Degree project

HÖGSKOLAN I SKÖVDE

The Effects of Mindfulness on Emotion Regulation During Adolescence – A Systematic Review

Bachelor Degree Project in Cognitive Neuroscience

First Cycle 22.5 credits

Spring term Year 2023

Students: Anna Andersson and Gladi Liiver

Supervisor: Rebecca Linder

Examiner: Monica Bergman

Abstract

Emotion Regulation refers to the process of controlling our emotions. However, the brain regions which are involved in emotional processes, such as the prefrontal cortices, are the last regions to be developed throughout the human brain. Those who are most affected by this slow development are adolescents especially since they undergo hormonal and neural changes. Previous research has shown mindfulness meditation improves emotional stability and inhibitory control. Since our brain is not fully developed until the age of 25, it is particularly interesting to get knowledge of the effect of mindfulness on emotion regulation in adolescents, which is the aim of this thesis. A total of three studies met the inclusion criteria and were included in this systematic review. The results showed a larger reaction in the amplitude of P2, N2, and late positive potentials on both negative and positive stimuli but not neutral stimuli. Differences were observed in the high vs low mindfulness adolescents in frontal EEG asymmetry during emotion regulation tasks. These findings suggest that even brief mindfulness can have a positive effect on emotion regulation processes by enhancing pre-frontal cortices. These findings contribute to the understanding of whether mindfulness affects emotional regulation in a developing brain. However, future research is needed to clarify the effects of mindfulness on emotion regulation in adolescents.

Keywords: mindfulness, adolescence, electroencephalography, trait mindfulness, emotion regulation

The Effect of Mindfulness on Emotion Regulation During Adolescence

People may experience strong emotions in unsuitable situations which could possibly lead to negative consequences. To prevent this from happening individuals use emotion regulation (Gross, 1998). Emotions have a central role in our lives - they help us respond effectively to challenges or great opportunities coming our way (Ford & Gross, 2018; Gross, 1999). When an individual consciously or non-consciously decides whether a stimulus has positive or negative effects it sets off cognitive, subjective, physiological, and motor changes, resulting in a reaction (Etkin et al., 2015). There are two age-old debates, where the first debate relates to whether emotions are purely good (e.g., useful and desirable) or bad (e.g., useless and harmful) (Ford & Gross, 2018, 2019). The second debate is whether our emotions are uncontrolled (e.g., emerging without our permission and leaving on their own) versus controlled (e.g., regulated to our wishes) (Ford & Gross, 2018, 2019). A process for controlling and influencing individuals' expression and experiences is referred to as emotion regulation (Ford & Gross, 2018). There are two common strategies of emotion regulation - suppression and reappraisal (Gross, 2002). Suppression is a type of emotion regulation strategy that involves inhibiting or controlling the outward expression of emotion to avoid negative consequences in social situations (Gross, 2002). Reappraisal, on the other hand, involves changing the way an individual thinks about a situation to regulate their emotional response. This strategy involves reinterpreting the meaning of a situation in a way that reduces the emotional impact of the event (Gross, 2002).

Emotion regulation can be enhanced by developing the ability to attend to both internal and external circumstances with the help of mindfulness (Shapiro et al., 2018). The skills in mindfulness can help individuals divert their focus away from distressing emotional triggers (Gross, 2014). Ahmed et al. (2015) suggest that while there exists a diverse array of strategies to regulate emotions, adolescents may experience a narrower range of these strategies. This could be due to insufficient practice or that they require more advanced executive function and/or social cognition skills. These have been shown to develop continuously during adolescence (Ahmed et al., 2015), especially as they are getting more experience in peerfocused contexts (Desatnik et al., 2017). Furthermore, Lamm and Lewis (2010) suggest as adolescents mature, their prefrontal cortex becomes more efficient, which subsequently results in a better ability to regulate their emotions. Adolescents may employ expressive suppression more frequently due to its perceived efficacy in uncertain situations (Desatnik et al., 2017).

Adolescence and The Developing Brain

The period of life between childhood and adulthood is referred to as the adolescence phase (Sawyer et al., 2018) which is characterized by both hormonal and neural changes (Amada & Shane, 2019), together with challenges that are perceived as intense such as social rejection and academic stress (Gross, 2014). There are different definitions for the ages during adolescence. According to the World Health Organization (WHO) (n.d.), the age of an individual during adolescence are the ages between 10 to 19. Whereas Chan and Marinellie (2008) describe the different age stages as; pre-adolescent 10-12, young adolescents 13-15, and older adolescents 16-18.

Adolescence is generally regarded as a positive phase of life, despite being characterized by emotional turbulence with neuronal reorganization and functional changes (Deng et al., 2020). Research has been conducted, which shows there are differences in prefrontal cortex maturity in relation to the brain regions that support bottom-up processing compared to the brain regions in top-down processing (Amada & Shane, 2019). Due to this, adolescents are particularly prone to engaging in risky behavior, which can make them appear unstable, (Ahmed et al., 2015; Amada & Shane, 2019; Sanger & Dorjee, 2015), particularly when the decision is emotionally driven or rushed, and the rewards are notable. Subcortical structures supporting the bottom-up process are the ventral striatum, the amygdala, and the hippocampus, each engaged in specific processes such as reward processing, emotional processing, and novelty processing (Amada & Shane, 2019).

Many features of adolescents' emotional experiences are largely influenced by their ability to regulate their emotions (Gross, 2014). Further challenges that adolescents face involve the processes of self-regulation, volitional actions, and attention shifting due to the fact that these processes are supported by the prefrontal cortex (Amada & Shane, 2019). The prefrontal cortex is responsible for attention control and is vital for regulating emotions through the inhibition, shifting, and monitoring of attention (Sanger & Dorjee, 2015). Furthermore, the prefrontal cortex is able to inhibit the outputs from the amygdala and regulate the output, but this connection develops at a slow pace limiting the capabilities of emotion regulation in adolescents (Amada & Shane, 2019). In addition, this means that the ability to regulate emotions through attention processes is subject to changes during adolescence, indicating that emotion regulation is a dynamic process (Sanger & Dorjee, 2015).

Emotion Regulation Strategies

Emotion regulation is defined as the process of trying to control our own or another's emotions (McRae & Gross, 2020) and even influencing which emotion to have, when, and how you have them as an individual (Wante et al., 2018). Gross (1998) suggests that there are two different ways to regulate one's emotions; antecedent-focused emotion regulation, such as reappraisal which means that the individual can re-evaluate their emotions about the situation (Gross, 1998). The second one is referred to as response-focused emotion regulation, such as suppression which prevents the individual from expressing their internal emotions (Gross, 1998). McRae and Gross (2020) suggest that reappraisal is more adaptive and effective, assisting individuals to reflect on the situation and regulating their emotional response. Frequently using reappraisal is suggested to have several positive outcomes such as better physical health, increased positive social outcomes, improved well-being (McRae & Gross, 2020) as well as better executive functioning, and improved inhibitory control in adolescents' daily life (Lantrip et al., 2016). On the contrary, frequently suppressing emotions is related to decreased well-being and reduced relationship satisfaction (McRae & Gross, 2020), and is furthermore associated with stress (Moore et al., 2008). It is suggested that several brain regions are involved in emotion regulation such as the dorsolateral - and ventrolateral prefrontal cortex, anterior cingulate cortex (which contributes to the executive control process), and the parietal cortex (a part of the frontoparietal executive network which activation is associated with reappraisal) (Etkin et al., 2015). Additionally, the temporal parietal junction is activated during task-unrelated cognitions or mind wandering (Malinowski, 2013). Etkin et al. (2015) mention brain regions such as the amygdala (emotional and motivational processes), ventral striatum (various levels of contextual information), and dorsal- and anterior cingulate cortex which are emotion-related brain regions, involved in the process of emotion regulation.

Moreover, due to the unmatured prefrontal cortex in adolescents, it limits their capabilities of emotion regulation (Amada & Shane, 2019). According to Deng et al. (2021), mindfulness may have a positive impact on emotion regulation by enhancing prefrontal functioning during changes in emotional responses, particularly when it comes to reappraisal. Resulting in reduced negative reactivity to emotional stimuli along with improved cognitive flexibility and inhibitory control during emotion regulation (Deng et al., 2021).

Mindfulness

Mindfulness originates as the "heart" (Kabat-Zinn, 2003) and a central concept (Pallozzi et al., 2017) of Buddhist meditation as a factor from Buddha's training (Gross, 2014; Kabat-Zinn, 2003). Furthermore, one common definition of mindfulness is "the awareness that emerges through paying attention on purpose, in the present moment, and non-judgementally to the unfolding of experience moment by moment." (Kabat-Zinn, 2003, pp. 145). New research demonstrates that a high level of trait mindfulness in adolescence has a positive effect on emotion regulation (Deng et al., 2020). The practice of state mindfulness meditation (non-judgemental awareness and attention to moment-by-moment without fixation on thoughts (Kiken et al., 2015)) over time is prone to increase the individual trait of mindfulness, in terms of being mindful in daily life (Kiken et al., 2015). The term trait of mindfulness is described as "one's predisposition to be mindful in daily life" (Kiken et al., 2015, pp. 41). Disposition is a term often used interchangeably with personality traits, referring to enduring and stable characteristics (Rau & Williams, 2016). It has been shown that high traits of mindfulness are characteristic qualities of self-regulation and attention, higher quality of life, and less reactivity towards negative emotional stimuli (Deng et al., 2021). Further studies have shown that mindfulness meditation (exercise for mind and body mostly by focusing on the present moment) (Wu et al., 2019) is associated with increased activity in the prefrontal cortex, anterior cingulate cortex, and insula, which are brain regions involved in attention and emotional regulation (Hölzel et al., 2007). Furthermore, Wu et al. (2019) assess the positive effects of brief mindfulness meditation (15 min per day for seven days). The results revealed that brief mindfulness meditation improved various aspects of emotion processing, such as the intensity of the emotion and emotional memory without negative effects on the participants' emotions (Wu et al., 2019). In addition, brief breath-focused mindfulness (BFM) (a mindfulness-based intervention consisting of focus on breath) also showed a decrease in the intensity of unpleasant emotions (Zhang et al., 2019). According to Oberle et al. (2012), the benefits of mindfulness include lowered stress and anxiety, which improves mental health. Feeling fewer negative emotions, negative consequences, less fear, and less sadness are some other relationships that mindfulness is linked to (Pepping et al., 2016). Moreover, in an external context, mindfulness might lead to fewer rule violations i.e., violations of age-appropriate rules and expectations (Pepping et al., 2016).

Assessing Mindfulness: Neuroimaging Techniques and Questionnaires

There are several ways to measure mindfulness: through questionnaires such as; the Mindful Attention Awareness Scale (MAAS; Chen et al., 2012) to evaluate variations in an individual's mindful states; the Child and Adolescent Mindfulness Measure (CAMM; De Bruin et al., 2013) that measures dispositional mindfulness in adolescence; the Five Facet Mindfulness Questionnaires (FFMQ; Baer et al., 2006) which measures the level of trait mindfulness in adolescents or the Attentional Control Scale (ACS; Derryberry & Reed, 2002) which assesses self-reported attention control skills.

There are several different ways to measure brain activity. Two of the most commonly used methods for assessing brain activity during mindfulness are functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) (Kabat-Zinn, 2003). EEG measures the electrical activity of neurons in the brain (Kirschstein & Köhling, 2009). EEG electrodes are placed on the scalp to detect the electric potential differences (voltages) generated by synchronized neural activity (Warbrick, 2022) and recorded over time (Beres, 2017). According to Warbrick (2022), EEG is a crucial tool for comprehending brain function as the electric signal takes approximately one millisecond to reach the electrode, requiring it to pass through both the skull and brain tissue. In EEG, measures are shown in the following frequency bandwidths: Delta (1–4 Hz), Theta (4–8 Hz), Alpha (8–13 Hz), Beta (13–30 Hz), and Gamma (36–44 Hz) (Lomas et al., 2015). In addition, EEG measurements are shown as event-related potentials (ERP) with different amplitude components, for example, P1 peaks approximately around 80-150ms post-stimulus, which is more sensitive to the early attention of inner tasks, such as visual imagery (Zhang et al., 2019). N2, a negative wave that peaks around 200–350ms post-stimulus and is found at the anterior scalp sites, subsequently N2 seems to relate to the attention-monitoring process that originates from the dorsomedial prefrontal cortex (Zhang et al., 2019). Late positive potential is a positive wave with a distribution on the central parietal scalp site and peaks 400–500ms after stimulus onset additionally is related to emotional stimuli rather than neutral stimuli (Zhang et al., 2019). P2 amplitude occurs at approximately 200ms post-stimulus which indicates emotion arousal and reacts to emotional stimuli in the early stage of emotion regulation (Deng et al., 2020).

When referring to EEG, the researchers also mention frontal EEG asymmetry that describes the variation in measured alpha activity between corresponding right and left frontal electrodes during both resting state and task conditions (Reznik & Allen, 2018; Sabu et al., 2022; Smith et al., 2017). Researchers have linked this asymmetry to patterns of emotion processing for several decades (Lomas et al., 2015). Previous research has shown a significant increase in alpha power during mindfulness which has been observed both in the frontal and posterior regions of the brain (Lomas et al., 2015). This indicates an increase in neural synchronization, suggesting that mindfulness may involve a state of relaxation and attentional focus (Kirschstein & Köhling, 2009; Lomas et al., 2015).

Furthermore, fMRI is a non-invasive brain imaging technique that detects changes in blood flow to indirectly measure neural activity (Heeger & Ress, 2002), commonly used to study mindfulness-related brain activity (Hölzel et al., 2007). As a response to increased neural activity, the brain requires more oxygen and nutrients, leading to an increase in blood flow. In response to this, the concentration of oxygenated and deoxygenated haemoglobin changes which can be detected with fMRI as a blood oxygen level-dependent (BOLD) signal (Heeger & Ress, 2002). Since the BOLD signal reflects the metabolic response of the brain to neural activity, it is used as an indirect measure of neural activity (Heeger & Ress, 2002). Both EEG and fMRI can be useful methods to assess brain activity during mindfulness, with EEG having poor spatial resolution yet it is useful for its high temporal resolution (Warbrick, 2022).

Mindfulness Interventions.

Thanks to different neuroimaging techniques such as EEG and fMRI, it is suggested by Amada and Shane (2019), that adolescents possess the cognitive ability to engage in mindfulness practices, likely to yield significant benefits. Research indicates that less mindful adolescents are more likely to use suppression, which further increases the likelihood of depression, anxiety, and stress symptoms (Pepping et al., 2016). Furthermore, it is shown that increased self-awareness influenced by mindfulness enhances cognitive flexibility and inhibition control during emotion regulation (Deng et al., 2020). Although, it might be challenging for adolescents to engage in mindfulness since the connectivity between cortical and subcortical regions is not fully developed until early adulthood (Amada & Shane, 2019). Despite the developmental limitations, research has shown that mindfulness interventions may help adolescents in enhancing their emotion regulation abilities with less cognitive effort (Deng et al., 2020). In particular, these interventions can help adolescents learn to regulate their emotions more effectively by relying on automatic processes rather than conscious effort

(Deng et al., 2020). In addition, mindfulness practice in adolescents may foster connections between prefrontal structures that are relevant to emotion regulation, leading to greater stability in arousal and a reduction in harmful risk-taking behaviors (Sanger & Dorjee, 2015).

The Aim

The current state of research indicates a substantial understanding of how both mindfulness and emotion regulation affects the adult brain. However, the research on this effect on adolescents remains comparatively limited due to the fact that their brains are still undergoing significant changes, particularly in the prefrontal cortex which is involved in emotion regulation (Amada & Shane, 2019). The purpose of this thesis is to address this gap in knowledge by conducting a systematic review of studies that utilize EEG and fMRI to explore mindfulness and emotion regulation in relation to each other. Finally, the aim of this thesis is to investigate the effect of mindfulness on emotion regulation in adolescents.

Methods

Search Strategy

The beginning of our search to get an overview of the field included keywords such as emotion regulation, mindfulness, and adolescence. The final search string was the following: mindfulness AND (adolescen* or youth or teen*) AND "emotion regulation" AND ("neur*" OR "eeg" OR "electroencephalography" OR "fmri" OR "functional magnetic resonance imaging"). The search was conducted on the 7th of March 2023, where the search was set on all fields on both Web of Science and Medline EBSCO (see Figure 1). The literature search resulted in 124 (79 = Web of Science, 45 = Medline EBSCO) articles that were imported to Rayyan (Ouzzani et al., 2016) where 28 duplicates were removed. The remaining 96 articles were screened by their title and abstract, and additionally, 81 studies were excluded according to our inclusion and exclusion criteria. The final step was to screen the 15 articles, resulting in the exclusion of 12 articles due to wrong population (n=2), wrong study design (n=1), wrong outcome (n=2), wrong aim (n=5), and no access (n=2). The total sum of the screening resulted in 3 studies included in this systematic review.

Inclusion Criteria & Exclusion Criteria

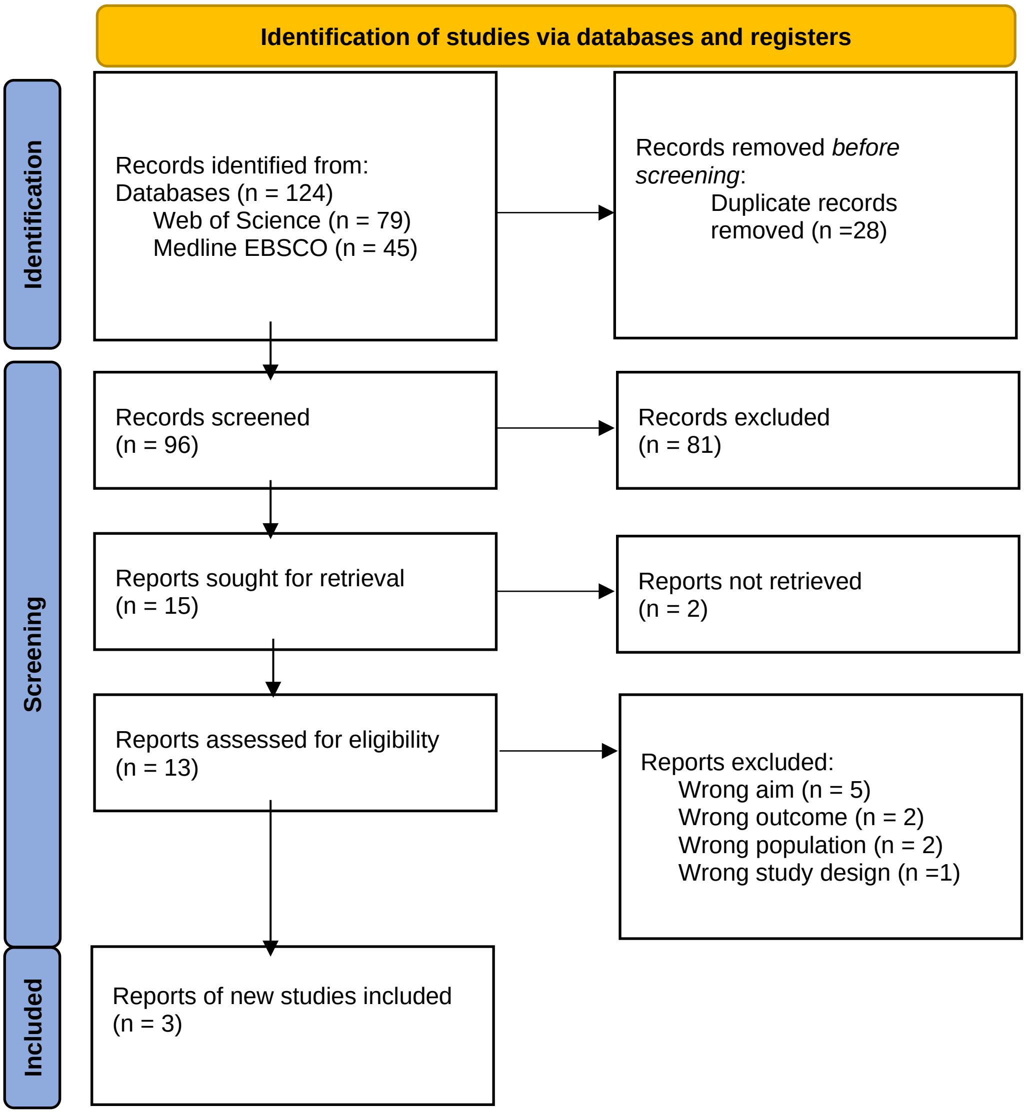
The inclusion criteria for the systematic review were, 1) the participants had to be adolescents, the ages between 10-19, 2) both mindfulness and emotion regulation must be included in the article, 3) electroencephalogram (EEG) or functional magnetic resonance imaging (fMRI), 4) written in English, 5) published in a peer-review journal, 6) original research, 7) fully available through open access or the university databases. The exclusion criteria included, 1) articles that had a participant group with a diagnosis of a neurodevelopmental disorder, e.g., autism, ADHD, or dyslexia, 2) Articles with participants who had a diagnosis of mental disorder, e.g., bipolar, generalized anxiety, psychosis symptoms or major depressive disorder, 3) Articles investigating explicitly on mobile phone addiction, study protocols, reviews due to wrong aim and not being original articles were excluded, 4) Studies that had a population range of e.g., 18-55, were excluded as they did not align with the target population. Due to the limited availability of fMRI studies that met the inclusion criteria, only studies that utilized EEG as the primary method to measure brain activity were included. Thus, all three studies used EEG as their method to assess mindfulness and emotion regulation.

Data Extraction

From the included articles, the following data were extracted and presented in seven categories: article, sample size, study population and age, design/task, regulation strategy, stimuli, neural measurements, and main results (see Table 1).

Figure 1

PRISMA flow chart



Note. The literature search process, illustrated in a PRISMA 2020 Flow Diagram. Adapted from Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C, D., et al. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews, *BMJ*, 372:n71. https://doi.org/10.1136/bmj.n71.

Results

This review consists of three studies that met the inclusion criteria (see Table 1). The studies had a total of 108 participants. Sample sizes ranged from 20 to 43 with a mean age of 12.02 to 12.53 in two studies (Deng et al., 2020, 2021), considered early adolescence according to Chan and Marinellie (2008). The third study (Zhang et al., 2019) had a mean age of 18.89 which is considered late adolescence according to Chan and Marinellie (2008). All three studies were conducted in China. Collectively, all three studies revealed divergent positive results, including differences in prefrontal asymmetry, high vs low mindful adolescents, and observing and nonjudging during adolescence.

Study Characteristics

Two of the three studies (Deng et al., 2020, 2021) used The Five Facet Mindfulness Questionnaires (FFMQ; Baer et al., 2006). This questionnaire is a measurement of the five facets of mindfulness including observation (e.g., “I intentionally stay aware of my feelings”), nonjudging (e.g., “I tend to evaluate whether my perceptions are right or wrong”), acting with awareness (e.g., “I rush through activities without being really attentive to them”), description (e.g., “My natural tendency is to put my experiences into words”), nonreactivity (e.g., “I watch my feelings without getting lost) (Deng et al., 2020). FFMQ consists of 39 items that measure the five facets to assess adolescents' trait mindfulness levels. It contains a 5-point Likert scale (1 = never or very rarely true, 5 = very often or always true) (Deng et al., 2020). A total score of each of the 39 items shows either a high or low score equivalent to high or low mindfulness (Deng et al., 2020). Importantly, Deng et al., 2020 and Deng et al., 2021 did not incorporate a mindfulness intervention during the task. However, in contrast to the abovementioned studies, Zhang et al. (2019) specifically researched the impact of mindfulness intervention during the task. In addition, Zhang et al. (2019) used two other scales at the beginning of the experiment to get a mindfulness baseline: the Mindful Attention Awareness Scale (MAAS; Chen et al., 2012) to evaluate variations in an individual's frequency of mindful states over a period of time, with a focus on whether they are attentive and aware of the current moment or not. It consists of 15 items where a higher score implies higher mindfulness whereas a lower score implies lower mindfulness. The second scale is the Attentional Control Scale (ACS) which assesses three different dimensions of attentional control: to focus attention, to shift attention, or to flexible control thought (Derryberry & Reed, 2002). Although Zhang et al. (2019) selected to only estimate the dimension of focusing attention.

Zhang et al. (2019) aim their research on Breath-focused meditation (BFM), a type of mindful meditation. Subsequently, the participants were introduced to BFM for three minutes to familiarize themselves with the procedure. Post-experiment the participants answered a questionnaire to indicate to what extent they practiced BFM during the task (Zhang et al., 2019).

Reactivity and Regulation-Image (REAR-I) were used in two of the three studies (Deng et al., 2020, 2021). REAR-I task assesses both emotion regulation and emotional reactivity by presenting various images intended to evoke different emotions. The participants received instructions to use one of three options for the regulation of emotion during the REAR-I. Up-regulation, referring to perceiving the image as if the participants were actively involved in the event, a first-person perspective. Down-regulation, referring to observing the picture in one of two ways: either from a third-person perspective as an outsider with no personal connection to the object/event or as if the image was fake. Lastly, non-regulation, referring to observing the pictures in a passive manner and responding in a natural way (Deng et al., 2020, 2021).

The pictures in all three studies (Deng et al., 2020, 2021; Zhang et al., 2019) were obtained from the Chinese Affective Picture System (CAPS) (Lu et al., 2005). Two of the three studies (Deng et al., 2020, 2021) sectioned the images into negative and neutral pictures whereas the third study (Zhang et al., 2019) sectioned the images into negative, positive, and neutral pictures.

In the study by Zhang et al. (2019), the participants were shown a Chinese symbol “view” or “focus” between each experimental block, once the symbol was shown the participants had to carry out the task until the image vanished. During the focus/BFM task, participants were instructed to focus their attention on their breath and to maintain a non-judgmental awareness of any thoughts or feelings that arose. This task was intended to induce a mindful state (Zhang et al., 2019). During the Viewing task, participants were instructed to simply view positive, neutral, or negative pictures without attempting to regulate their emotions. The viewing task was designed to elicit emotional responses to serve as a baseline to compare the neural activity during the BFM task for the researchers to find any significant differences between the two tasks (Zhang et al., 2019).

EEG and Neural Mechanisms

Zhang et al. (2019) measured three amplitude components during the BFM task. The P1 component is associated with attentional and cognitive processes, while the late positive potential is thought to reflect the sustained processing of emotional stimuli. The results showed that there was a significant decrease in the amplitude of the late positive potentials during emotional processing due to mindfulness. As a result of BFM, which is affected by how the brain responded to emotional stimuli by significantly reducing P1 (early-stage response) to continue as a prolonged effect on later stages of emotional processing i.e., a decrease of the late positive potential amplitude (Zhang et al., 2019). Furthermore, the study shows that breath-focused mindfulness was associated with a significant decrease in the amplitude of the N2 component in response to both positive and negative pictures but not neutral images during the emotion regulation task (Zhang et al., 2019). On the contrary, the results showed a non-significant association between breath-focused mindfulness and increased amplitude of the P1 component in response to negative and positive images compared to neutral pictures during the emotion regulation task (Zhang et al., 2019).

In the study by Deng et al. (2020), they measured the amplitude of the P2, N2, and late positive potential components during the emotion regulation task, where participants were instructed to use up-regulation, down-regulation, or no-regulation when viewing positive, negative or neutral pictures. However, for the negative pictures, there was not a significant difference between the three strategies. The results showed an association between higher levels of trait mindfulness and increased amplitude of the P2 component in response to negative emotional stimuli. An increase in the amplitude of the P2 component, which reacts to emotional stimuli in the early stage of emotion regulation, was also associated with higher levels of observation (Deng et al., 2020). Furthermore, in the early stage of emotion regulation processes after stimulus onset, the result showed a significant increase of the amplitude N2 component in response to negative emotional stimuli. In addition, Deng et al. (2020) found significant positive correlations between the N2 and late positive potential amplitudes during the negative no-regulation condition and nonjudging assessed by FFMQ results. Furthermore, the result shows that higher levels of mindfulness, assessed by FFMQ, in adolescents were associated with increased amplitude of the late positive potential component in response to negative emotional stimuli (Deng et al., 2020).

In the study by Deng et al. (2021), they measure specifically frontal EEG during emotion regulation. They measured the asymmetry of alpha activity in the frontal brain regions during the task. The results of the study by Deng et al. (2021) showed that adolescents with higher levels of mindfulness, as assessed by FFMQ, had significantly greater left frontal EEG asymmetry during the emotion regulation task. On the contrary, adolescents with lower levels of mindfulness, assessed by FFMQ showed significantly lower left frontal EEG asymmetry. The results also showed that the asymmetry scores of adolescents with higher levels of mindfulness were significantly greater than those with lower levels of mindfulness when they used up-regulation and down-regulation as their strategies during the task. However, during non-regulation, there was no significant difference observed (Deng et al., 2021).

Table 1

Study characteristics of the included publications' data extraction

Article	Sample size, Study population, and age (SD)	Design/task	Regulation strategy	Stimuli	Outcome measurements	Main results
Zhang et al. (2019)	20 undergraduate students 18.89 (±0.71)	Practice BFM and view pictures in different blocks Manipulation task, to which extent they performed BFM.	Top-down emotion regulation	180 images 60 positive events 60 negative events 60 neutral events	EEG The mindful attention awareness scale (MAAS) Attention Control Scale (ACS)	Breath-focused mindfulness was associated with a significant decrease in the amplitude of the N2 component in response to both positive and negative pictures. A significant decrease in the amplitude of the late positive potentials was associated with mindfulness.
Deng et al. (2020)	43 early adolescents 12.02 (±0.63)	Reactivity and Regulation-Image (REAR-I) task	Up-regulation vs. down-regulation vs. no- regulation	80 images/four sections = 10 negative and 10 neutral pictures.	EEG The Five Facet Mindfulness Questionnaires (FFMQ,)	Adolescents with a higher score for observing showed smaller ERP amplitudes during the emotion regulation task. A significant increase in N2 was associated with higher levels of nonjudging in adolescents.

Deng et al. (2021)	22 low mindfulness adolescents 12.53 (±1.10) 23 high mindfulness adolescents 12.34 (±0.88)	Reactivity and Regulation-Image (REAR-I) task	No-regulation vs. up-regulation vs. down-regulation repeated measures design	80 images; 40 negative, 40 neutral	EEG The Five Facet Mindfulness Questionnaires (FFMQ)	High mindfulness adolescents showed a greater left frontal EEG asymmetry during the emotion regulation task. The asymmetry scores were significantly greater than those with lower levels of mindfulness when they used up-regulation and down-regulation strategies during the task. Low mindfulness adolescents showed significantly lower left frontal EEG asymmetry.

Note. EEG = Electroencephalography; PFC = Prefrontal cortex; ERP = Event-Related potential; BFM = Breath-focused mindfulness; FFMQ = The Five Facet Mindfulness Questionnaires (Baer et al., 2006); MAAS = The Mindful Attention Awareness Scale (Chen et al., 2012); ACS = The Attention control scale (Derryberry & Reed, 2002)

Discussion

The aim of this systematic review was to investigate what is known about the effects of mindfulness on emotion regulation among adolescents. This review planned to focus on the studies that utilized the methods of EEG or fMRI to investigate the effect of mindfulness on emotion regulation, however, only EEG studies were found when filtering through inclusion and exclusion criteria. Thus, the included studies investigated the relationship between mindfulness meditation and emotion regulation, as well as the neural mechanisms involved in these processes, such as electrical activity, which is an indicator of neural activity, as measured by EEG. In all three included studies, the overall findings indicated that mindfulness is positively correlated with adolescents' ability to regulate their emotions (Deng et al., 2020, 2021; Zhang et al., 2019)

Zhang et al. (2019) found that breath-focused meditation led to changes in early and late components of emotional processing, suggesting that brief breath-focused mindfulness improves visuospatial processing, executive function, and emotional regulation by enhancing cognitive control over emotional processing. In the viewing condition, it was shown that both negative and positive pictures induced larger amplitudes from early P1 to late positive potential compared to neutral pictures (Zhang et al., 2019). In addition, results found that BFM significantly reduced the N2 amplitude while the adolescents were presented with positive and negative pictures compared to the viewing condition. The N2 is an important component in the top-down functional network of emotion regulation and the location of frontal N2 is in the ventromedial PFC (Zhang et al., 2019). These results indicate that practicing BFM helps sustain greater attention toward the present moment since it may activate the dorsal executive network (Zhang et al., 2019). However, Zhang et al. (2019) did not use an eye-tracking system coherently with EEG, and as such it remains unclear if the participants used BFM and not distraction. Previous research by Warbrick (2022) has shown that eye movements and muscle movements create artifacts, and Beres (2017) mentions that even accidental head turns, and swallowing can create artifacts that affect ERPs. Therefore, to obtain more reliable results, further research should investigate the combination of the eye-tracking system with EEG.

In Zhang et al. (2019) the results showed a significant decrease in the amplitude of the N2 component. This decrease was related to both negative and positive pictures (Zhang et al., 2019) whereas Deng et al. (2020) found a significant increase in the N2 component which is related to negative emotional stimuli. Furthermore, Deng et al. (2020) indicated positive correlations between both N2 and late positive potential during negative no-regulation and nonjudging conditions. This might be due to the reason that nonjudging needs a mature ability to regulate one's emotions in order to develop, which adolescents do not possess due to the undeveloped brain (Deng et al., 2020). Previous research indicates that during adolescence, there are significant transformations in metacognitive and emotion-regulatory abilities (Dahl, 2004). It appears that some degree of development in these areas may be necessary before meaningful differences in dispositional mindfulness can emerge in adolescents (Ciesla et al., 2012). In the study by Deng et al. (2020) another finding showed that during neutral stimuli, down-regulation induced larger amplitudes of P2, meanwhile, there were no significant differences found between up-regulation and no-regulation. This indicates that viewing stimuli from an observing perspective, results in larger reactivity than experiencing the stimuli from a first-person view (Deng et al., 2020).

It has been observed that both P2 and N2 are particularly responsive to emotional information and are associated with an enhanced focus on emotional stimuli, indicating an increased level of attention to such information (Deng et al., 2020). Additionally, adolescents who scored higher for observing, as assessed by FFMQ, showed smaller ERP amplitudes during the emotion regulation task (Deng et al., 2020). In adolescents, a higher level of observing might promote their mental health, by moderating the early response to an emotional stimulus prior to the occurrence of a following emotional response. Thereby reducing the intensity of their emotional response (Deng et al., 2020). A review by Lin et al. (2019) suggests that mindfulness may provide numerous health benefits to adolescents such as increased mental health, physical health, and quality of life. Deng et al. (2020) observed an increase in the late positive potential component in response to negative emotional stimuli in high mindful adolescents. Late positive potential is regarded as a critical indicator of emotion regulation, particularly as it relates to the cognitive processing of emotional information (Deng et al., 2020). This increase in late positive potential suggests that high mindful adolescents may have a greater ability to regulate their emotions in response to negative emotional stimuli (Deng et al., 2020).

In addition, when passively viewing highly arousing, unpleasant images, the late positive potential amplitude is lower for more mindful individuals than for less mindful individuals (Brown et al. 2012). Developmentally, because of their relatively undeveloped emotional abilities, adolescents show higher late positive potential amplitudes than adults when using different regulatory strategies (Deng et al., 2020). On the contrary, research conducted by Desatnik et al. (2017) has demonstrated that during the processes of emotion generation and regulation, adolescents can effectively modify their emotions at an early stage by utilizing suppression. Research has shown that suppressing one's emotions can affect the ability to inhibit or control outward expressions (Gross, 2002). However, when adolescents practice mindfulness they may induce connections which have been shown to lead to greater stability in emotion regulation (Amada & Shane, 2019; Sanger & Dorjee, 2015), which in turn might help adolescents react to emotional stimuli in a more adaptive manner by re-evaluating the situation during reappraisal. The result indicates that mindfulness meditation may improve emotional processes by enhancing self-awareness, inhibition control, and cognitive flexibility during emotion regulation (Deng et al., 2020).

The most recent article by Deng et al. (2021) focused particularly on frontal brain activity in high and low trait mindfulness in adolescents, as assessed by FFMQ. Today, EEG asymmetry is widely used by scientists worldwide to investigate various constructs such as temperament, personality, psychopathology, motivation, emotion, and cognitive control (Smith et al., 2017). Alpha activity is a well-known indicator of neural activity related to emotion regulation (Deng et al., 2021). In the study by Deng et al. (2021), they observed that during up-regulation and down-regulation, those with a higher level of trait mindfulness adolescents scored a larger asymmetry than adolescents with a lower level of trait mindfulness. Furthermore, in neutral up-regulation conditions, the adolescence showed a greater left asymmetry (which is connected to emotions). Previous research indicates that left frontal EEG activation is linked to emotions characterized by a more positive valence (Kim & Bell, 2006). In particular, it is thought that the left frontal regions play a primary role in appetitive motivation and approach-related effect, which includes emotions such as elation, hope, and happiness but it also includes anger (Reznik & Allen, 2018). Whereas right frontal regions are linked with behavioral inhibition and vigilant attention that is often observed during certain negative affective states (Reznik & Allen, 2018). Finally, the results showed significantly greater left-sided asymmetry in the prefrontal areas in higher levels of trait mindfulness adolescents especially in up-regulation and down-regulation conditions (Deng et al., 2021). This indicates that mindfulness could improve the efficacy of emotion regulation and that high trait mindfulness could minimize the risks of mental illness in adolescents (Deng et al., 2021).

Amada and Shane (2019) mention that research on how both mindfulness and emotion regulation affects the brain in adolescents is affected by the fact that their brain is still undergoing significant changes. This is noticeable in the results of the study by Deng et al. (2020), it is suggested that adolescents do not possess particular abilities such as nonjudging due to the undeveloped brain. Moreover, it is suggested that the prolonged maturation of the PFC may complicate the ability of adolescents to regulate their emotions (Andrews et al., 2021). Furthermore, very few articles were found where the healthy brains of adolescents were investigated. Most studies focused on autism (e.g., Susam et al., 2022) and youth with familial risk for bipolar disorder (e.g., Hafeman et al., 2020).

To summarize, the findings indicate that mindfulness meditation may be a useful tool to improve emotion regulation. Mindfulness seems to increase the prefrontal functions during changes in emotional responses compared to inducing a stable emotional state prior to emotion regulation (Deng et al., 2021). Even so, despite such positive effects, high levels of trait mindfulness in adolescents could possibly lead to maladaptive outcomes, by affecting judgment. This could lead to problems in adulthood due to insufficient long-term preparation and planning when being too non-judgemental during adolescents (Deng et al., 2020). Furthermore, Amada and Shane (2019) mention maturity differences in the prefrontal cortex in relation to the brain regions that support bottom-up processing compared to the brain regions in top-down processing. The findings by Zhang et al. (2019) however indicate that BFM seems to activate the dorsal PFC network that uses the top-down process to help adolescents regulate their emotional reactions (Zhang et al., 2019). Zhang et al. (2019) also suggest that mindfulness could be an individual emotion regulation strategy instead of affecting the emotion regulation strategies.

Ethical and Societal Aspects

All three included studies had the procedures performed according to ethical standards and were approved by an ethical committee. There were none of the studies that acknowledged any ethical dilemmas or conflicts of interest.

Adolescence is a period that is unique to each individual, as family dynamics and social environments can significantly impact the appearance of social intelligence and the ability to communicate with other people. Additionally, given the diversity of experiences and circumstances that adolescents encounter during this phase, it can cause challenges to establish a reliable baseline for future studies.

Limitations

There are numerous limitations in the included studies. Deng et al. (2020) did not raise the relationship between FFMQ and emotion regulation. Deng et al. (2021) only focused on the nuances of negative emotion regulation. The third study, by Zhang et al. (2019) used ERP during long- or short-term BFM practice, although the researchers suggest that ERP has a poor spatial resolution and hence why it might be necessary to approach the identification of neural substrates associated with BFM with caution. In addition, Zhang et al. (2019) used smiling faces as positive stimuli whereas negative and neutral stimuli were not faces and it has been shown that N2 is usually activated during stimuli such as faces and other affective stimuli. However, Zhang et al. (2019) mentioned that this did not confound their results since N2 is also commonly activated for other affective stimuli. Furthermore, none of the three studies used control groups when conducting the research. Lastly, the adolescents in the included articles were in different periods of adolescence which could lead to difficulties during comparison.

One of the most notable limitations of this systematic review is that the number of studies included is relatively small, due to few studies on adolescence without neurodevelopmental disorder, which may affect the generalizability of the results. Another limitation could be that two of the studies were conducted by similar researchers, which may lead to biases. The inclusion of only one study using mindfulness intervention is also a limitation, as it limits the ability to make comparisons across studies. Lastly, only open-access articles or those accessed via the school library were included, and only articles published in English were considered, which may result in a biased sample.

Future Research

Future research should conduct studies on trait mindfulness in real-life settings to gain more knowledge on the topic. Furthermore, future studies should also examine adolescents' different FFMQ profiles and the profiles' influence on adolescents' ability to emotion regulation. In addition, this topic needs significantly more research on adolescence and the effect of mindfulness e.g., longitudinal studies to find more significant results and clear descriptions of why mindfulness meditation is a promising strategy for emotion regulation processes. Due to the poor spatial resolution in ERP regarding Zhang et al. (2019) future research should combine ERP with fMRI to confirm temporal dynamics and neural substrates. In addition to this previous research by Warbrick (2022) has shown that eye movements and muscle movements create artifacts, and Beres (2017) mentions that even accidental head turns, and swallowing can create artifacts that affect ERPs. Therefore, to obtain more reliable results, further research should investigate the combination of the eye-tracking system with EEG.

In general, there needs to be more research conducted on the topic due to the low quantity of studies. Thus, the existing articles are a good background for further research on this topic. The studies of Deng et al. (2020) and Deng et al. (2021) complemented each other already. Despite not being the same authors, Deng et al. (2021) took limitations and recommendations for future studies from Deng et al. (2020) into consideration and conducted further research on the same topic. Lastly, future research should utilize control groups to provide a baseline to which the effects of mindfulness interventions can be compared.

Final Conclusion

This systematic review was conducted to gather and compare research on the effects of mindfulness on emotion regulation during adolescence. The results suggest that brief mindfulness meditation enhances the activity of the left prefrontal cortex, which is associated with positive affect and emotion regulation, indicating greater emotional stability. However, the results should be considered preliminary. As mentioned earlier, adolescence is an emotionally unstable period that mindfulness could improve by stabilizing the emotion regulation process and outward emotional reactions. There seem to be some challenges for future studies such as limited research on the topic of the healthy brain of adolescents. Even so, these findings contribute to future research.

References:

Ahmed, S. P., Bittencourt-Hewitt, A., & Sebastian, C. L. (2015). Neurocognitive bases of emotion regulation development in adolescence. *Developmental Cognitive Neuroscience*, *15*, 11–25. https://doi.org/10.1016/j.dcn.2015.07.006

Amada, N. M., & Shane, J. (2019). Mindfulness as a Promoter of Adaptive Development in Adolescence. *Adolescent Research Review, 4*, 93-112. https://doi.org/10.1007/s40894-018-0096-1

Andrews, J. R., Ahmed, S. P., & Blakemore, S. (2021). Navigating the Social Environment in Adolescence: The Role of Social Brain Development. *Biological Psychiatry, 89*(2), 109–118. https://doi.org/10.1016/j.biopsych.2020.09.012

Baer, R. A., Smith, G. T., Hopkins, J., Krietemeyer, J., & Toney, L. (2006). Using Self-Report Assessment Methods to Explore Facets of Mindfulness. *Assessment*, *13*(1), 27–45. https://doi.org/10.1177/1073191105283504

Beres, A. (2017). Time is of the Essence: A Review of Electroencephalography (EEG) and Event-Related Brain Potentials (ERPs) in Language Research. *Applied Psychophysiology and Biofeedback*, *42*(4), 247–255. https://doi.org/10.1007/s10484-017-9371-3

Brown, K. W., Goodman, R., & Inzlicht, M. (2012). Dispositional mindfulness and the attenuation of neural responses to emotional stimuli. *Social Cognitive and Affective Neuroscience*, *8*(1), 93–99. https://doi.org/10.1093/scan/nss004

Chan, Y. L., & Marinellie, S. A. (2008). Definitions of Idioms in Preadolescents, Adolescents, and Adults. *J Psycholinguist Res, 37*, 1–20. https://doi.org/10.1007/s10936-007-9056-9

Chen, S. Y., Cui, H., Zhou, R. L., & Jia, Y. Y. (2012). Revision of mindful attention awareness scale (MAAS). *Chinese Journal of Clinical Psychology, 20*, 148–151.

Ciesla, J. A., Reilly, L., Dickson, K. S., Emanuel, A. S., & Updegraff, J. A. (2012). Dispositional Mindfulness Moderates the Effects of Stress Among Adolescents: Rumination as a Mediator. *Journal of Clinical Child and Adolescent Psychology, 41*(6), 760–770. https://doi.org/10.1080/15374416.2012.698724

Dahl, R. E. (2004). Adolescent Brain Development: A Period of Vulnerabilities and Opportunities. Keynote Address. Annals of the New York Academy of Sciences, 1021(1), 1–22. https://doi.org/10.1196/annals.1308.001

De Bruin, E. I., Zijlstra, B. J. H., & Bögels, S. M. (2013). The Meaning of Mindfulness in Children and Adolescents: Further Validation of the Child and Adolescent Mindfulness Measure (CAMM) in Two Independent Samples from The Netherlands. *Mindfulness*. https://doi.org/10.1007/s12671-013-0196-8

Deng, X., Gao, Q., Zhang, L., & Li, Y. (2020). Neural Underpinnings of the Role of Trait Mindfulness in Emotion Regulation in Adolescents. *Mindfulness 11*, 1120–1130. https://doi.org/10.1007/s12671-019-01276-7

Deng, X., Yang, M., & An, S. (2021). Differences in frontal EEG asymmetry during emotion regulation between high and low mindfulness adolescents. *Biological Psychology, 158*. https://doi.org/10.1016/j.biopsycho.2020.107990

Derryberry, D., & Reed, M. A. (2002). Anxiety-related attentional biases and their regulation by attentional control. *Journal of Abnormal Psychology*, *111*(2), 225–236. https://doi.org/10.1037/0021-843x.111.2.225

Desatnik, A., Bel-Bahar, T., Nolte, T., Crowley, M. J., Fonagy, P., & Fearon, P. (2017). Emotion regulation in adolescents: An ERP study. *Biological Psychology, 129*, 52–61. https://doi.org/10.1016/j.biopsycho.2017.08.001

Etkin, A., Büchel, C., & Gross, J. J. (2015). The neural bases of emotion regulation. *Nature reviews. Neuroscience*, *16*(11), 693–700. https://doi.org/10.1038/nrn4044

Ford, B. Q., & Gross, J. J. (2018). Emotion regulation: Why beliefs matter. *Canadian Psychology, 59*(1), 1–14. https://doi.org/10.1037/cap0000142

Ford, B. Q., & Gross, J. J. (2019). Why Beliefs About Emotion Matter: And Emotion Regulation Perspective. *Current Directions in Psychological Science, 28*(1), 74-81. https://doi.org/10.1177/0963721418806697

Gross, J. J. (1998). Antecedent- and response-focused emotion regulation: Divergent consequences for experience, expression, and physiology. *Journal of Personality and Social Psychology, 74*(1), 224–237. https://doi.org/10.1037/0022-3514.74.1.224

Gross, J. J. (1999). Emotion Regulation: Past, Present, Future. *Cognition & Emotion, 13*(5), 551-573. https://doi.org/10.1080/026999399379186

Gross, J. J. (2002). Emotion regulation: Affective, cognitive and social consequences. *Psychophysiology, 39*, 281-291. https://doi.org/10.1017.S0048577201393198

Gross, J. J. (2014). *Handbook of Emotion Regulation (2nd ed.)*. The Guilford Press.

Hafeman, D., Ostroff, A. N., Feldman, J. L., Hickey, M. B., Phillips, M. L., Creswell, D., Birmaher, B., & Goldstein, B. I. (2020). Mindfulness-based intervention to decrease mood lability in at-risk youth: Preliminary evidence for changes in resting state functional connectivity. *Journal of Affective Disorders*, *276*, 23–29. https://doi.org/10.1016/j.jad.2020.06.042

Heeger, D. J., & Ress, D. (2002). What does fMRI tell us about neuronal activity? *Nature Reviews Neuroscience, 3*(2), 142–151. https://doi.org/10.1038/nrn730

Hölzel, B. K., Ott, U., Gard, T., Hempel, H., Weygandt, M., Morgen, K., & Vaitl, D. (2007). Investigation of mindfulness meditation practitioners with voxel-based morphometry. *Social Cognitive and Affective Neuroscience*, *3*(1), 55–61. https://doi.org/10.1093/scan/nsm038

Kabat-Zinn, J. (2003). Mindfulness-Based Interventions in Context: Past, Present, and Future. *Clinical Psychology: Science and Practice, 10*(2), 144-156. https://doi.org/10.1093/clipsy/bpg016

Kiken, L. G., Garland, E. L., Bluth, K., Palsson, O. S., & Gaylord, S. (2015). From a state to a trait: Trajectories of state mindfulness in meditation during intervention predict changes in trait mindfulness. *Personality and Individual Differences*, *81*, 41–46. https://doi.org/10.1016/j.paid.2014.12.044

Kim, K. H., & Bell, M. A. (2006). Frontal EEG Asymmetry and Regulation during Childhood. *Annals of the New York Academy of Sciences*, *1094*(1), 308–312. https://doi.org/10.1196/annals.1376.040

Kirschstein, T., & Köhling, R. (2009). What is the Source of the EEG? *Clinical Eeg and Neuroscience, 40*(3), 146–149. https://doi.org/10.1177/155005940904000305

Lamm, C., & Lewis, M. D. (2010). Developmental Change in the Neurophysiological Correlates of Self-Regulation in High- and Low-Emotion Conditions. *Developmental Neuropsychology, 35*(2), 156–176. https://doi.org/10.1080/87565640903526512

Lantrip, C., Isquith, P. K., Koven, N. S., Welsh, K. A., & Roth, R. H. (2016). Executive Function and Emotion Regulation Strategy Use in Adolescents. *Applied Neuropsychology. Child, 5*(1), 50–55. https://doi.org/10.1080/21622965.2014.960567

Lin, J., Chadi, N., & Shrier, L. A. (2019). Mindfulness-based interventions for adolescent health. *Current Opinion in Pediatrics*, *31*(4), 469–475. https://doi.org/10.1097/mop.0000000000000760

Lomas, T., Ivtzan, I., & Fu, C. H. (2015). A systematic review of the neurophysiology of mindfulness on EEG oscillations. *Neuroscience & Biobehavioral Reviews*, *57*, 401–410. https://doi.org/10.1016/j.neubiorev.2015.09.018

Lu, B., Hui, M. A., & Yu-Xia, H. (2005). The Development of Native Chinese Affective Picture System–A Pretest in 46 College Students. *Chinese Mental Health Journal, 19*(11), 719–722.

Malinowski, P. (2013). Neural mechanisms of attentional control in mindfulness meditation. *Frontiers in Neuroscience, 7.* https://doi.org/10.3389/fnins.2013.00008

McRae, K., & Gross, J. J. (2020). Emotion regulation. *Emotion, 20*(1), 1–9. https://doi.org/10.1037/emo0000703

Moore, S. A., Zoellner, L. A., & Mollenholt, N. (2008). Are expressive suppression and cognitive reappraisal associated with stress-related symptoms?. *Behaviour Research and Therapy, 46*(9), 993-1000. https://doi.org/10.1016/j.brat.2008.05.001

Oberle, E., Schonert-Reichl, K. A., Lawlor, M. S., & Thomson K, C. (2012). Mindful and Inhibitory Control in Early Adolescence. *Journal of Early Adolescence. 32*(4), 565-588. https://doi.org/10.1177/0272431611403741

Ouzzani, M., Hammady, H., Fedorowicz, Z., & Elmagarmid, A. (2016). Rayyan — a web and mobile app for systematic reviews. *Systematic Reviews,* 5:210. https://doi.org/10.1186/s13643-016-0384-4.

Pallozzi, R., Wertheim, E., Paxton, S., & Ong, B. (2017). Trait Mindfulness Measures for Use with Adolescents: a Systematic Review. *Mindfulness. 8,* 110-125. https://doi.org/10.1007/s12671-016-0567-z

Pepping, C. A., Duvenage, M., Cronin, T. J., & Lyons, A. (2016). Adolescent mindfulness and psychopathology: The role of emotion regulation. *Personality and Individual Differences, 99,* 302-307. https://doi.org/10.1016/j.paid.2016.04.089.

Rau, H. K., & Williams, P. G. (2016). Dispositional mindfulness: A critical review of construct validation research. *Personality and Individual Differences*, *93,* 32–43. https://doi.org/10.1016/j.paid.2015.09.035

Reznik, S. J., & Allen, J. F. (2018). Frontal asymmetry as a mediator and moderator of emotion: An updated review. *Psychophysiology*, *55*(1), e12965. https://doi.org/10.1111/psyp.12965

Sabu, P., Stuldreher, I. V., Kaneko, D., & Brouwer, A. (2022). A Review on the Role of Affective Stimuli in Event-Related Frontal Alpha Asymmetry. *Frontiers in Computer Science*, *4*. https://doi.org/10.3389/fcomp.2022.869123

Sanger, K. L., & Dorjee, D. (2015). Mindfulness training for adolescents: A neurodevelopmental perspective on investigating modifications in attention and emotion regulation using event-related brain potentials. *Cognitive, Affective, & Behavioral Neuroscience*, 15(3), 696–711. https://doi.org/10.3758/s13415-015-0354-7

Sawyer, S. M., Azzopardi, P. S., Wickremarathne, D., & Pattor, G. C. (2018). The age of adolescence. *Lancet Child & Adolescent Health, 2*(3), 223-228. https://doi.org/10.1016/S2352-4642(18)30022-1

Shapiro, S., Siegel, R., & Neff, K. D. (2018). Paradoxes of Mindfulness. *Mindfulness, 9*, 1693-1701. https://doi.org/10.1007/s12671-018-0957-5

Smith, E. E., Reznik, S. J., Stewart, J. L., & Allen, J. F. (2017). Assessing and conceptualizing frontal EEG asymmetry: An updated primer on recording, processing, analyzing, and interpreting frontal alpha asymmetry. *International Journal of Psychophysiology*, *111*, 98–114. https://doi.org/10.1016/j.ijpsycho.2016.11.005

Susam, B. T., Riek, N. T., Beck, K., Eldeeb, S., Hudac, C. M., Gable, P. A., Conner, C., Akcakaya, M., White, S., & Mazefsky, C. (2022). Quantitative EEG Changes in Youth With ASD Following Brief Mindfulness Meditation Exercise. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, *30*, 2395–2405. https://doi.org/10.1109/tnsre.2022.3199151

Wante, L., Van Beveren, M. L., Theuwis, L., & Braet, C. (2018). The effects of emotion regulation strategies on positive and negative affect in early adolescents. *Cognition and Emotion, 32*(5), 988-1002. https://doi.org/10.1080/02699931.2017.1374242

Warbrick, T. (2022). Simultaneous EEG-fMRI: What Have We Learned and What Does the Future Hold? *Sensors, 22*(6), 2262. https://doi.org/10.3390/s22062262

World Health Organization. (n.d.). Adolescent health. Retrieved March 10, from https://www.who.int/health-topics/adolescent-health#tab=tab_1

Wu, R., Liu, L., Zhu, H., Su, W., Cao, Z., Zhong, S., Liu, X., & Jiang, C. (2019). Brief Mindfulness Meditation Improves Emotion Processing. *Frontiers in Neuroscience*, *13*. https://doi.org/10.3389/fnins.2019.01074

Zhang, W., Ouyang, Y., Tang, F., Chen, J., & Li, H. (2019). Breath-focused mindfulness alters early and late components during emotion regulation. *Brain and Cognition*, *135*, 103585. https://doi.org/10.1016/j.bandc.2019.103585