science, Technology and Research, 1 Fusionopolis Way, 138632, Singapore
[c] College of Engineering, School of Computer Science and Engineering, Nanyang Technological University, 639798, Singapore
[d] Department of Psychological Medicine, Yong Loo Lin School of Medicine, National University of Singapore, 1E Kent Ridge Road, 119228, Singapore
[e] Institute for Health Innovation and Technology (iHealthtech), National University of Singapore, 119228, Singapore
[f] Center of Excellence in Behavioral Medicine, Nguyen Tat Thanh University, Ho Chi Minh City 70000, Viet Nam
[g] Faculty of Education, Huaibei Normal University, 100 Dongshan Road, Huaibei 235000, China

ARTICLE INFO

Keywords:
fNIRS
Hemodynamics
Asia
Mindfulness

ABSTRACT

Introduction: Mindfulness interventions have been increasingly incorporated into clinical settings. Evidence supporting mindfulness practices are predominantly established in Western populations. Neurophysiological evidence has not been established to support the effectiveness of mindfulness practice in Asian populations. Greater understanding of the neurophysiological mechanisms underlying mindfulness would enable hemodynamics as measured by fNIRS to be used to monitor mindfulness practice as an adjunct to psychotherapy with Asian clients.

Method: Research relating to fNIRS and hemodynamics for mindfulness in Asians was reviewed. The inclusion criteria for this review were recent publications in peer-reviewed journals from 2008 to 2018, with the search terms 'fNIRS', 'hemodynamics' and 'mindfulness', for studies in Asia.

Findings: Databases included Medline, PubMed, PSYCINFO, Google Scholar and SCOPUS. Initial searches yielded 86 results. Five duplicated articles were removed, and remaining abstracts were screened; and assessed for eligibility against the structured performa. Three full text papers which fit the inclusion criteria were included in the current review.

Conclusion: This review highlighted the paucity of rigorous empirically validated research for hemodynamics as measured with fNIRS for mindfulness practice in Asia.

1. Introduction

Meditation is an umbrella term used to refer to a number of contemplative practices, of which mindfulness meditation garnered the most interest in scholarly literature (Tang et al., 2015). In contemporary psychology, mindfulness interventions that stemmed from traditional meditation practices have increasingly been incorporated into clinical settings (Bishop et al., 2004; Dimidjian and Segal, 2015). Of these mindfulness-based interventions (MBIs), the mindfulness-based stress reduction (MBSR) program was the most widely cited intervention in mindfulness research (Creswell, 2017; Kabat-Zinn, 1982). Much of the interest that MBIs generated revolved around the effect on mental health, and treatment of various mental health issues (Creswell, 2017). MBIs had been effective in producing positive mental health outcomes, such as reducing physiological symptoms related to anxiety, levels of self-perceived stress, and alleviating symptom severity of patients with mental illness (Chen et al., 2013; Chien and Lee, 2013; Phang et al., 2016). While much of the evidence supporting mindfulness practices has been established in mainly Western populations (Boccia et al., 2015), mindfulness-based therapy has also been shown to be an effective treatment for Asian clinical populations with diverse conditions (Chen et al., 2013; Chien and Lee, 2013; Luoma and Villatte, 2012; Wong et al., 2011). Recent literature has cautioned against the assumption that research outcomes from Western countries could be generalized to Asian populations, due to cultural differences (Choo et al., 2017a, 2018a), which provided an impetus for the current review in Asian populations, which could inform the delivery of ethno-culturally sensitive mental health services (Choo et al., 2017b).

* Corresponding author.
E-mail addresses: carol.choo@jcu.edu.au (C.C. Choo), johnjuanwen.lee@my.jcu.edu.au (J.J.W. Lee), hkue4882@uni.sydney.edu.au (J.H.L. Kuek), kkang@i2r.a-star.edu.sg (K.K. Ang), jyu@i2r.a-star.edu.sg (J.H. Yu), su_hui_ho@nuhs.edu.sg (C.S. Ho), pcmrhcm@nus.edu.sg (R.C. Ho).

https://doi.org/10.1016/j.ajp.2019.07.035
Received 22 April 2019; Received in revised form 20 June 2019; Accepted 23 July 2019

Randomized Controlled Trials (RCTs) showed positive outcomes from MBIs, and these therapies were increasingly utilized in clinical settings (Baer, 2003; Grossman et al., 2004). There has been a corresponding proliferation of interest in the mechanisms underlying these effects (Creswell, 2017). When considering mechanisms underlying mindfulness, the assessment of psychological mechanisms had inherent shortcomings (Visted et al., 2015). While much of the research on the outcomes of mindfulness-based practices had utilized self-reports to determine psychological changes, findings had been inconsistent (Creswell, 2017). In a RCT examining the effect of MBSR on Post Traumatic Stress Disorder (PTSD) symptoms in veterans, the program produced greater self-reported mindfulness, with these improvements corresponding with reduction in symptoms (Polusny et al., 2015). However, a recent meta-analysis reported contrary findings, having found that approximately 50% of studies on MBIs failed to produce significant improvement in self-reported mindfulness, pre- and post-intervention (Visted et al., 2015). Such inconsistent findings raised doubts regarding the validity of self-report mindfulness questionnaires, which could be inherently problematic (Visted et al., 2015). In addition to being liable to socially desirable responding and recall bias, self-reporting does not take into account that individuals may lack insight into how attentive and aware they are (Creswell, 2017; Davidson and Kaszniak, 2015). While self-reports measures still provide certain depth in findings, supplementary measures are worth exploring to better monitor changes over time and across contexts (Davidson et al., 2015). Measures such as ecological momentary assessment and task-based measures of mindfulness allow the study of behaviours and experiences in real-world context, permitting more ecologically valid and objective assessments of functioning (Creswell, 2017; Davidson and Kaszniak, 2015).

There has been longstanding interest in the neurobiological substrates of mindfulness (Creswell, 2017). Mindfulness meditation is thought to exert its effect by enhancing three components: control of attention, emotional regulation, and awareness of self (Brown et al., 2014). When examining the brain regions associated with these components during mindfulness meditation, the anterior cingulate cortex and the striatum were implicated in the regulation of attention. The insula, medial Pre-Frontal Cortex (PFC), posterior cingulate cortex, and praecuneus were involved in self-awareness, and multiple prefrontal regions, limbic regions and the striatum had been associated with emotion regulation (Tang et al., 2015).

The PFC has often been implicated in investigations of the effects of mindfulness mediation (Tang et al., 2015). Table 1 will summarize some of the relevant findings from recent studies.

Research highlighted the role of the functional connectivity of multiple prefrontal regions which contributed to stress regulation and activity, and connections in brain areas were related to the fight-flight response. Besides investigating the brain mechanisms underlying stress responses, studies also associated neural changes with positive emotional effects (Creswell, 2017), given that the PFC dictates the ability to be aware of one's own subjective experiences (Brown et al., 2014). In a study utilizing an affect labelling task, Holzel and colleagues (2013) found that MBSR increased activity in the ventrolateral PFC and strengthened connectivity between the PFC and the amygdala, leading to the amelioration of anxiety symptoms. The importance of the functional integration and connectivity was also implicated in more recent research (Doll et al., 2015, 2016). Chen et al. (2015) similarly found that MBIs aided the regulation of PFC activity and might be helpful in the formulation of cognitive restructuring strategies that could in turn regulate brain activity. The theory underpinning such studies is that mindful regulation of affect exerted effect by bolstering prefrontal cognitive control processes, while reducing activity in areas such as the amygdala, which is pertinent to emotional processing (Tang et al., 2015). However, a recent systematic review examining changes in brain activity following manualized MBIs did not support consistent evidence of increased activity in specific prefrontal cortical regions, suggesting

Table 1
Table of Neurophysiological findings in recent Mindfulness Studies.

Author/Year	Participants Characteristics/ Grouping /Tasks	Study objectives	Results	Brain areas and links to mindfulness outcomes
Gundel et al. (2018)	14 (6 male, 8 female) participants (M_{age} = 49.2, SD_{age} = 9.1) with meditation experience (M_{years} = 16.6, SD_{years} = 10.2) and 16 (6 male, 10 female) participants (M_{age} = 22.5, SD_{age} = 7.7) without meditation experience both underwent a 17-minute mindfulness task.	To examine the effects of regular meditation practice on cortical activation patterns in the auditory cortex and its adjacent cortical areas during an auditory mindfulness task.	Compared to the control, participants with meditation experience had a wider pattern of activation in the auditory cortex when resting. In the mindfulness condition, the group with no meditation experience showed a decrease of activation in higher auditory areas while those with meditation experience showed an increase.	Significant activation in the primary somatosensory cortex, gyrus temporalis superior, supramarginal gyrus, and Broca's Area during mindfulness condition.
Hölzel et al. (2011)	26 (14 females, 12 males) participants (M_{age} = 37.9, SD_{age} = 12.2) with Generalized Anxiety Disorder were block randomized into either the experimental eight-week mindfulness-based stress reduction program group or a control eight-week stress management education group.	To investigate the neural mechanisms underlying improvements in Generalized Anxiety Disorder symptoms of a mindfulness intervention relative to an active control intervention.	There was a significant reduction of stress over time for both groups $F(124) = 30.32$, $p < .001$, but no differences between groups $F(124) = .013$, $p = .91$.	Increase in response in ventrolateral prefrontal regions. Increased functional connectivity between amygdala and prefrontal regions.
Zeidan et al. (2011)	15 (6 males, 9 females) participants (M_{age} = 26) underwent 4 20-minute mindfulness-based training.	To better understand how mindfulness influences sensory experiences.	Pain intensity ratings were lower following mindfulness training $F(114) = 23.43$, $p < .001$, $\eta 2 = .63$. This led to decrease in pain intensity ratings $F(114) = 14.23$, $p < .001$, $\eta 2 = .50$. Reduced pain unpleasantness was also observed $F(114) = 87.99$, $p < .001$, $\eta 2 = .86$.	Reduced pain-related activation in contra lateral primary somatosensory cortex. Reduced pain intensity was due to an increased activation in anterior cingulate cortex and anterior insula. Reductions in pain unpleasantness was due to increased activation of orbitofrontal cortex; and thalamic deactivation.

the need for a greater understanding of meta-cognitive processes during mindfulness meditation (Young et al., 2018). More research is thus needed to further uncover the neural mechanisms underlying mindfulness interventions.

Neural activity in the brain is followed by alterations in cerebral blood flow (CBF) and blood oxygenation, with these responses measurable by neuroimaging techniques (Buxton et al., 2004). The dynamics involved in the circulation of blood in the brain, otherwise known as the hemodynamic response, is a physiological event from which brain activity can be assessed (Irani et al., 2007). In order to elucidate the brain activity brought about by MBIs, structural and functional neuroimaging methods had been used to examine the neurobiology of mindfulness (Creswell, 2017). In the domain of mindfulness-based neuroscience, two neurophysiological methods were primarily used to uncover the neural mechanisms underlying mindfulness meditation (Brown et al., 2014). The first method, which includes techniques such as electroencephalography (EEG), enables the direct measurement of neural electromagnetic activity (Irani et al., 2007). The second method, which describes neuroimaging techniques such as functional Magnetic Resonance Imaging (fMRI), enables investigators to attain both direct and indirect measures of blood flow in the brain (Irani et al., 2007), and is able to access subcortical regions of the brain including hippocampus and amygdala during executive tasks (Mak et al., 2012; Ren et al., 2012). FMRI also provides data on the volumes of neuroanatomical structures and measures degree of atrophy (Mak et al., 2016).

A study using EEG found that mindfulness training increased left-frontal activity during an affective challenge (Zhou and Liu, 2017). However, as neuroimaging methods such as fMRI enable the indirect measurement of CBF and offer superior spatial resolution, providing a higher possibility of identifying the location of neural activation, the latter method is often preferred (Brown et al., 2014). As it is also considered safe and non-intrusive, and able to access subcortical regions of the brain, fMRI has been regarded as the optimal method to measure functional brain activity (Irani et al., 2007). It has thus been widely utilized in mindfulness and/or meditation research in both clinical (Chen et al., 2015; Hölzel et al., 2013) and non-clinical populations (Lee et al., 2012; Zeidan et al., 2011).

Objective neuroimaging investigations had linked the positive emotional and cognitive effects of mindfulness meditation with neural correlates such as increased activity in the PFC (Tang et al., 2015). However, traditional neuroimaging techniques such as fMRI suffer from functional shortcomings, limiting its applicability (Irani et al., 2007; Lu et al., 2015). Such techniques require participants to adopt a supine position within a magnet bore, resulting in limited applicability (Irani et al., 2007; Lu et al., 2015). In addition, a fixed head position is required to avoid invalidating the data (Irani et al., 2007). As a result, it is unsuitable for measuring brain activation during functional activities (Parsons and Kane, 2017).

Beyond the traditional neuroimaging described above, recent technological developments such as functional Near-Infrared Spectroscopy (fNIRS) have helped clinicians better understand brain activity underpinning day-to-day human functioning (Lu et al., 2015). When compared against other neuroimaging methods, fNIRS offers several advantages. In contrast to fMRI, the portable nature and low sensitivity to movement of fNIRS allows it to measure brain activity and cognition while participants engage in various day-to-day tasks (Parsons and Kane, 2017). For example, a wearable fNIRS system was used in a recent study to monitor brain activity while participants pedalled on bicycles outdoors (Piper et al., 2014). FNIRS is particularly suitable for clinical studies with psychiatric patients who have phobia of enclosed environments and motor restlessness (Ho et al., 2016). Therefore, as a relatively non-intrusive, safe, and portable neuroimaging technique, it permits more ecologically valid investigations of brain hemodynamics (Irani et al., 2007). FNIRS offers an additional advantage because it allows multimodal measurements to be performed with clinical and non-clinical samples e.g. fNIRS and fMRI; fNIRS and EEG (Lai et al., 2017; Yu et al., 2013).

The overarching principle governing the operation of fNIRS systems is that brain function is associated with several physiological changes, two of which, oxygenated hemoglobin (oxy-Hb), and deoxygenated hemoglobin (deoxy-Hb), can be measured with optical imaging techniques (Irani et al., 2007; Lee et al., 2012). Cerebral blood flow (CBF) and cerebral blood volume (CBV) are increased during neural activity, following increased consumption of glucose and oxygen; this phenomenon is referred to as neurovascular coupling (Irani et al., 2007; Pasley and Freeman, 2008). During neurovascular coupling, oxy-Hb and deoxy-Hb alter in concentration; projecting near- infrared light into cortical regions of the brain, allowing these changes to be detected with impressive temporal resolution (Irani et al., 2007; Parsons and Kane, 2017). Monitoring changes in the oxy-Hb to deoxy-Hb ratio as indicators of brain activation represent the most widely utilized method of near-infrared spectroscopy (Irani et al., 2007), with the quantifying of changes in hemodynamic data enabling the real-world study of cognitive processing tasks (Vasta et al., 2018; Yuan and Ye, 2013). By means of optical sensors, fNIRS is able to detect hemodynamic changes in the PFC (Lu et al., 2015; Mirelman et al., 2014; Singh et al., 2016). Its applicability has led to its use in a wide array of fields, including research in rehabilitation, sports science, psychology (Pfeifer et al., 2017), and environmental research (Yu et al., 2017).

Several recent studies have used fNIRS to monitor changes in brain activity during walking, and while simultaneously engaging in a task. Holtzer and colleagues (Holtzer et al., 2011) examined hemodynamic changes in a non-clinical adult sample while walking, as well as while walking and talking, and found increased levels of oxy-Hb in the PFC in the latter condition. Similar results were thereafter found in a study conducted by Lu and colleagues (2015), with the left PFC shown to have the greatest and most constant activation when participants walked while completing a cognitive task.

However, few studies have used fNIRS to investigate the effect of mindfulness on brain hemodynamics. One such study was done in Germany (Gundel et al., 2018), and generalizability to Asian samples is unclear. This study sought to examine the differences in brain hemodynamics between meditation experts and novices in a mindfulness condition and a baseline condition. The authors primarily focused on monitoring patterns of cortical activity in the auditory cortex and neighbouring cortical regions (Gundel et al., 2018). It was found that expert meditators had greater activations in a number of auditory cortex regions and adjacent areas, as compared to novice meditators not only in the mindfulness condition, but also in the baseline condition (Gundel et al., 2018). Although activity in the PFC was not monitored, the study had important implications, suggesting that experience in meditation can produce enduring changes in the brain which engender positive psychological outcomes (Gundel et al., 2018). In addition, the study provided support for fNIRS as a suitable method to monitor changes in brain hemodynamics in mindfulness paradigms (Gundel et al., 2018). With a greater understanding of the neurophysiological mechanisms underlying mindfulness practice, there is the potential for fNIRS to be used as biofeedback to monitor mindfulness practice to enhance psychotherapy, with the combination of both biofeedback and mindfulness shown to reduce levels of anxiety (Ratanasiripong et al., 2015; Wyner, 2015) and chronic stress (Steffen et al., 2017).

Much of the evidence supporting mindfulness practices was established in Western populations (Boccia et al., 2015; Gundel et al., 2018). However, neurophysiological evidence had not been clearly established to support the effectiveness of mindfulness practice in Asian populations. The aim of this paper is to review research relating to objective evidence base for fNIRS and hemodynamics for mindfulness practice in Asian samples.

2. Methods

The authors employed the same standard and systematic methodology and result reporting format as our recently published paper in performing the literature review (Choo et al., 2018b). The database search was conducted in November 2018. The inclusion criteria for this review were recent publications in peer-reviewed journals from 2008 to 2018, with usage of search terms namely 'fNIRS', 'hemodynamics' and 'mindfulness', for studies conducted in Asia. The Boolean operator 'AND' was used to combine the search terms. Databases included Medline, PubMed, PSYCINFO, Google Scholar and SCOPUS. The structured proforma for evaluating eligibility for inclusion involved the following: Recent papers that contain original research conducted in Asia, and published in peer-reviewed journals after the year 2008; related to fNIRS, hemodynamics, and mindfulness. The main purpose was to obtain primary citations on studies which were completed in Asia, and not review papers, that fit the inclusion criteria.

3. Results

The aforementioned databases were initially used to identify peer-reviewed papers with the inclusion criteria named above, which yielded 86 results, using all search terms. From the original search results, 5 duplicated articles were removed, and remaining 81 abstracts were screened; and assessed against the inclusion criteria. Many articles screened were not relevant to the focus of the study. Specifically, 79 papers were excluded as there was no practice of mindfulness in the study. One mindfulness study was excluded as it was not conducted in Asia. See Fig. 1 for the PRISMA flow chart (Moher et al., 2009). The results of the review were presented in Table 1. Two recent papers deemed to be suitable were included in the current review.

Similar to the methodology employed in our recently published paper on another clinical topic (Choo et al., 2018b), these papers in Table 2 were examined by extracting pertinent information namely study design, sample characteristics, primary objective and outcome measures pertaining to our research aim, and if these results were significant. The pertinent information was summarized in Table 2. Only quantitative studies were included in the review and presented in Table 2.

4. Discussion

A review of papers presented in Table 2 demonstrated a lack of rigorous and convincing objective evidence of hemodynamics, measured using fNIRS, to support the efficacy of mindfulness interventions for Asian samples, details will be discussed below. It should be noted that due to the lack of research in the area in Asia, it is hard to reach a definite conclusion as to the use of hemodynamics, measured using fNIRS, to support the efficacy of mindfulness interventions for Asian samples. From the review of recent papers presented in Table 2, only one of the two studies employed a robust methodology of Randomized Controlled Trials (RCT), a gap remained in establishing convincing objective evidence of brain hemodynamics, using fNIRS, to examine the efficacy of mindfulness meditation, for non-clinical Asian populations. Deepeshwar et al (2015) used non-Randomized Controlled Trial (RCT) design while Gagrani et al. (2018) used RCT design. The more rigorous design is the study with RCT (Gagrani et al., 2018) which showed that mindfulness meditation significantly improved brain oxygenation in the

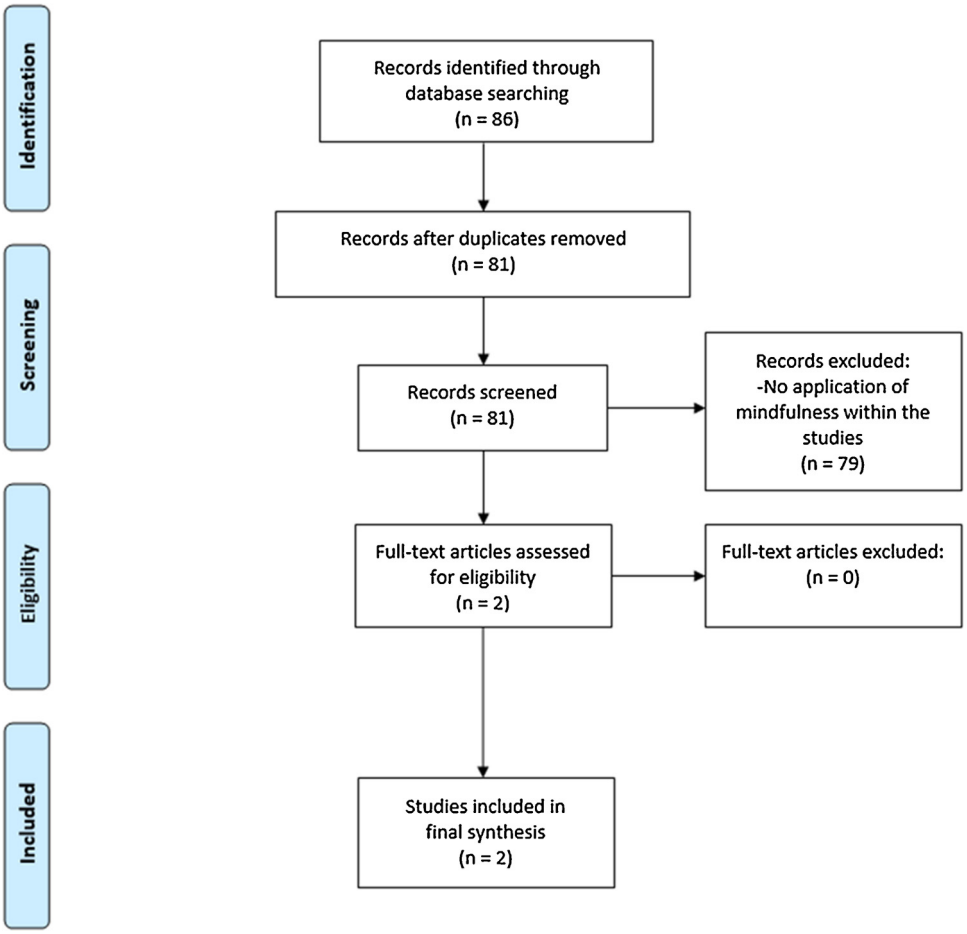

Fig. 1. PRISMA flow diagram.

Table 2
Summary of Evidence.

Author/Year	Study Design/ Participants Characteristics/ Grouping	Study objectives	Results
Deepeshwar et al. (2015)	Repeated Measures Design 22 male university students in India (M_{age} = 22.9, SD_{age} = 4.6) in both the meditative experimental and random thinking control conditions.	The study aimed to examine the bilateral prefrontal hemodynamic response in 2 sessions of meditation and random thinking, and hemodynamic changes and performance during a Stroop color word task.	A significant decrease in concentration of oxy-hemoglobin (ΔHbO) in the left prefrontal cortex (PFC), p = .016 and in the right PFC (p = .032) following the random thinking session during the Stroop task while there was a significant improvement in the left PFC (p = .006) and right PFC (p = .046) after meditation. There was also a significant increase in deoxy-hemoglobin (ΔHbR) at the right PFC (p = .005) after random thinking while there was a significant decrease in the left PFC (p = .02) and right PFC (p < .001) after meditation.
Gagrani et al. (2018)	Randomized Controlled Trial 60 glaucoma patients from India (21 females, 39 males; M_{age} = 57.28, SD_{age} = 9.37) were randomly allocated to a meditation intervention or treatment as usual group.	The study aimed to investigate the effects of meditation on blood flow and oxygenation status of the brain.	A significant improvement in oxygenated hemoglobin change in the PFC was observed in the intervention group across multiple channels of the fNIRS (p = 0.01, 0.04, 0.06, 0.001, 0.002, 0.02, 0.04 respectively).

Pre-Frontal Cortex (PFC) across multiple channels of the fNIRS. Gagrani et al. (2018) used a convenience sample of 60 glaucoma patients in India. It was found that the 6-week meditation program was associated with significant improvement in brain oxygenation, along with a reduction in stress markers. It was concluded that meditation may be a useful as an adjunct to standard treatment in glaucoma patients, and potentially decreased the risk of glaucoma progression. However, the generalizability of the results to other non-clinical samples in other Asian countries is unclear. Deepeshwar et al. (2015) also demonstrated that mindfulness meditation increased brain oxygenation and enhanced performance, which was associated with activation of the PFC. However, the study utilized a small sample size of 22 male university students in India, which limited the generalizability of the results to female students, across the lifespan.

One paper was excluded from this review as it was done in Germany. Gundel et al. (2018) found different lateralization and activation patterns of the brain in expert meditators in a resting state, and in the mindfulness condition. The authors concluded that these results suggested long-term changes in the brain, with positive effects on metacognitive skills and health. Although the research outcome was of interest, but the study included a relatively small sample size of 14 German participants in the intervention and 16 in the control group, which limited the generalizability of the results to Asian samples. A recent study (Kang et al., 2013) provided preliminary neural evidence suggesting that there could be individual and cultural variations in brain activity between Asian and Western participants when engaging in similar tasks, thus cautioning against the generalizability of research outcomes from Western studies to Asian populations.

There were a number of limitations in the aforementioned studies which used fNIRS to explore the effect of mindfulness intervention. The duration of the mindfulness intervention ranged from 2 to 6 sessions (Deepeshwar et al., 2015; Gagrani et al., 2018), and it was unclear what might be the optimal duration, and which specific components of the intervention were linked to the outcomes. Future research could focus on empirical and randomized controlled trials (RCT) in larger samples from different Asian countries that conform to CONSORT guidelines (Eysenbach, 2011). Multidisciplinary research would add further dimensions to this relatively novel area of research. A recent fMRI study suggested that the amygdala-dorsal PFC integration is a potential neural pathway of emotion regulation by mindfulness practice (Doll et al., 2016). Subsequent studies could endeavour to access subcortical regions of the brain such as the hippocampus and amygdala during executive tasks to further understand functional brain activity (Mak et al., 2012; Ren et al., 2012) in non-clinical samples, and explore possible relationships between hemodynamics, mindfulness, and performance in tasks requiring executive function for clinical and non-clinical samples. As a limitation of the fNIRS is its limited penetration depth, another possibility for future research is to include multiple measures e.g., fNIRS and fMRI (Lai et al., 2017; Yu et al., 2013). Additional data on the volumes of neuroanatomical structures and measures for degree of atrophy in clinical samples could be helpful to clinicians (Mak et al., 2016) to explore the relationships between hemodynamics, mindfulness and brain health, for clinical samples with a range of chronic conditions.

Nevertheless, the strength of the review included the investigation of an important clinical issue, highlighted limitations in generalizability of results to other Asian non-clinical samples, across the lifespan, as the studies were done in adult clinical samples (Gagrani et al., 2018) or male university students in India (Deepeshwar et al., 2015). Our review underscored the need for more research on this pertinent topic for Asian countries. Singapore is a multicultural society, with the main ethnic groups consisting of Chinese, Malays and Indians, which offers unique opportunity to examine possible cultural influences in this area (Choo et al., 2017a). Multidisciplinary research is indicated to explore the different dimensions of the pertinent topic in both clinical and non-clinical populations. While self-reported outcomes and other clinical measures (Polusny et al., 2015; Visted et al., 2015) such as reduction of symptoms (Chen et al., 2013; Chien et al., 2013; Phang et al., 2016) could be helpful in gaining insight into the impact of mindfulness; hemodynamics and other neurophysiological evidence could potentially be considered as objective evidence for examining the effect of mindfulness, although research is still in its infancy in Asian populations.

5. Conclusion

In summary, mindfulness interventions have increasingly been incorporated into clinical settings. A greater understanding of the neurophysiological mechanisms underlying mindfulness practice, would potentially enable hemodynamics as measured by fNIRS to be used as biofeedback to monitor mindfulness practice as an adjunct to psychotherapy with Asian clients. However, evidence base is currently lacking. More research is needed to address the current gaps in knowledge. While self-reported outcomes and other clinical measures (Polusny et al., 2015; Visted et al., 2015) such as reduction of symptoms (Chen et al., 2013; Chien et al., 2013; Phang et al., 2016) could be helpful in gaining insight into the impact of mindfulness; neurophysiological evidence could potentially be considered as objective evidence for examining the effect of mindfulness, although research is still in its infancy in Asian populations. More rigorous research and evaluations are needed to establish usage of fNIRS to examine brain

hemodynamics as objective evidence, to further support the efficacy for mindfulness practice with Asians.

Declaration of competing interest

The authors declare no competing financial interest.

Funding sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgement

The postgraduate students CC supervised: AL and DT contributed to some initial support.

References

Baer, R., 2003. Mindfulness training as a clinical intervention: a conceptual and empirical review. Clin Psychol Sci Pract. 10 (2), 125–143.
Bishop, S., Lau, M., Shapiro, S., Carlson, L., Anderson, N., Carmody, J., et al., 2004. Mindfulness: a proposed operational definition. Clin Psychol Sci Pract. 11 (3), 230–241.
Boccia, M., Piccardi, L., Guariglia, P., 2015. The meditative mind: a comprehensive meta-analysis of MRI studies. Biomed Res. Int. 11.
Brown, K., Creswell, J., Ryan, R., 2014. Handbook of Mindfulness: Theory, Research, and Practice. Guildford Press, New York.
Buxton, R.B., Uludağ, K., Dubowitz, D.J., Liu, T.T., 2004. Modeling the hemodynamic response to brain activation. Neuroimage. 23 (1), S220–S233.
Chen, Y., Yang, X., Wang, L., Zhang, X., 2013. A randomized controlled trial of the effects of brief mindfulness meditation on anxiety symptoms and systolic blood pressure in Chinese nursing students. Nurse Educ. Today 33 (10), 1166–1172.
Chen, F., Lv, X., Fang, J., Yu, S., Sui, J., Fan, L., et al., 2015. The effect of body–mind relaxation meditation induction on major depressive disorder: a resting-state fMRI study. J. Affect. Disord. 183, 75–82.
Chien, W.T., Lee, I.Y., 2013. The mindfulness-based psychoeducation program for Chinese patients with schizophrenia. Psychiatr. Serv. 64 (4), 376–379.
Choo, C.C., Harris, K.M., Chew, P.K.H., Ho, R.C., 2017a. Does ethnicity matter in risk and protective factors for suicide attempts and suicide lethality? PLoS One 12, e0175752.
Choo, C.C., Chew, P.K.H., Ho, C.S., Ho, R.C., 2017b. Prediction of quality of life in Asian patients with schizophrenia: a cross-sectional pilot study. Front. Psychiatry 8, 198.
Choo, C.C., Chew, P.K.H., Lai, S., Soo, S., Ho, C.S., Ho, R.C., Wong, R., 2018a. Effect of cardiac rehabilitation on quality of life, depression and anxiety in Asian patients. Int. J. Environ. Res. Public Health 15 (6), E1095.
Choo, C., Kuek, J., Burton, A.A.D., 2018b. Smartphone applications for mindfulness interventions with suicidality in Asian older adults: a literature review. Int. J. Environ. Res. Public Health 15 (12), E2810.
Creswell, J.D., 2017. Mindfulness interventions. Annu. Rev. Psychol. 68 (1), 491–516.
Davidson, R.J., Kaszniak, A.W., 2015. Conceptual and methodological issues in research on mindfulness and meditation. Am. Psychol. 70 (7), 581–592.
Deepeshwar, S., Vinchurkar, S.A., Visweswaraiah, N.K., Nagendra, H.R., 2015. Hemodynamic responses on prefrontal cortex related to meditation and attentional task. Front. Syst. Neurosci. 8, 252.
Dimidjian, S., Segal, Z.V., 2015. Prospects for a clinical science of mindfulness-based intervention. Am. Psychol. 70 (7), 593–620.
Doll, A., Hölzel, B., Boucard, C., Wohlschläger, A., Sorg, C., 2015. Mindfulness is associated with intrinsic functional connectivity between default mode and salience networks. Front. Hum. Neurosci. 9, 461.
Doll, A., Hölzel, B., Mulej Bratec, S., Boucard, C., Xie, X., Wohlschläger, A., Sorg, C., 2016. Mindful attention to breath regulates emotions via increased amygdala–prefrontal cortex connectivity. Neuroimage 134, 305–313.
Eysenbach, G., 2011. CONSORT-EHEALTH: improving and standardizing evaluation reports of Web-based and mobile health interventions. J. Med. Internet Res. 13 (4), e126.
Gagrani, M., Faiq, M.A., Sidhu, T., Dada, R., Yadav, R.K., Sihota, R., et al., 2018. Meditation enhances brain oxygenation, upregulates BDNF and improves quality of life in patients with primary open angle glaucoma: a randomized controlled trial. Restor. Neurol. Neurosci. 36 (6), 741–753.
Grossman, P., Niemann, L., Schmidt, S., Walach, H., 2004. Mindfulness-based stress reduction and health benefits: a meta-analysis. J. Psychosom. Res. 57 (1), 35–43.
Gundel, F., Von Spee, J., Schneider, S., Haeussinger, F.B., Hautzinger, M., Erb, M., et al., 2018. Meditation and the brain – neuronal correlates of mindfulness as assessed with near-infrared spectroscopy. Psychiatry Res Neuroimaging. 271, 24–33.
Ho, C.S.H., Zhang, M.W.B., Ho, R.C.M., 2016. Optical topography in psychiatry: A chip off the old block or a new look beyond the mind-brain frontiers? Front. Psychiatry 7, 74.
Holtzer, R., Mahoney, J.R., Izzetoglu, M., Izzetoglu, K., Onaral, B., Verghese, J., 2011. fNIRS Study of walking and walking while talking in young and old individuals. J. Gerontol. A Biol. Sci. Med. Sci. 66 (8), 879–887.
Hölzel, B.K., Lazar, S.W., Gard, T., Schuman-Olivier, Z., Vago, D.R., Ott, U., 2011. How does mindfulness meditation work? Proposing mechanisms of action from a conceptual and neural perspective. Perspect. Psychol. Sci. 6 (6), 537–559.
Hölzel, B.K., Hoge, E.A., Greve, D.N., Gard, T., Creswell, J.D., Brown, K.W., et al., 2013. Neural mechanisms of symptom improvements in generalized anxiety disorder following mindfulness training. Neuroimage Clin. 2 (1), 448–458.
Irani, F., Platek, S.M., Bunce, S., Ruocco, A.C., Chute, D., 2007. Functional near infrared spectroscopy (fNIRS): an emerging neuroimaging technology with important applications for the study of brain disorders. Clin. Neuropsychol. 21 (1), 9–37.
Kabat-Zinn, J., 1982. An outpatient program in behavioral medicine for chronic pain patients based on the practice of mindfulness meditation: theoretical considerations and preliminary results. Gen. Hosp. Psychiatry 4 (1), 33–47.
Kang, P., Lee, Y., Choi, I., Kim, H., 2013. Neural evidence for individual and cultural variability in the social comparison effect. J. Neurosci. 33 (41), 16200–16208.
Lai, C.Y.Y., Ho, C.S.H., Lim, C.R., Ho, R.C.M., 2017. Functional near-infrared spectroscopy in psychiatry. BJPsych Adv. 23 (5), 324–330.
Lee, T., Leung, M., Tang, J., Yin, J., Chack-Fan, L., Chan, C., 2012. Distinct neural activity associated with focused-attention meditation and loving-kindness meditation. PLoS One 7 (8), e40054.
Lu, C., Liu, Y., Yang, Y., Wu, Y., Wang, R., 2015. Maintaining gait performance by cortical activation during dual-task interference: a functional near-infrared spectroscopy study. PLoS One 10 (6), e0129390.
Luoma, J.B., Villatte, J.L., 2012. Mindfulness in the treatment of suicidal individuals. Cogn. Behav. Pract. 19 (2), 265–276.
Moher, D., Liberati, A., Tetzlaff, J., Altman, D., PRISMA Group, 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ. 339 (7716), b2535.
Mak, A., Ren, T., Fu, E.H., Cheak, A.A., Ho, R.C., 2012. A prospective functional MRI study for executive function in patients with systemic lupus erythematosus without neuropsychiatric symptoms. Semin. Arthritis Rheum. 41 (6), 849–858.
Mak, A., Ho, R.C., Tng, H.Y., Koh, H.L., Chong, J.S., Zhou, J., 2016. Early cerebral volume reductions and their associations with reduced lupus disease activity in patients with newly-diagnosed systemic lupus erythematosus. Sci. Rep. 6, 22231.
Mirelman, A., Maidan, I., Bernad-Elazari, H., Nieuwhof, F., Reelick, M., Giladi, N., Hausdorff, J.M., 2014. Increased frontal brain activation during walking while dual tasking: an fNIRS study in healthy young adults. J. Neuroeng. Rehabil. 11 (1), 85.
Parsons, T., Kane, R., 2017. The Role of Technology in Clinical Neuropsychology. Oxford University Press, UK.
Pasley, B., Freeman, R., 2008. Neurovascular coupling. Scholarpedia. 3, 5340.
Pfeifer, M.D., Scholkmann, F., Labruyère, R., 2017. Signal processing in functional near-infrared spectroscopy (fNIRS): methodological differences lead to different statistical results. Front. Hum. Neurosci. 11 641–641.
Piper, S.K., Krueger, A., Koch, S.P., Mehnert, J., Habermehl, C., Steinbrink, J., et al., 2014. A wearable multi-channel fNIRS system for brain imaging in freely moving subjects. Neuroimage. 85, 64–71.
Phang, C.K., Chiang, K.C., Ng, L.O., Keng, S., Oei, T.P.S., 2016. Effects of brief group mindfulness-based cognitive therapy for stress reduction among medical students in a Malaysian university. Mindfulness 7 (1), 189–197.
Polusny, M., Erbes, C., Thuras, P., Moran, A., Lamberty, G., Collins, R., et al., 2015. Mindfulness-based stress reduction for posttraumatic stress disorder among veterans: a randomized clinical trial. JAMA. 314 (5), 456–465.
Ratanasiripong, P., Park, J.F., Ratanasiripong, N., Kathalae, D., 2015. Stress and anxiety management in nursing students: biofeedback and mindfulness meditation. J. Nurs. Educ. 54 (9), 520–524.
Ren, T., Ho, R.C., Mak, A., 2012. Dysfunctional cortico-basal ganglia-thalamic circuit and altered hippocampal-amygdala activity on cognitive set-shifting in non-neuropsychiatric systemic lupus erythematosus. Arthritis Rheum. 64 (12), 4048–4059.
Tang, Y.Y., Hölzel, B.K., Posner, M.I., 2015. The neuroscience of mindfulness meditation. Nat. Rev. Neurosci. 16 (4), 213–225.
Singh, K., Bhargav, H., Srinivasan, T.M., 2016. Effect of uninostril yoga breathing on brain hemodynamics: a functional near-infrared spectroscopy study. Int. J. Yoga 9 (1), 12–19.
Steffen, P., Austin, T., Debarros, A., 2017. Treating chronic stress to address the growing problem of depression and anxiety: biofeedback and mindfulness as simple, effective preventive measures. Policy Insights Behav. Brain Sci. 4 (1), 64–70.
Vasta, R., Cutini, S., Cerasa, A., Gramigna, V., Olivadese, G., Arabia, G., Quattrone, A., 2018. Physiological aging influence on brain hemodynamic activity during task-switching: a fNIRS study. Front. Aging Neurosci. 9, 433.
Visted, E., Vøllestad, J., Nielsen, M., Nielsen, G., 2015. The impact of group-based mindfulness training on self-reported mindfulness: a systematic review and meta-analysis. Mindfulness 6 (3), 501–522.
Wong, S.Y., Mak, W.W., Cheung, E.Y., Ling, C.Y., Lui, W.W., Tang, W.K., et al., 2011. A randomized, controlled clinical trial: the effect of mindfulness-based cognitive therapy on generalized anxiety disorder among Chinese community patients: protocol for a randomized trial. BMC Psychiatry 11 (1), 187.
Wyner, D., 2015. Pilot study of a university counseling center stress management program employing mindfulness and compassion-based relaxation training with biofeedback. Biofeedback 43 (3), 121–128.
Young, K.S., van der Velden, A.M., Craske, M.G., Pallesen, K.J., Fjorback, L., Roepstorff, A., Parsons, C.E., 2018. The impact of mindfulness-based interventions on brain activity: a systematic review of functional magnetic resonance imaging studies. Neurosci. Biobehav. Rev. 84, 424–433.
Yu, J., Ang, K.K., Guan, C., Wang, C., 2013. A multimodal fNIRS and EEG-based BCI study on motor imagery and passive movement. 2013 6th International IEEE/EMBS Conference on Neural Engineering (NER) 5–8.
Yu, J.H., Ang, K.K., Ho, S.H., Sia, A., Ho, R., 2017. Prefrontal cortical activation while viewing urban and garden scenes: a pilot fNIRS study. In Conference Proceedings:

Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual Conference. pp. 2546–2549 2017.
Yuan, Z., Ye, J., 2013. Fusion of fNIRS and fMRI data: identifying when and where hemodynamic signals are changing in human brains. Front. Hum. Neurosci. 7, 676.
Zeidan, F., Martucci, K.T., Kraft, R.A., Gordon, N.S., Mchaffie, J.G., Coghill, R.C., 2011. Brain mechanisms supporting the modulation of pain by mindfulness meditation. J. Neurosci. 31 (14), 5540–5548.
Zhou, R., Liu, L., 2017. Eight-week mindfulness training enhances left frontal EEG asymmetry during emotional challenge: a randomized controlled trial. Mindfulness 8 (1), 181–189.