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Psychophysiology of Meditation

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Abstract

Psychophysiological research on meditation examines modulations in brain and body physiology resulting from, or associated with, meditation. This chapter considers the available evidence regarding the effects of meditation on psychophysiological markers, including frontal electroencephalography (EEG) alpha asymmetry, event-related brain potentials (ERPs), heart-rate variability (HRV) and its derivative indexes, and galvanic skin response (GSR). The emerging mosaic of findings suggests an inconclusive mixed pattern of evidence regarding changes in frontal EEG alpha asymmetry (as an index of approach/withdrawal or positive/negative emotions) with meditation. The evidence-base on ERP changes resulting from meditation is more consistent, particularly pointing to improvements in attention control. However, ERP evidence on modulations in emotion processing, language processing and existential awareness (such as decentering) with meditation is very limited, not allowing for conclusive answers. Results across studies on HRV and HRV-derived indexes of sympathetic/parasympathetic activity suggest differential modulations in these markers with different meditation types. Finally, a very small number of studies on changes in GSR points to possible reductions indicating improvements in parasympathetic activity (however, this pattern needs to be interpreted with caution due to methodological limitations of the studies). Overall, the current evidence on psychophysiological changes with meditation underscores the potential of these methods in providing novel insights into the effects and mechanisms of meditation. More rigorous studies with long-term follow up, comprehensive systemic assessments and explorations of convergent/divergent patterns of findings across psychophysiological indexes are needed.

Keywords: psychophysiology; meditation; mindfulness; frontal alpha asymmetry; event-related brain potentials (ERP); heart-rate variability (HRV); galvanic skin response (GSR)

Introduction

Psychophysiology can be described as the science of bodily functioning in relation to psychological processes. Such broad definition of psychophysiology encompasses a wide range of research methods investigating the relationship between mental processing and brain functioning, sweat response, hormonal stress response, heart rate and related markers, facial muscle activity etc. The psychophysiological brain measures used in this field traditionally include electroencephalography (EEG) derived indexes, such as prefrontal alpha asymmetry and event-related brain potentials (ERPs). More recent brain imaging methods could also be considered under the label of psychophysiology, but in this chapter, we will focus on meditation studies employing the historically most typical psychophysiological indexes including ERPs, heart-rate variability measures and galvanic skin response (see Chapter by Fox & Cahn in this volume for magnetic resonance imaging and related EEG frequency research on meditation).

Before we consider the specifics of the different psychophysiological markers and their associations with, or modulations by, meditation, it might be helpful to consider a few general methodological points. The first one relates to the participant samples in current psychophysiological meditation research - most of the participants in these studies have been adults with different levels of meditation proficiency compared to meditation novices. Accordingly, very few studies using psychophysiological methods involved children and adolescents (e.g., Sanger et al., 2018) or older adults (e.g., Malinowski et al., 2017). Similarly, most participants in the studies were healthy and there is very little research on the effects of meditation in clinical samples (for an exception see Bostanov et al., 2012). Therefore, in this review we will be mostly focusing on the psychophysiology of meditation in adults but will also consider initial research evidence from research with children, adolescents, older adults and clinical samples, where relevant, to encourage further research.

The second methodological point is applicable across different methodologies in meditation research and relates to types of study designs - within research on psychophysiology of meditation some (dispositional) studies investigated links between self-reported trait mindfulness and psychophysiological indexes (e.g., Brown et al., 2013) and other (cross-sectional) studies examined differences in psychophysiological markers between meditators and non-meditators at one point in time (e.g., Teper et al., 2012). Dispositional studies typically include participants without prior training in meditation and rely on natural variation in the mindfulness trait. In contrast, cross-sectional studies compare participants who underwent meditation training and those without meditation training on various psychophysiological markers and sometimes also on the mindfulness trait. The methodologically most rigorous category of psychophysiological studies on meditation focused either on pre-post effects of brief one-session meditation practices in comparison to a control group (e.g., Eddy et al., 2015) or on pre-post effects resulting from more extensive meditation training over days or weeks compared to a control group (e.g., Davidson et al., 2003). In this chapter we will primarily focus on the longitudinal 'several-session' studies since these provide strongest evidence of the causal impact meditation can have on psychophysiological changes.

The final methodological point pertains to systematic and comprehensive theory-driven considerations about the mechanisms of meditation. Most current research on the psychophysiology of meditation, just like research on neuroscience of meditation and cognitive effects of meditation, has so far mostly focused on associations and changes in attention- and emotion-related indexes. These two areas have been repeatedly highlighted as central in previous considerations about key mechanisms underlying meditation (e.g., Lutz et al., 2008; Tang et al., 2015). However, some recent theoretical models outlined more comprehensive mechanisms of mindfulness (Hölzel et al., 2011) and meditation (Dorjee, 2016). In what follows we will apply a proposal by Dorjee (2016; 2017) considering changes in the metacognitive self-regulatory capacity (MSRC) of the mind and modes of existential awareness (MEA) as the two core mechanisms modulated by meditation. The MSRC involves self-reflective metacognition and attention control, emotion regulation and relevant language processes linked to processing of meaning. Self-reflective metacognition refers to the ability to notice and monitor processes of the mind and use this information in guiding attention control which in turn enables us to decide where we place attention and for how long. Flexible and adaptive self-reflective metacognition and attention control facilitate effective management of emotions, such as noticing early when emotions arise and increasing or decreasing their intensity in line with our goals. Language processes interact and get modified by the self-reflective metacognition, attention control and emotion regulation processes – for example, one can notice negative rumination arising and shift attention to some neutral activity or content, then with practice activation of negative meanings decreases. The MEA refer to phenomenological experiential shifts in the construal of self and reality gradually progressing from immersion in mental phenomena through decentering from them (perceiving them more as fleeting phenomena rather than facts) and towards more 'de-constructed' phenomenological sense of self and reality (states sometimes described as 'emptiness of self' or states of 'non-dual awareness'). Importantly, the model proposes direct reciprocal links between changes in the MSRC and the MEA with further reciprocal connections to the autonomic nervous system. While some psychophysiological methods (such as ERPs) are particularly suitable for assessing changes in the MSRC and MEA with meditation, others (e.g., heart-rate variability measures) can uniquely enhance our understanding of the links between MSRC/MEA and the autonomic nervous system.

Prefrontal EEG alpha asymmetry and meditation

The EEG signal is recorded from the surface of the scalp and measures cumulative electrical activity (on the scale of microvolts) of the brain. The electrical signal relates to neurotransmitter activity at the level of neuronal synapses. The EEG signal can be used to derive a variety of psychophysiological markers indexing brain activity. One of the simplest and historically oldest of these markers is the division of brain activity based on the frequency of the EEG signal into delta, theta, alpha, beta and gamma frequency bands. Prefrontal alpha asymmetry is a derivative index of the raw frequency band signal in the alpha band range (7 or 8 to 13 Hz). It compares (by subtracting logarithmic transformations of the signal) alpha band signal over the left brain hemisphere to the same alpha band measure over the right hemisphere with higher values suggesting increased left-sided activation (Sutton & Davidson, 2015; Towers & Allen, 2012).

The prefrontal alpha asymmetry is typically recorded during a several-minute long alternating sequence of resting with eyes open and closed. It has been used as an index of approach-oriented behaviour or positive emotions linked to higher left-sided prefrontal alpha activity vs. avoidance-oriented behaviour or negative emotions associated with higher right-sided prefrontal alpha activity. A relatively extensive body of research suggests that increased right-sided prefrontal alpha asymmetry, particularly during emotionally challenging situations, is associated with depression (Stewart et al., 2014) and prefrontal alpha asymmetry has been proposed as a psychophysiological marker of depression vulnerability (Allen & Reznik, 2015).

Within the framework of mechanisms underlying contemplative practice (Dorjee, 2016) the prefrontal alpha asymmetry can be considered as a marker of emotion regulation. However, the processes of emotion regulation inevitably also entail the contribution of metacognitive attention control involving noticing and monitoring of mental processes and associated shifts in attention focus. In addition, emotion regulation overlaps with regulation of ruminative conceptual processing such as management of repetitive negative thinking to decrease its frequency and associated intensity of emotions. It is also possible that prefrontal alpha asymmetry could be sensitive to changes in MEA, particularly since decentering - the ability to ‘step back’ and disidentify with own thoughts and emotions - has been proposed as the main therapeutic mechanism underlying positive effects of mindfulness-based approaches in depression (Bieling et al., 2012).

In meditation research, a prefrontal alpha asymmetry study by Davidson et al. (2003) that examined changes resulting from attending an 8-week mindfulness-based stress reduction (MBSR) course was the first psychophysiological investigation of a standardized secular meditation-based course. The study examined whether mindfulness training could result in a shift towards increased left-sided prefrontal activity associated with positive emotions and approach-oriented behaviour (tendency to seek social contact rather than withdraw from others). This randomized controlled study with healthy adults in a workplace context had a very good sample size for standards in psychophysiological research and included assessments before the MBSR course, after its completion and also a follow-up assessment after four months.

The predicted significant shift towards left anterior activity in the MBSR group in comparison to the control group was present at the post-test and at the follow-up whilst the groups didn't differ at the pre-test (Davidson et al., 2003).In addition, the study reported significant increases in antibodies in response to a flu vaccine in the MBSR group and the antibody increase was positively related to the shift towards left-sided anterior activity indexed by the change in prefrontal alpha asymmetry.

Other studies on mindfulness-based interventions tried to replicate and extend the findings of Davidson et al. (2003) using prefrontal alpha asymmetry as the main measure. To date the largest-sample longitudinal study on the effects of meditation examining changes in resting prefrontal alpha asymmetry was a randomised-controlled trial with healthy older adults (Moynihan et al. 2013). The effects of an 8-week MBSR course in comparison to treatment as usual were assessed from before to after the course and at 24 weeks follow-up. Basic statistical tests showed only marginal effects from baseline to post-test but between group comparisons at post-test revealed a significant group difference, due to reductions in left-sided anterior activity in the control group. There were no significant differences in prefrontal alpha asymmetry between the two groups at follow-up. Given the strong design of this study, the findings cast doubts on the modifiability of prefrontal alpha asymmetry by secular meditation training and sustainability of any initial gains.

The evidence of meditation effects in clinical populations assessed using the prefrontal alpha asymmetry is also mixed. One small-scale study investigated changes in prefrontal alpha asymmetry with participants that had a previous history of suicidal depression (Barnhofer et al. 2007). Participants were randomized to either an 8-week mindfulness-based cognitive therapy (MBCT) or a treatment as usual control group, and assessed before and after the 8 weeks. The results revealed no change in the MBCT group while the control group showed significant reductions in left-sided anterior activation suggesting decreases in positive affect/approach-oriented behaviour. However, this differential effect was not confirmed in a larger scale randomized controlled study with recurrently depressed patients in remission, where one group underwent MBCT training and was compared to a wait-list control group (Keune et al., 2011). While the MBCT group reported significant reductions in residual depressive symptoms and rumination, both groups showed shifts towards right-sided prefrontal activity with no significant MBCT training effects.

Some studies suggested that meditation can produce more stable short-term modulations of prefrontal alpha asymmetry, rather than lasting longer-term trait changes in this index. For example, one study evaluated the effects of mindfulness in recurrently depressed female participants following negative mood induction during and after brief meditation sessions, in comparison to effects of rumination challenge sessions in which participants heard sentences encouraging them to analyse their feelings (Keune et al. 2013). The findings showed significant shifts towards left-sided prefrontal activation during meditation only, suggesting more transient effects of meditation training on prefrontal alpha asymmetry.

Cumulatively the findings across the studies raise questions about the sensitivity and modifiability of prefrontal alpha asymmetry by meditation. It is possible that more intensive long-term meditation training would be needed to produce lasting 'trait' shifts in this psychophysiological index. Given the established nature of prefrontal alpha asymmetry as a marker of depression and depression vulnerability, further investigation of such long-term effects seems important for providing insights into the questions about long-term impact of meditation on health and well-being.

Event-related potentials and meditation

Event-related potentials (ERPs) are produced by averaging EEG signal arising in response to particular stimuli such as emotional images or sounds (Luck, 2012). ERP components are typically characterized by the polarity of their peak (based on positive or negative voltage), timing of the peak (latency) and its scalp distribution (e.g., frontal, parietal, central etc.). The main advantage of ERPs is their functional specificity; some event-related potentials for example, primarily index the ability to inhibit processing of irrelevant stimuli (the N2 ERP component) and other emotion regulation as the ability to modify an emotion response (the LPP component) . While many questions about functional specificity of ERP components remain, several decades of basic research underpin our current understanding of ERPs providing strong foundations for utilization of ERP indexes in meditation research.

The majority of ERP research on meditation has, thus far, focused on investigating changes in attention with meditation training. For example, one study examined the impact of intensive meditation training in a retreat setting on the P300 ERP component as an index of attention efficiency (Slagter et al. 2007). The study particularly focused on a subtype of the P300 called the P3b which has parietal distribution and signals detection of a target stimulus. Participants in the study were meditators and their P3b responses were compared to matched controls; both groups were tested before and after 3 months during which time the meditators engaged in a Vipassana retreat. This meditation retreat focused on paying attention to the present moment, as well as cultivating feelings of loving kindness and compassion. The experimental task involved the attention blink paradigm, in which a stream of letters and numbers is presented to participants in a fast succession, and participants are asked to identify certain types of visual stimuli. The term 'attention blink' refers to the difficulty in identifying a visual stimulus (such as a number) appearing within 500 ms after correct detection of another visual stimulus (such as a letter). The researchers in the current study wanted to examine whether meditation training could result in a reduction of the attention blink and corresponding modulations of the P3b.

The findings revealed that, after the retreat, the meditators but not the control group showed a better detection of the stimuli appearing within the brief 'attention blink' interval. Importantly, they also found a reduction in the P3 component peaks (their amplitude) to the first stimuli preceding the attention blink intervals. This suggested that, after the retreat, meditators used less attention resources to correctly detect the first stimulus; this allowed for sufficient attention resources to be allocated to the detection of the second stimulus appearing within the attention blink interval. However, the results also opened the question about the amount of meditation training needed for such modulations in the P3b to arise, given that the meditation training was intensive - involving 10-12 hours of meditation per day for 3 months.

This question was partially answered in a randomized controlled study, which assessed the effects of a less intensive meditation training, which consisted of an initial 2-hour introductory session (breath focus with an accepting attitude), followed by regular practice of 10 minutes per day during 16 weeks (Moore et al. 2012). The experimental task used was the Stroop test, which requires participants to suppress automatic responses to incongruous stimuli – these were words where the meaning of a word contrasted with the colour of the ink in which the word was written (e.g., the word red written in blue ink). The participants' task was to name the colour of the ink and they had to suppress the automatic reading of the word for the incongruous stimuli. The ERP responses were recorded to both congruous (such as the word red written in red ink) and incongruous stimuli. The focus of the ERP investigations in the study was again on the P300 component as a marker of attentional efficiency - the use of minimum cognitive resources needed to perform correctly on the task. The authors found reduced P300 amplitudes to incongruent stimuli after 16 weeks of meditation training; no changes were observed 8 weeks into the training. These findings indicate that even shorter meditation training may result in significant modulations of ERP markers that are sensitive to attention efficiency.

While the findings in these two studies are likely to reflect changes in attention efficiency related to attention control, other studies examined whether meditation training could impact meditators' distractibility. Cahn & Polich (2009) presented long-term meditators in the Goenka Vipassna tradition with a simple auditory oddball paradigm. The task consisted of frequent sounds (80% of stimuli), distractor white noise sounds (10% of stimuli) and oddball sounds (10%) – infrequent higher pitch sounds - during meditation and during a control thinking state. The meditation state involved focusing on sensations in the body, whereas the control thinking state consisted of thinking about emotionally neutral events. The P3a, an ERP component indexing automatic responding to infrequent stimuli, was derived from EEG responses to the sounds. As expected, P3a amplitudes were reduced to the distractor sounds in the meditative state in comparison to the control thinking state suggesting less automatic reactivity to the distractors during meditation. Interestingly, this effect was only found for meditators not reporting drowsiness during the meditation state. In addition, meditators with more time spent in daily meditation showed greater reductions in the P3a to distractors, providing stronger support for the effect being related to meditation practice.

There are also studies with adolescents and older adults which reported changes in ERP markers of attention processing resulting from meditation. For example, a school-based study with adolescents who participated in an 8-week mindfulness training delivered by their schoolteachers showed improvements in adolescents' abilities to inhibit irrelevant stimuli (Sanger & Dorjee, 2016). Furthermore, a study with older adults suggested improvements in attention based on a significant shift in an ERP component indexing the ability to inhibit irrelevant stimuli (more negative N2) after 8-weeks of regular brief (10 mins, 5 times per week) mindfulness training (Malinowski et al., 2017). Overall, the studies reviewed are indicative of the broader pattern of evidence on meditation effects assessed using ERPs, which suggests improvements in control-related facets of attention with meditation.

Attention control strongly contributes to our ability of managing emotions (Ochsner & Gross, 2005). Given the evidence suggesting improvements in attention control (including attention efficiency and inhibition) and the fact that various meditation practices often invite meditators to engage with emotional contents non-judgementally and without reactivity, it is expected that meditation training would result in emotion regulation improvements (Teper & Inzlicht, 2013). An ERP marker sensitive to different types of emotion regulation is the late positive potential (LPP) (Hajcak et al., 2010). Previous studies showed that more adaptive forms of emotion regulation, such as cognitive reappraisal involving an adaptive change in thinking about an emotional experience, are associated with less positive LPP mean amplitudes (Hajcak & Nieuwenhuis, 2006). Thus it can be predicted that meditation would improve emotion regulation skills, and accordingly, some ERP studies assessed if meditators would show reduced LPP amplitudes to emotional stimuli.

One study compared the LPP responses to negative, neutral and positive stimuli during passive viewing between a group of Buddhist meditators and a matched control group (Sobolewski et al. 2011). The findings revealed significantly reduced LPP mean amplitudes in meditators compared to controls for the negative pictures only - possibly suggesting less emotional reactivity in meditators in response to negative stimuli. The lack of group differences for the positive stimuli in this study may be explained by the fact that these stimuli had lower arousal (emotional intensity) ratings than the negative stimuli. Indeed, a dispositional mindfulness study found that participants with higher trait mindfulness, compared to those with lower trait mindfulness, showed reduced LPP amplitudes to both highly arousing negative stimuli and highly arousing positive stimuli (Brown et al. ,2012). This suggests that higher trait mindfulness may be linked to more effective management of emotional responses by reducing reactivity to emotionally arousing experiences.

Another cross-sectional ERP study comparing meditators and non-meditators found that meditators showed less emotional reactivity when they noticed making an error (Teper et al., 2012). In a Stroop task the study measured an ERP component called the error-related negativity; this measures how one monitors one's performance in response to an error. The meditators made less errors than controls and showed more negative ERN on error trials; this likely reflects their better metacognitive monitoring skills. Importantly, the more negative ERN was explained by increased self-reported acceptance scores (non-reactivity to experience) in meditators, who also showed significantly higher acceptance scores when compared to controls). These findings point to the intertwined nature of improvements in emotion regulation and attention control in meditators with enhanced attention skills likely enabling better emotion regulation resulting in better performance and in turn attention control being supported by improved acceptance (Teper & Inzlicht, 2013).

In addition to the LPP and ERN components, the P300 can also index emotion processing. One study examined the impact of an 8-week mindfulness program delivered by schoolteachers as part of regular school curricula on emotion processing in adolescents (Sanger et al. 2018). The emotional oddball task involved happy and sad face target oddballs (10% of stimuli each) embedded in a stream of neutral faces. The results indicated no changes in P300 amplitudes across the different stimuli types in the training group, whereas the control group showed reductions in the P300. This pattern of findings was interpreted as suggesting that the mindfulness-trained adolescents were able to sustain focus on socially-relevant stimuli in comparison to controls. Since reduced P300 amplitudes have been associated with depression in previous studies (e.g., Cavanagh & Geisler, 2006), the finding of maintained P300 might be indicative of possible protective effects of meditation on depression vulnerability.

The effects of meditation on attention control and emotion regulation potentially have an indirect effect on wellbeing through the meditator's ability to manage negative rumination — higher negative rumination has been associated with development and maintenance of anxiety and depression (Watkins 2008)). Yet ERP evidence on possible reductions of negative rumination due to meditation is virtually absent. Only one study has so far investigated possible links between meditation and language processing (Dorjee et al., 2015). This study assessed associations between trait mindfulness and ERP indexes of semantic integration (N400) and semantic reanalysis (P600). Participants were presented with pairs of negative or positive words matching in meaning, in addition to mismatching meaning pairs consisting of positive-negative and negative-positive word pairs. The findings indicated increased N400 differences to negative word targets in comparison to positive word targets in high trait mindfulness participants only. This suggests less frequent access to negative word meanings in those with higher trait mindfulness, which reflects a lower tendency towards negative rumination. The study also reported reductions in the P600 for those higher in trait mindfulness, suggesting an association between higher mindfulness and less re-analysis involving repeated thinking about the words presented, which might be linked to less rumination.

As for language processing, ERP evidence on the effects of mediation on decentering and other modes of existential awareness is very limited. The only relevant study so far (Eddy et al., 2015) assessed the effects of a brief 15-minute mindfulness session involving breath focus instructions on P300 and LPP components elicited by viewing positive, negative and neutral images. While the brief mindfulness session did not result in any ERP changes, the participants who reported higher state decentering during the session also showed less positive P300 responses to negative images. The effect was specific to decentering, not mindfulness. The authors interpreted the findings in terms of a change in the way participants attended to the images due to decentering – this involved disidentification with the emotions the stimuli induced, viewing the emotions as transient rather than identifying with them. This in turn led to reduced reactivity to the negative images indexed by less positive P300. This again highlights the interconnected and overlapping nature of various mechanisms — attention, emotion regulation, rumination and decentering (as a mode of existential awareness) — which underly meditation.

Overall, the pattern of ERP findings on meditation suggests that meditation practice modulates attention control (including attention efficiency, improved inhibition and reduced distractibility) and emotion regulation linked to reactivity to high intensity stimuli. The evidence on how meditation might impact language processing is currently very limited, as is our understanding of how decentering and other modes of existential awareness may modify ERPs. Most studies investigated the different mechanisms of the metacognitive self-regulatory capacity in isolation; only one of the studies linked attention control (indexed by the ERN) to emotion regulation (acceptance) (Teper et al., 2012). This highlights the need of investigating currently neglected aspects of mechanisms of meditation using ERPs, as well as the importance of examining the links between the different mechanisms to provide a more systemic understanding of how meditation works from a psychophysiological perspective. In addition, future research needs to meaningfully relate variations in these mechanisms to changes in the autonomic nervous system. In this way we will be able to bridge current gaps in the literature on the associations between mind/brain psychophysiological indexes and bodily sympathetic/parasympathetic activation measures.

Psychophysiological indexes of autonomic system activation and meditation

The largest body of research on meditation using psychophysiological measures of autonomic system activation involves heart-rate variability (HRV) and derived measures. HRV refers to the beat-to-beat variability (time gaps between heart beats) which has been linked to regulation of the sympathetic/parasympathetic system balance as the basic mechanism of the stress response (Thayer et al., 2012). While increases in sympathetic activation are associated with the fight-flight response, the parasympathetic system dominates during the rest-digest activities. Importantly, sympathetic activation can be induced not only by a real threat (e.g., fast approaching car when we are crossing the road), but also by a threat such as thinking of a stressful situation. Low frequency (LF) HRV (0.01 – 0.15 Hz) reflects sympathetic effects associated with neurotransmitter norepinephrine whereas high frequency (HF) HRV (0.15 – 0.40 Hz) is linked to parasympathetic activation mediated by acetylcholine changes. Importantly, low frequency HRV has been associated with disease and high frequency HRV has been liked to better emotion regulation (Appelhans & Luecken, 2006).

One interesting meditation study assessed changes in high frequency heart rate (HF HRV) in meditators who underwent meditation training over three months (daily guided meditation practice of 20 minutes plus 2-hour sessions each week) in three types of meditation: breathing meditation, loving-kindness meditation and observing-thoughts meditation (Lumma et al., 2015). The study investigated if all types of meditation resulted in increased HF HRV reflecting possible relaxing effects of meditation. Interestingly, the findings were contrary to this prediction and showed reductions in HF HRV over time, with these reductions being most pronounced for the loving kindness meditation and least reductions in the breathing meditation. These results indicate that different meditation types may module heart rate variability differently depending on the arousal and mental effort required.

An earlier cross-sectional study compared high frequency and low frequency heart rate variability in Theravada and Tibetan Buddhist meditators during different types of meditation (Amihai & Kozhevnikov, 2014). They found that Theravada meditators practicing Vipassana showed increases in HF HRV. However, Tibetan Buddhist meditators practicing visualization deity meditation and rigpa (abiding in the highest non-dual state of awareness) meditations showed decreases in HF HRV.

Yet, a study on integrative mind-body training (IMBT) with Chinese undergraduate students showed increases in HF HRV after only five days of 20-minute long daily sessions in comparison to a relaxation training of the same duration (Tang et al., 2009). Interesting, mindful breath focus is one of the key elements of the IMBT training. This further supports the proposal that different meditation types are associated with different modulations in the HRV.

There are other heart rate variability derived metrics that have been used to study meditation (Allen et al., 2007). The two most common ones are the respiratory sinus arrhythmia (RSA) and the cardiac sympathetic index (CSI). The RSA indexes the change in interbeat intervals in relation to the inbreath and outbreath phases of respiration. It reflects the parasympathetic control with higher values indexing better emotion regulation. In contrast, the CSI (Toichi, 1997) measures sympathetic influence. A higher CSI has been linked to psychopathology and higher stress (Weinberg et al., 2009). The RSA and CSI and dissociable antagonist indexes, higher RSA is typically associated with low CSI.

The RSA and CSI indexes have been rarely used in research on meditation. In, so far, the most comprehensive study Ditto et al. (2006) compared the effects of body scan meditation, progressive muscular relaxation or wait-list control group after four weeks of daily practice. The results revealed increases in the RSA only during the meditation sessions after the four weeks. With regards to CSI, a study which recorded changes in CSI during Zen meditation (involving sustain breath focus) in comparison to a control rest condition reported increased CSI during meditation (Kubota et al., 2001). Just like the pattern of findings for the HF and LF HRV, the results from these two studies again demonstrate that changes in RSA and CSI as indexes of parasympathetic and sympathetic activation respectively may depend on the meditation type.

In addition to measures described above, galvanic skin response (GSR) has been traditionally considered an index of sympathetic activation, because is measures sweat gland secretions innervated by sympathetic autonomic neurons. In terms of emotion processing, the magnitude of the GSR is positively correlated with subjective reports of intensity of emotions (Greenwald, Cook, & Lang, 1989).

Decreases in GSR indicate reduced sympathetic activation and have been reported in a few meditation studies. In a study with meditation novices, they found a significant decrease in GSR during 20 minutes of meditation (Mohan et al. 2011). An earlier study comparing the first and last 3 minutes of a 20-minute meditation session with control conditions also found reductions in GSR (Wenk-Sormaz 2005). A similar pattern of findings has been reported with longer-term meditation (1-month of daily practice) (Singh & Talwar, 2012). However, the overall evidence base on the effects of meditation on GSR is currently very limited, precluding any firm conclusion.

In summary, the emerging pattern of modulations in psychophysiological indexes of autonomic system activity is currently mixed and limited by an insufficient number of longitudinal studies. The evidence so far suggests that changes in heart rate variability, as well as its derivative indexes,, resulting from meditation depend on the type of meditation. While breath focus meditation tends to result in increased parasympathetic activity, other kinds of meditation, such as loving-kindness practices may decrease parasympathetic activation. Available evidence on changes in GSR suggest that reductions in this marker are associated with increased parasympathetic activity, but all of the studies seem to have involved basic breath-focus style meditation practices. The pattern of modulations in the GSR might be different with other meditation types. Further research is needed to elucidate these complex findings and to assess longer term state and trait effects of meditation on these indexes.

Limitations and future directions

The general methodological limitations of meditation research (e.g., Davidson & Kaszniak, 2015; Van Dam et al., 2018) are applicable to the psychophysiology of meditation. This includes the need for larger sample sizes, randomization of participants, and active control group studies. There is also the need for clear specification of meditation experience/training of participants and the experience of meditation teachers delivering the interventions. Nonetheless, there are some methodological issues that are specific to research in the psychophysiology of meditation.

While the psychophysiological markers used in meditation research, such as the P300 and N400 components, or HRV and RSA, are one of the most established indexes in the field of psychophysiology with decades of underpinning research, their application in intervention research, such as meditation training studies, is much more recent. Consequently, the interpretation of changes in these indexes within an intervention study can often be ambiguous and purely reliant on self-report measures. For example, in two studies discussed earlier in this chapter, the P300 has been found to decrease with meditation training in attention blink (Slagter et al., 2007) and a Stroop task (Moore et al., 2012). This decrease has been interpreted as an indicator of improved attention efficiency. However, in studies of mind-wandering, which is a state inversely correlated with mindfulness, reduced P300 was associated with self-reported mind wandering. This is at odds with what one would expect, as mind-wandering reflects lack of attentiveness (more distraction) to the target stimuli.

Another concern is that changes in psychophysiological indexes of autonomic system activation vary greatly based on the type of meditation participants are performing. Increased parasympathetic activity has been mostly associated with breath-focus meditation styles whereas increased sympathetic activity seems linked to ‘more effortful’ kinds of meditation such as loving kindness or visualization-based meditation. How such differences translate into long-term effects on health and well-being is currently unknown. Overall, the predicted changes in psychophysiological markers often seem to depend on particular experimental tasks and meditation types.

Further issues to be considered pertain to replicability of findings, the context of meditation training, and the long-term effects of meditation. The replicability of findings is a particularly important topic in psychophysiological and neuroscience research, since psychophysiological markers are more subject to variability depending on experimental conditions, participant sample type and data collection and analysis methods than standardized self-report methods. It is very rare to see replications of findings within the same labs and replications across labs are virtually absent. This obviously relates to a broader problem of replication studies being ‘less valued’ than original new findings; however, this seems to be more the case in psychophysiological and neuroscience research than in questionnaire-based intervention research. For example, in clinical intervention studies the replication of RCTs are often required and funded to inform implementation efforts, as in the case of MBCT for recurrent depression (Kuyken et al., 2008; Kuyken et al., 2015; Williams et al., 2015).

The context of meditation practice and associated motivations for engaging in meditation are two factors which quite likely impact changes in the mechanisms of underlying meditation

(Dorjee, 2016). For example, the psychophysiological effects of meditation might be different for somebody who is practicing meditation to relieve backpain in comparison to another person who meditates in order to reach spiritual insight. The context of meditation practice and motivation training has so far not been explicitly assessed as a possible modulator of findings in psychophysiological studies. These factors need to be considered in the future as possible modulators, particularly since we already know that different meditation types (including Buddhist meditation styles from different schools) may differentially modulate psychophysiological markers (Amihai & Kozhevnikov, 2014).

Finally, while there are a few studies using self-reports that investigated longer-term effects of meditation (3-5 year follow up), psychophysiological studies with a follow-up of any length are virtually absent. This is to a large extent the result of the cost and logistical challenges associated with repeated psychophysiological measures. Yet, to advance our understanding of meditation, it is essential that psychophysiological longitudinal studies include follow-up assessments to evaluate the sustainability or reversibility of the initial changes by the amount (or lack of) further meditation practice, as well as long-term trajectories of changes with practice.

Conclusion

While psychophysiological research holds considerable promise for providing unique insights into the modulations in the brain and body physiology resulting from meditation, and their possible implications for health and well-being, much of this potential remains untapped. Most of the available evidence in this area, including research on prefrontal alpha asymmetry and psychophysiological indexes of autonomic system activation, portrays a picture of mixed findings with a strong need for further rigorous investigation. Research on modulations in ERP indexes with meditation, particularly with regards to changes in attention, provides the most consistent evidence for improvements in attention control and associated attention efficiency with meditation. In contrast, psychophysiological studies about the impact of meditation on relevant language processes and modes of existential awareness, such as decentering, are extremely limited, yet they are much needed in order to provide a more comprehensive understanding of the mechanisms underlying meditation. Future research on the psychophysiology of meditation also needs to address the pitfalls of ambiguous interpretations of findings, include more replication studies and assessments of context and motivation for meditation as well as evaluate the long-term effects of meditation.

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