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# Dispositional Mindfulness and Neural Activity in Youth: A Systematic Review

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## Abstract

**Objectives** Dispositional mindfulness has been associated with improved emotional regulation, reduced stress, and increased well-being. Interventions aiming at developing dispositional mindfulness are thus promising non-invasive, early interventions for youth at risk for psychiatric disorders. However, little is known about the neural correlates of dispositional mindfulness in adolescents although this could inform response to preventive interventions in youth. This systematic review identified and synthesized existing literature on the functional MRI correlates of dispositional mindfulness in adolescents, to guide and pave the way for interventional studies.

**Method** This systematic review included observational studies investigating resting-state or task-based fMRI correlates of mindfulness traits in participants aged between 6 and 25 years, following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Four databases were searched up to October 2023, and narrative synthesis of the extracted results was conducted.

**Results** The 7 included studies (out of the 2348 screened) had one task-based and six resting state analyses. We focused on reporting resting state studies, where neural correlates of dispositional mindfulness were found in various brain regions, including the frontal cortex, the insula, the thalamus. It was also related to transitions between brain states. These findings suggest that dispositional mindfulness may be associated to underlying processes such as attention, emotion regulation and mind wandering.

**Conclusions** Due to the low number of papers, it is difficult to reach a conclusion. Given the need to further investigate the neural correlates of dispositional mindfulness in adolescents to understand the positive behavioral outcomes that are associated with mindfulness, we suggest caveats and perspectives for future studies.

**Preregistration** This systematic review is not preregistered.

**Keywords** Mindfulness Trait · Dispositional Mindfulness · Functional Magnetic Resonance Imaging · Youth · Systematic Review

Adolescence is a developmental period with many psychological, biological, and socio-behavioral changes (Coleman & Hendry, 1999). It is described as a transition from childhood to adulthood, starting with puberty, extending through

the second decade of human life until the end of brain maturation around mid-twenties (Arain et al., 2013; Dahl, 2004; Spear, 2000). Being a period of vulnerability and shaping of the stress response, it can lead to the emergence of many psychiatric disorders (Casey et al., 2008; Kessler et al., 2005; Paus et al., 2008). In a recent large global meta-analysis, the peak age of any mental disorder was shown to be 14.5 years, where a third of the individuals had the onset of the first mental disorder before the age of 14, and more than half of them by the age of 25 (Solmi et al., 2022). Therefore, research aiming at enhancing resilience factors, finding protective measures, early detection and early interventions is especially critical for this age range.

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Mindfulness-based interventions have become increasingly applied in medicine and psychology for psychiatric and physical disorders (such as review for MBI effects on anxiety and depression: Hofmann & Gómez, 2017; chronic pain: Majeed et al., 2018; addiction: Rosenthal et al., 2021). Their effectiveness is also investigated in school settings for youth (Fulambarkar et al., 2023; Kuyken et al., 2022). In parallel, the quantification of the construct of mindfulness has gained interest (Grossman, 2008). A growing number of studies have conceptualized mindfulness as a dispositional characteristic that varies naturally among individuals even without a mindfulness practice and reflects the ability to self-regulate, cultivating self-awareness and positive emotional states (Brown & Ryan, 2003). Dispositional mindfulness has been shown to increase with mindfulness-based interventions in adults (Tortella-Feliu et al., 2020), and individuals with higher scores before the training seem to benefit from it even one year later, compared to those with lower scores (Shapiro et al., 2011). However, there is also evidence that mindfulness trait increases with active control conditions and is not specific to mindfulness training (Goldberg et al., 2016; Kral et al., 2022), in addition there are reports of mindfulness trait measures having no association with the amount of meditation practice in adults (Manuel et al., 2017) or in late teens (MacKillop & Anderson, 2007).

Mindfulness as a dispositional trait can be measured by different questionnaires for adults, with some modified versions for adolescents (Pallozzi et al., 2017). They each have their advantages and disadvantages (Bergomi et al., 2013). For example, Mindful Attention Awareness Scale (MAAS) measures a single facet of mindfulness: the presence or absence of attention to the present moment (Brown & Ryan, 2003; MacKillop & Anderson, 2007), with an adapted version for adolescents (MAAS-A; Brown et al., 2011). The Kentucky Inventory of Mindfulness Skills (KIMS; Baer et al., 2004) and Freiburg Mindfulness Inventory (FMI; Walach et al., 2006), on the other hand, measure multiple facets of mindfulness, which are distinctly presented in KIMS and are overlapping in FMI (Bergomi et al., 2013). The Five Facet Mindfulness Questionnaire (FFMQ; Baer et al., 2006) is the most elaborate measure of mindfulness, and includes one more factor than KIMS (non-reactivity, observing, acting with awareness, describing, nonjudgement). Adapted from KIMS, the Child and Adolescent Mindfulness Measure (CAMM) is multifaceted and measures observing thoughts and feelings, acting with awareness and accepting without judgement, but does not separate them into sub-scores (Greco et al., 2011). This heterogeneity in measure might explain the non-conclusive results so far in adults.

Dispositional mindfulness has been linked to many positive psychological traits in youth. In children and adolescents, higher dispositional mindfulness is associated with

less negative emotional states (Mestre et al., 2019). In adolescents, it is influenced both by genetic and non-shared environmental factors as shown in twins (Waszczuk et al., 2015) and parental factors, where mindful parents help their children develop higher levels of mindfulness (Moreira et al., 2018). It has protective effects against mobile phone addiction (Liu et al., 2023) and lower levels have been linked to problematic social media use (Meynadier et al., 2023). In university students, dispositional mindfulness is positively correlated with self-related health, self-regulated behavior, executive function performance and well-being (Lyvers et al., 2014; Zimmaro et al., 2016) and negatively associated with depression scores and negative mood (Brown & Ryan, 2003; Wang et al., 2017). In response to social stress, high scores have been shown to predict lower cortisol in undergraduates (Brown et al., 2012). The opposite relationship was found in adolescents, higher scores predicted higher cortisol level, even though there was reduced emotional and cardiovascular responses (Lucas-Thompson et al., 2019). Among college students, dispositional mindfulness has a negative correlation with physical aggressiveness (Gao et al., 2016). In addition, increased dispositional mindfulness is linked to engaging in protective behavioral strategies leading to a decrease in alcohol related consequences (Brett et al., 2017) and a decrease in emotional reactivity, where mindfulness mediates the relationship between state rumination and state anger in undergraduates (Borders & Lu, 2017). Therefore, trait mindfulness seems in general associated with positive outcomes for mental well-being in adolescents, however its relationship with physiological stress reactivity is not clear.

At the neural pathways level, there has been discussion on whether trait mindfulness and mindfulness-based interventions represent the same construct (Davidson, 2010). Structurally, higher dispositional mindfulness has been associated with decreased gray matter volume in the right amygdala and left caudate (Taren et al., 2013). In parallel, mindfulness-based interventions have been shown to reduce gray matter volume in the right amygdala, which correlated with a decrease of perceived stress (Hölzel et al., 2010) and contrastingly with increased gray matter volume in the left caudate (Farb et al., 2013). However, these structural changes with mindfulness interventions have failed replication in a recent large randomized control trial where no structural changes were found (Kral et al., 2022). Functionally, trait mindfulness correlates negatively with right insula activity while expecting negative pictures using mindful instructions, indicative of the use of less resources to reduce emotional arousal in adults (Lutz et al., 2014). A similar outcome is observed after intervention on emotional face processing in young adults (Johnson et al., 2014). Therefore, there is some evidence pointing toward similar brain mechanisms between trait and acquired mindfulness skills. However, the literature

on mindfulness-based interventions and trait mindfulness presents such a variety of experimental paradigms, populations and analysis methods that it remains difficult to draw a definitive conclusion.

Given the importance of the topic for youth, and in particular the potential of mindfulness as an early intervention for adolescents, we aimed here at reviewing the neural correlates of trait mindfulness focusing on adolescents. In order to capture all of adolescence, we followed Sawyer et al. (2018), who summarizes the phase of brain growth of adolescence, starting before the visible signs of puberty with adrenarche (around 6 years of age); going on until mid-twenties (Sawyer et al., 2018). Despite the growing literature on mindfulness and its psychological benefits, where many studies have populations consisting of university students, there is little neuroimaging data focused on the specific age range, up to 25 years of age. We systematically reviewed the current literature on the functional neuroimaging data associated with dispositional aspect of mindfulness in this population and attempted to distinguish the different aspects of mindfulness with brain activity. By understanding the underlying neural mechanisms behind trait mindfulness, we aim to help design more specific interventions in adolescents adapting to their individual needs.

## Method

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines (Moher et al., 2009).

### Eligibility criteria

We included peer-reviewed, English-written observational studies investigating resting-state or task-based fMRI correlates of mindfulness in participants aged between 6 and 25 years of age. Studies investigating trait mindfulness or mindfulness-based interventions were included; trait mindfulness results are reported here, intervention will be reported elsewhere (Celen et al., 2023). All types of populations (vulnerabilities, psychiatric conditions, etc.) were included if they fitted the age range. We therefore excluded articles with samples outside this age range. Studies that reported only mean age below 25 years were subjected to further scrutiny to ensure the sample age range did not extend beyond our criteria. In details, we requested the age-range via individual e-mails to the authors of these studies, and we discarded studies whose authors confirmed that the population included participants above 25 years, or where we could not get a response from the corresponding author and two other authors. We excluded non-peer reviewed articles, studies employing other neuroimaging techniques (such

as diffusion tensor imaging, structural MRI, PET, magnetic resonance spectroscopy). Additionally, we excluded the following article types: preclinical studies, case series with less than 10 participants, case reports, interventional or randomized controlled trials, letters to the editor, editorials, book chapters, conference abstracts, reviews and metaanalyses.

### Search strategy and study selection

We searched four databases (MEDLINE, EMBASE, PsychINFO and the Cochrane Library) from inception until 14th October, 2023. Our database-specific search strategy included the following keywords: (“mindful\*” or “meditat\*” or “MBSR” or “MBCT”) and (“functional magnetic resonance imaging” or “fMRI” or “MRI” or “neuroimaging”). Gray literature was not included in the search. We searched the references of the included articles to screen for additional relevant articles that could go through the screening process.

Three reviewers (ZC, LFS and CP) independently screened titles, abstracts and then full-text studies for eligibility using an online systematic review software (Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia; [www.covidence.org](http://www.covidence.org)). A fourth author (AM) resolved conflicts.

### Data extraction

Data extraction was performed by two independent researchers (ZC, LFS). Any discrepancy was discussed until a consensus was reached. Disagreements were resolved by a third reviewer (CP).

The following variables were extracted from each article: authors, year of publication, sample size, epidemiological data of the sample (number and percentage of females, mean age, standard deviation of the mean age, age range), self-reported mindfulness scale employed to test the mindfulness trait and mindfulness subscales characterizing this scale, MRI task (where applicable), behavioral results in relation to mindfulness scales, other results and findings, additional relevant comments or aspects (where applicable), technical details on data collections and technique of analysis.

### Data analyses

We conducted a qualitative review of the results and presented them in summarized tables. Due to the methodological differences among the studies and the limited number of studies that met our criteria, it was not feasible to perform a quantitative meta-analysis.

## Public and patients' involvement

The public and patients were not involved in this work.

## Results

### Search Results

In total, 2348 potentially relevant articles were screened, and data from 23 studies met our search criteria. Out of these, 7 studies focused on functional neural correlates associated with mindfulness as a dispositional trait without a mindfulness intervention. The remaining 16 studies were neural correlates associated with mindfulness intervention and will be reported elsewhere (Celen et al., 2023). We retrieved 6 studies focusing on resting state and only one on task-based activity (Stein et al., 2022), therefore, we decided to exclude the task-based study out of the systematic analysis, and to report only resting-state studies. The screening process is shown in Fig. 1.

All studies extracted were cross-sectional, most of them had healthy populations. One study was a case-controlled study, that was conducted on adolescents who were in full or partial remission from Major Depressive Disorder (rMDD), with a mean age of 15.61 years (Peters et al., 2016). Another included a group of children and adolescents at risk of psychopathology with a mean age of 10.3 years (Marusak et al., 2018). The

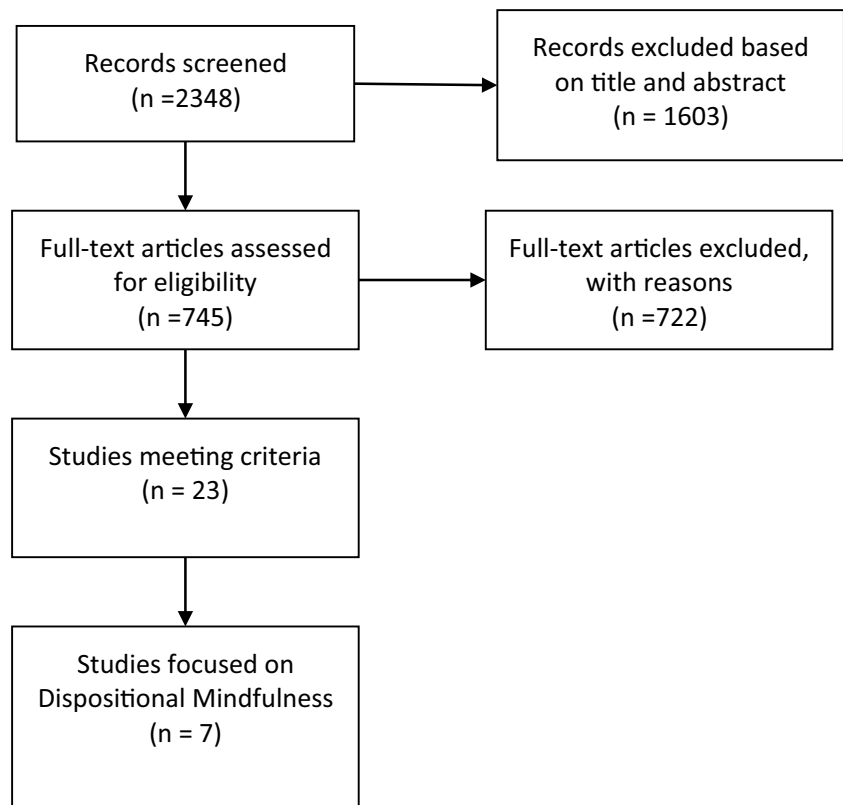
size of the study groups varied significantly from 23 (Peters et al., 2016) to 283 participants (Kong et al., 2016). The main characteristics of the studies are shown in Table 1.

There were a range of dispositional mindfulness measures used in these studies. Three studies used MAAS as a mindfulness scale (Bilevicius et al., 2018; Kong et al., 2016; Wang et al., 2014). One study chose FFMQ as a measure and compared brain activity to its subscales as well as total score (Li et al., 2022). The two studies that included participants under the age of 18 years, reported trait mindfulness through CAMM (Marusak et al., 2018; Peters et al., 2016).

### Summary of Functional MRI Recording and Analysis

All studies recorded fMRI using 3 T scanners. However, there was a heterogeneity in the techniques used for investigation and analysis (Table 1). Among the resting state recordings, four studies instructed their participants to keep eyes closed, and two recorded resting state with eyes open, both presenting a fixation cross (Li et al., 2022; Peters et al., 2016). One study examined dynamic connectivity (as well as static connectivity) using independent component analysis (ICA) method and a sliding windows approach (Marusak et al., 2018). One study examined Regional Homogeneity (ReHo) (Kong et al., 2016), two studies examined whole brain seed based functional connectivity (SBFC) (Peters et al., 2016; Wang et al., 2014). One study examined functional connectivity using independent

**Fig. 1** PRISMA chart of the screening process (Moher et al., 2009)



**Table 1** Summary of the population demographics and techniques of the extracted studies

Author (year)	Number of Subjects, [number of females]	Mean Age (SD)	Age Range	Population Description	Dispositional Mindfulness Scale	Mindfulness Subscales [Facets without subscale]	MRI Task	Data Collection, Analysis
Bilevicius et al. (2018)	32 [22F]	18.16 (1.08)	18–22	Non meditating	MAAS	[Attention]	Resting State	3T, eyes closed, brain voyager, ICA
Kong et al. (2016)	290 [157F]	21.56 (1.01)	18–25	No psychiatric disorders	MAAS	[Attention]	Resting State	3T, eyes closed, FSL, ReHo
Wang et al. (2014)	245[129F]	21.7 (1.05)	18–25	No psychiatric disorders	MAAS	[Attention]	Resting State	3T, eyes closed, FSL, SBFC
Marusak et al. (2018)	49 [23F]	10.3 (2.9)	6–17	Youth at risk for emotional psychopathology via social disadvantage	CAMM	[Observing, Acting with Awareness, Acceptance]	Resting State	3T, eyes closed, multi-echo/ multi-band, ICA, static + dynamic connectivity
Peters et al. (2016)	rMDD: 23 [13F] Control: 10 [7F]	rMDD: 15.61 (1.90) Control: 15.80 (1.99)	12–18	Full or partial remission from MDD	CAMM	[Observing, Acting with Awareness, Acceptance]	Resting State	3T, eyes open, SPM8, SBFC
Li et al. (2022)	89 [63F]	20.40 (1.63)	18–23	No mindfulness training experience, No psychiatric disorders	FFMQ	Observing, Describing, Acting with Awareness, Non-Judging, Non-Reactivity	Resting State	3T, eyes open, DPABI, ALFF, fALFF

*Note.* ALFF: Amplitude of Low Frequency Fluctuations; CAMM: Child and Adolescent Mindfulness Scale; DPABI: Data Processing and Analysis for Brain Imaging; FFMQ: Five Facet Mindfulness Questionnaire; fALFF: fractional Amplitude of Low Frequency Fluctuations; ICA: Independent Component Analysis; MAAS: Mindful Attention Awareness Scale; MDD: Major Depression Disorder, ReHo: Regional Homogeneity; SBFC: Seed Based Functional Connectivity; SPM: Statistical Parametric Mapping

component analysis (ICA) (Bilevicius et al., 2018). Another study explored the relationship of amplitude of low frequency (ALFF) and fractional amplitude of low frequency (fALFF) in regions of interest (ROI) (Li et al., 2022).

## Behavioral Results

One study using MAAS found a positive correlation between this trait and hedonic wellbeing (positive affect), eudaimonic wellbeing, and negatively correlated with negative affect in late adolescents (Kong et al., 2016) (Table 2).

A study reporting CAMM showed youth with higher trait score reporting less symptoms of anxiety and more thoughts focused on the present moment during the fMRI scan (Marusak et al., 2018). However, the same study showed no correlation with depressive symptoms as well as other indices such as income, parental education, IQ, puberty or sex (Marusak et al., 2018). In the study with a sample of adolescents with rMDD, CAMM had no correlation with depression or rumination scores (Peters et al., 2016).

## Dispositional Mindfulness and Resting State Activity

### Single Facet: MAAS

Three papers correlated MAAS with resting state activity with seemingly different techniques: ReHo (Kong et al., 2016), functional connectivity using posterior cingulate cortex (PCC) as a seed to identify DMN (Wang et al., 2014) and functional connectivity using independent component analysis to identify different networks (Bilevicius et al., 2018). The main difference between ReHo and the other techniques is functional connectivity inquires into long-distance relationships whereas ReHo is a measure of local or short distance interactions (Jiang & Zuo, 2016; Zang et al., 2004). During resting state, MAAS was shown to correlate positively with the local synchronization of brain activity, ReHo, in the right insula, left parahippocampal gyrus (PHG), left orbitofrontal cortex (OFC) and negatively with ReHo in the right inferior frontal gyrus (IFG) in healthy adolescents (Kong et al., 2016). MAAS was also reported to mediate the association between spontaneous brain

**Table 2** Summary of behavioral and functional brain activity correlations /associations with increasing dispositional mindfulness in adolescents

Author (year)	Dispositional Mindfulness Scale	Technique	Behavioral Results ↑ mindfulness	MRI Results ↑ mindfulness	Extra comment
Bilevicius et al. (2018)	MAAS	Functional Connectivity, ICA		DMN component: ↓ connectivity left MeFG, ↓ left IFG, ↓ left insula ↑right MeFG, ↑ right PHG, ↑left caudate; SN component: ↑ACC, ↑ left insula, ↓ right cuneus; CEN component (bilateral): ↑ right MFG, right CEN: ↓ cuneus, left CEN: ↓ precuneus	
Kong et al. (2016)	MAAS	Regional Homogeneity, Whole Brain Analysis	↑ positive affect (hedonic wellbeing) and eudaimonic wellbeing; ↓ negative affect	↑ local synchronization of spontaneous brain activity in left OFC, ↑ left PHG, ↑ right insula, ↓ right IFG	
Wang et al. (2014)	MAAS	Functional Connectivity, Seed based		DMN nodes: ↓ connectivity between thalamus and PCC, ↓ involvement thalamus in DMN (graph theory)	
Marusak et al. (2018)	CAMM	Functional Connectivity, ICA/ Sliding Windows	↓ symptoms of anxiety; ↑ present focused thoughts during scan	Static: No correlation with connectivity between (DMN, SEN and CEN) Dynamic: within the 5 dynamic connectivity states identified ↑ transitions between brain states; ↓ time in specific connectivity state; ↓ strength SEN-left CEN connectivity	Mindfulness and decreased anxiety mediated by higher transitioning between states
Peters et al. (2016)	CAMM	Functional Connectivity, Seed based	(-) No correlation to depression or rumination	↓ connectivity between left dlPFC-left IFG	Pilot study
Li et al. (2022)	FFMQ	Whole Brain Analysis, Region of Interest ALFF/fALFF		WBA: ↓ spontaneous activation of left premotor cortex. ROI: ↓ spontaneous activation of left PCC (subscale: non-reactivity)	

*Note.* ALFF: Amplitude of low frequency fluctuations; ACC: anterior cingulate cortex; CAMM: Child and Adolescent Mindfulness Scale; CEN: central executive network; dlPFC: dorsolateral prefrontal cortex; DMN: default mode network; fALFF: fractional Amplitude of Low Frequency Fluctuations; FFMQ: Five Facet Mindfulness Questionnaire; ICA: Independent Component Analysis; IFG: inferior frontal gyrus; MAAS: Mindful Attention Awareness Scale; MeFG: medial frontal gyrus, MFG: middle frontal gyrus; OFC: orbitofrontal cortex; PCC: posterior cingulate cortex; PHG: parahippocampal gyrus; ROI: region of interest; SEN: salience network; STG: superior temporal gyrus; WBA: whole brain analysis

activity in these regions and well-being scores such as positive affect and eudaimonic well-being (Kong et al., 2016).

One of the two papers reporting functional connectivity analysis of the default mode network (DMN) showed healthy late adolescents with higher mindfulness scores having the spontaneous neural activity of the thalamus correlating weakly with other DMN nodes (Wang et al., 2014). The other paper showed mindfulness scores correlating negatively with functional connectivity in the DMN, particularly in the left medial frontal gyrus, left superior temporal gyrus and left insula, even though insula is not considered a part of DMN but is a part of the salience network (SN) (Bilevicius et al., 2018). The authors note that according to their results, MAAS scores involve cross-network functional connectivity (Bilevicius et al., 2018). In addition, the connectivity of the precuneus in the salience network (SN) and central executive network (CEN) correlated negatively with mindfulness (Bilevicius et al., 2018). The left insula and anterior cingulate cortex (ACC) connectivity in the SN revealed positive correlations with mindfulness (Bilevicius et al., 2018).

Overall, in the three papers, MAAS was associated to connectivity in three major brain networks and involved key regions such as insula, IFG and thalamus. The results are summarized in Table 2.

### Multifaceted: CAMM, FFMQ

In the study with the only clinical population, adolescents with rMDD, connectivity between left dorsolateral PFC and left IFG was inversely related to multifaceted mindfulness scale (Peters et al., 2016). In another study, participants with higher mindfulness transitioned more between brain states, and showed a state-specific reduction in strength of connectivity of the salience and emotion network (SEN) and the CEN (Marusak et al., 2018). The number of state transitions was shown to mediate the link between high mindfulness and low anxiety (Marusak et al., 2018). In the study with a population of late adolescents, spontaneous brain activity of the PCC correlated negatively with non-reactivity, whereas in whole brain analysis FFMQ scores and subscales were negatively correlated with the spontaneous activation of the left premotor cortex (Li et al., 2022). Results are summarized in Table 2.

In summary, multifaceted dispositional mindfulness was related to increased transitions between brain states and decreased connectivity in specific frontal cortex locations and inferior parietal lobe.

## Discussion

We have reviewed the studies that investigate the neural correlates of dispositional mindfulness without an intervention, in adolescents up to 25 years of age. Mindfulness

as a trait in adolescents is correlated with resting state activity in regions that have been associated with emotion regulation, attention, introspection and transitioning between resting state-networks. The number of studies that investigate trait mindfulness in this age range is very low and unfortunately the results cannot be generalized due to the differences in the types of scales and analysis techniques used, warranting further research. However, we discuss here the findings in the context of a larger literature.

In adolescents, subscales of mindfulness trait have been linked to neural correlates of emotion regulation, for example in an event-related potential study (Deng et al., 2020). Supporting this, one study extracted here linked trait mindfulness to the connectivity of two regions, left dorsolateral PFC and left IFG (Peters et al., 2016), which are regions involved in emotion regulation, especially reappraisal in young adults (Morawetz et al., 2016). In the pilot study using a group of adolescents with rMDD, higher level of multifaceted mindfulness was associated with lower connectivity between these two regions (Peters et al., 2016). In adults, on the other hand, mindfulness-based interventions result in an increase in resting state functional connectivity between left dorsolateral PFC and right IFG among other regions (Taren et al., 2017). Peters et al. (2016) explain the decrease in connectivity between the two frontal regions associated with high mindfulness to be indicative of the requirement of less effort to reduce or suppress emotional responding, and a sign of accepting the emotion, which is the basis of mindfulness. These two patterns could actually subtend two emotion regulation strategies involved in mindfulness but somehow opposite: acceptance and reappraisal, the latter being more likely to be used in older participants (Theurel & Gentaz, 2018). This remains to be tested.

There is a debate on whether mindfulness training improves attention regulation even though mindfulness practice involves focusing of attention, as well as open monitoring. This is not the case for sustained attention and cognitive inhibition in university students (Wimmer et al., 2020). MBIs might be promising for adolescents and children's attention and executive functions, however more specific studies are still needed (Mak et al., 2018). In our review, single faceted mindfulness trait, measuring mainly the attention to the present moment, is correlated with the connectivity of right middle frontal gyrus in the central executive network (Bilevicius et al., 2018). Right middle frontal gyrus is involved in reorienting attention, serving as a gateway between ventral and dorsal attentional networks (Fox et al., 2006; Japee et al., 2015). Another region involved in attention, as well as emotion regulation, is the right IFG, associated with the detection of important cues (Hampshire et al., 2010). Kong et al. (2016), examining a large number of late adolescents, with the same single

faceted scale on attention, found a negative relationship with ReHo in the right IFG during rest. This might seem unexpected, and indeed, mindfulness training has been shown to enhance activity in IFG in college students during rest (Tang et al., 2013) and during insightful problem solving (Ding et al., 2015). This discrepancy in findings could be due to the different techniques being used, and the physiological significance of ReHo that needs further investigation to interpret the direction of the results, as noted by the authors (Kong et al., 2016).

Insula is a region frequently evoked in mindfulness research, given its role in interoception and awareness (Craig, 2009). A review on the neural correlates of MBIs concluded that an increase in insula activity was the most common effect of mindfulness trainings (Young et al., 2018). Mindfulness strengthens interoception and affects the insula network (Sharp et al., 2018). In the studies we examined, there were several findings on the insula, with different methods whose results are not uniform. Single facet mindfulness scale correlated positively with right insula ReHo and with connectivity between left insula and the salience network (Bilevicius et al., 2018; Kong et al., 2016). In a study with young adults, authors similarly showed increased left insula connectivity in the attentional network, in the “observing” facet of a multifaceted mindfulness scale (Parkinson et al., 2019). The “observing” subscale of the FFMQ measures attentional awareness component of mindfulness, similar to single-faceted MAAS. However, the study we extracted also reported a negative correlation reported between the left insula and the DMN component (Bilevicius et al., 2018). With insula being part of the salience network, this is an example of cross-network connectivity. The authors explain that their technique is focused on within network connectivity and they can only speculate on the patterns of the cross-network connectivity they report. Cross-network connectivity has previously been linked to mindfulness, especially as a recent meta-analysis showed that cross-network connectivity between the SN and DMN is strengthened by mindfulness training, suggesting a more flexible control of inward attention (Rahrig et al., 2022). Therefore, we cannot draw a unique conclusion on the relationship of the insula with trait mindfulness in adolescents.

In early adolescents multifaceted mindfulness trait did not show any correlation to static functional connectivity between networks (Marusak et al., 2018). However, dynamic functional connectivity revealed that mindfulness trait is positively correlated to an increase in transitions between brain states during rest, which mediates a decrease in anxiety (Marusak et al., 2018). This is in line with a study in young adults, when breath counting is used as an objective dispositional mindfulness scale, instead of a self-reported scale as investigated in Marusak et al. (2018). The group with higher scores transitioned more between brain states

and spent more time in a task ready state, however, there was no correlation with self-reported multifaceted mindfulness scale (Lim et al., 2018). In conclusion, transitioning between brain states, as well as increased cross-network connectivity, are linked to mindfulness, both intervention and trait, however this is inferred from a very low number of studies for adolescents.

An additional region that was reported to be linked to dispositional mindfulness was the thalamus. One of the extracted studies here showed that during rest, late adolescents with higher single faceted mindfulness scores, have lower correlation of thalamus spontaneous neural activity with the other DMN nodes activity. The authors suggest that thalamus could be acting as a switch between focused mindful state and mind wandering, where the lower involvement in DMN might mean less mind wandering (Wang et al., 2014). Indeed, a negative correlation with MAAS and thalamus activity is also observed with other modalities such as PET (Gartenschläger et al., 2017). In adults, the thalamus is one of the regions that is deactivated during mindfulness meditation related to pain relief (Zeidan et al., 2015), which is an example of the similarity between mindfulness intervention and trait.

Another region that seems to show the same pattern is the PCC. Within the DMN, PCC is the region where self-driven processes begin (Davey et al., 2016). Mindfulness training in young adults results in decreased left PCC amplitude of spontaneous activity during rest which is also reflected in lower depression scores (Yang et al., 2019). In adolescents, a study extracted here showed, a subscale of trait mindfulness, non-reactivity, correlating negatively with the same mode of measurement of left PCC activity (Li et al., 2022). There seems to be a few parallels between intervention effects in young adults and trait mindfulness in adolescents. However, more data, especially for adolescents is needed.

In summary, although mindfulness, with its multiple components of bringing attention to the present moment, opening up to experience, in a non-judgmental way; is an interesting putative intervention for transdiagnostic early interventions, this review shows that more work is needed to understand it as a self-reported disposition and its consequences on brain function and development in adolescents. Inferring that different regions of the brain become integrated for different aspects of the practice and dispositional measure is tempting. However, in this age group, the studies on neural correlates of dispositional mindfulness, as we have summarized, is very limited. Understanding how dispositional mindfulness relates to neural activity during this period could shed light on the potential role of mindfulness on these maturing circuits. Therefore, deciphering the various pathways through which mindfulness trait, as well as mindfulness interventions, act as psychological resilience factors will help target early interventions for specific

sub-groups of individuals and benefit clinical precision psychiatry. We would encourage more studies focusing on this specific notion of individual facets of mindfulness, to be investigating developmental neural pathways in adolescents.

## Limitations and Future Directions

We would like to emphasize a few things that might help develop the research in this field. Firstly, we strongly encourage investigators to report the age range of their participants, as well as mean age and standard deviation. This would allow transparency and to help reviewers that aim to investigate certain population groups based on age. University students do represent a specific population, but not a uniform population as there can be a very wide age range. We observed that the maximal age can go up to 36 years, in studies with undergraduates, during our extraction process.

In addition, during reporting, we would recommend emphasizing the facets of trait mindfulness, even when a single facet is used, in the title and abstract rather than just labelling it “mindfulness”. Mindfulness is a very broad term, and this multidimensional term is aimed to be measured as a disposition, by different scales, measuring different aspects, in adults and adolescents. We have presented and discussed the results on the basis of the facets of the trait scales used in order to summarize the neural correlates of different aspects of mindfulness. However, due to the low number of studies, we are not able to make general inferences.

In conclusion, to our knowledge, this is the first review reporting the neural correlates of dispositional mindfulness and its relevance to youth up to 25 years of age. There are many good quality reviews on mindfulness (Ahola Kohut et al., 2017; Tang et al., 2015), including on the impact of mindfulness-based intervention on brain mechanisms (Rahrig et al., 2022; Young et al., 2018), however no review had been done on dispositional mindfulness and adolescents despite its high relevance in the context of promoting mental health in that stage. From behavioral studies, the positive effects of mindfulness on mental health and well-being is clear. The main limitation of our review is the sparsity of studies on the subject, leading to large heterogeneity in the number of subjects, analysis techniques and in the dispositional mindfulness scales. However, the results of this qualitative review should encourage further research.

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## Declarations

**Conflict of Interest** The authors declare that they have no conflict of interest.

**Informed Consent statement** No informed consent was needed in this study as it is a systematic analysis of previously published studies.

**Use of Artificial Intelligence Statement** Artificial intelligence tools were not used in the production of this work.

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