DOCTOR OF PHILOSOPHY

A neurophysiological investigation of mindfulness training in secondary schools: Modifications in cognitive control and emotion processing in adolescents

Sanger, Kevanne

Award date:
2016

Awarding institution:
Bangor University

PRIFYSGOL
BANGOR
UNIVERSITY

A neurophysiological investigation of mindfulness training in secondary schools: Modifications in cognitive control and emotion processing in adolescents

Kevanne Louise Sanger

School of Psychology
Bangor University

May 2016

Thesis submitted to the School of Psychology, Bangor University in partial fulfilment of the requirements for the degree of Doctor of Philosophy

Declaration and Consent

Details of the Work

I hereby agree to deposit the following item in the digital repository maintained by Bangor University and/or in any other repository authorized for use by Bangor University.

Author Name: Kevanne Sanger

Title: A neurophysiological investigation of mindfulness training in secondary schools: Modifications in cognitive control and emotion processing in adolescents

Supervisor/Department: Dr. Dusana Dorjee School of Psychology

Funding body (if any): Economic and Social Research Council

Qualification/Degree obtained: PhD

This item is a product of my own research endeavours and is covered by the agreement below in which the item is referred to as "the Work". It is identical in content to that deposited in the Library, subject to point 4 below.

Non-exclusive Rights

Rights granted to the digital repository through this agreement are entirely non-exclusive. I am free to publish the Work in its present version or future versions elsewhere.

I agree that Bangor University may electronically store, copy or translate the Work to any approved medium or format for the purpose of future preservation and accessibility. Bangor University is not under any obligation to reproduce or display the Work in the same formats or resolutions in which it was originally deposited.

Bangor University Digital Repository

I understand that work deposited in the digital repository will be accessible to a wide variety of people and institutions, including automated agents and search engines via the World Wide Web.

I understand that once the Work is deposited, the item and its metadata may be incorporated into public access catalogues or services, national databases of electronic theses and dissertations such as the British Library's EThOS or any service provided by the National Library of Wales.

I understand that the Work may be made available via the National Library of Wales Online Electronic Theses Service under the declared terms and conditions of use (http://www.llgc.org.uk/index.php?id=4676). I agree that as part of this service the National Library of Wales may electronically store, copy or convert the Work to any approved medium or format for the purpose of future preservation and accessibility. The National Library of Wales is not under any obligation to reproduce or display the Work in the same formats or resolutions in which it was originally deposited.

Statement 1:

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree unless as agreed by the University for approved dual awards.

Signed ………………………………………….. (Candidate)

Date ……………………………………………..

Statement 2:

This thesis is the result of my own investigations, except where otherwise stated. Where correction services have been used, the extent and nature of the correction is clearly marked in a footnote(s).

All other sources are acknowledged by footnotes and/or a bibliography.

Signed …………………………………………. (Candidate)

Date …………………………………………….

Statement 3:

I hereby give consent for my thesis, if accepted, to be available for photocopying, for inter-library loan and for electronic repositories, and for the title and summary to be made available to outside organisations.

Signed …………………………………………. (Candidate)

Date …………………………………………….

<u>Statement 4</u>:

Choose **<u>one</u>** of the following options

a)	I agree to deposit an electronic copy of my thesis (the Work) in the Bangor University (BU) Institutional Digital Repository, the British Library ETHOS system, and/or in any other repository authorized for use by Bangor University and where necessary have gained the required permissions for the use of third party material.	
b)	I agree to deposit an electronic copy of my thesis (the Work) in the Bangor University (BU) Institutional Digital Repository, the British Library ETHOS system, and/or in any other repository authorized for use by Bangor University when the approved **bar on access** has been lifted.	
c)	I agree to submit my thesis (the Work) electronically via Bangor University's e-submission system, however I **opt-out** of the electronic deposit to the Bangor University (BU) Institutional Digital Repository, the British Library ETHOS system, and/or in any other repository authorized for use by Bangor University, due to lack of permissions for use of third party material.	

Options B should only be used if a bar on access has been approved by the University.

In addition to the above I also agree to the following:

1. That I am the author or have the authority of the author(s) to make this agreement and do hereby give Bangor University the right to make available the Work in the way described above.

2. That the electronic copy of the Work deposited in the digital repository and covered by this agreement, is identical in content to the paper copy of the Work deposited in the Bangor University Library, subject to point 4 below.

3. That I have exercised reasonable care to ensure that the Work is original and, to the best of my knowledge, does not breach any laws – including those relating to defamation, libel and copyright.

4. That I have, in instances where the intellectual property of other authors or copyright holders is included in the Work, and where appropriate, gained explicit permission for the inclusion of that material in the Work, and in the electronic form of the Work as accessed through the open access digital repository, *or* that I have identified and removed that material for which adequate and appropriate permission has not been obtained and which will be inaccessible via the digital repository.

5. That Bangor University does not hold any obligation to take legal action on behalf of the Depositor, or other rights holders, in the event of a breach of intellectual property rights, or any other right, in the material deposited.

6. That I will indemnify and keep indemnified Bangor University and the National Library of Wales from and against any loss, liability, claim or damage, including without limitation any related legal fees and court costs (on a full indemnity bases), related to any breach by myself of any term of this agreement.

Signature: ………………………………………………………… Date : …………………………

Acknowledgements

I would like to use this opportunity to thank my examiners for taking time out of their busy schedules, and using up valuable ink / pencil supplies, in order to grade this thesis and help me bring this piece of research to fruition. I also want to thank my supervisor and second supervisor, Dusana and Guillaume, for believing me capable of taking on the exciting ideas they had regarding this project and allowing me to go on my merry way down the *mindfulness for teenagers* rabbit-hole. It's been really fun, and I've learnt so much from both of you.

To my fellow 'mindfulness nymphs' Bekah and Shelby, I couldn't have wished for two better office mates and research companions. I could say a lot more, but it would really just be emotional waffle. Thanks also to my extended research family – Christopher Saville for being my guide, Amy Hulson-Jones for recommending I apply for this PhD in the first place, and Lowri Hadden and Justine Walker for being such good 'academic ladies who lunch'. Thanks also to everyone who let me crash at their pads around Bangor when I needed to work late, I owe you so many cups of tea!

Thank you to Sarah Silverton who gave up so much of her time in order get this project off the ground, deliver the training, and offer her extensive wisdom, always with a smile I may add. And thank you to the schools and students who threw themselves into the mindfulness programme and taught me a lot about current school life. You all work so hard, and I hope this helped just a little.

And finally thank you to my family and wonderful fiancé Simon. You've always grounded me, taken care of me, and bought me pizza when I really needed it. I love you all.

Summary

Over the last decade an increasing number of studies have investigated the impact of mindfulness-based training on young people’s well-being and cognitive performance. There has also been an upsurge of interest from educators and policy makers given the potential of mindfulness training to enhance well-being, which is becoming a key area of health and education policy change. Despite this keen interest, our understanding of the neurocognitive mechanisms underlying mindfulness from a developmental perspective is limited. Nevertheless, such understanding could help guide further research and implementation efforts within education. To that end, this project aimed to discuss and evaluate a mindfulness-based training programme for older adolescents who are at a sensitive period of psychological development, both from a neurodevelopmental and clinical mental health perspective.

The first three chapters of this thesis provide its theoretical grounding, including an overview of the current state of adolescent well-being, a review of developmental and neuroscientific mindfulness intervention research, and introduces electroencephalographic methodology. Chapters Four and Five then outline the longitudinal mindfulness intervention studies with 16-18 year old students following a non-randomised wait-list control design. The findings indicated that an 8-week mindfulness programme can result in enhanced attention inhibition for task-irrelevant stimuli (indexed by more a negative N200 event-related potential [ERP]) and sustained attention to emotional faces (marked by maintained P3b positivity over time). These ERP modifications were supported by converging evidence from self-report measures – increases in metacognition and well-being, as well as high levels of course acceptability. The potential ramifications of these findings are discussed further in Chapters Six and Seven, including the broader implications for further developmental research on mindfulness, and well-being policy in schools. In conclusion, mindfulness-based training in schools may facilitate specific neural maturation processes in older adolescents, particularly within the frontal lobe regions associated with cognitive control, which could positively impact their learning and emotion regulation skills.

Table of Contents

Chapter One – An introduction to Mindfulness-Based Interventions

The term 'mindfulness' originates in Buddhism, and was first translated from the Pali word 'sati' in 1921, alluding to a state of awareness, attention, and remembering (Siegel, Germer & Olendzki, 2008). The conceptualisation of mindfulness as an active process also appears inherent in current operational models of nonspiritual mindfulness, although it is important to highlight that there are still many philosophical differences between western secular mindfulness and the more traditional Buddhist approaches. Bishop et al. (2004) proposed a two-component model of mindfulness, involving 'self-regulation of attention' (maintained on immediate experience) and 'attitudinal orientation' (curiosity, openness, and acceptance). They described mindfulness as a form of mental training that develops a reflective rather than reflexive mode of responding to internal and external events. Shapiro, Carlson, Astin, and Freedman (2006) later extended the model to include a third axiom: intention, in addition to attention and attitude (IAA). They refer to Jon Kabat-Zinn's description of mindfulness to explain their three axioms *"paying attention (Attention) in a particular way (Attitude) on purpose (Intention), in the present moment, and non-judgementally"* (Kabat-Zinn, 1994, p.4).

The beginning of mainstream mindfulness-based interventions are attributed to Jon Kabat-Zinn's work starting in 1979 at the University of Massachusetts Medical Centre. Ten-week group courses, instructing people in secular meditation-based practices, were offered to patients with chronic conditions, e.g. chronic pain, arthritis, cancer, and psoriasis. The aim of these sessions was to help patients relate to their pain or suffering in a different way. Mindfulness was used to teach them to accept what could not be changed by traditional medicine, and to approach life moment by moment with a 'beginners mind' that did not judge their experiences based on established negative schemas, or dismiss its positive aspects. The preliminary research studying the efficacy of these interventions was encouraging, showing health benefits for patients with chronic pain (Kabat-Zinn, Lipworth, & Burney, 1985) and psoriasis (Kabat-Zinn et al., 1988). This led to the development of Mindfulness-Based Stress Reduction (MBSR; Kabat-Zinn, 1990), now an established clinical intervention programme. MBSR is typically offered in an eight-week format with weekly sessions, plus a day of silent meditation-based practice. Whilst the client focus of MBSR has been very broad since its beginnings, other derivative programmes have been developed, targeting specific clinical populations. The most notable adaptation is Mindfulness-Based Cognitive Therapy (MBCT; Segal, Williams, & Teasdale, 2002), designed to cater for individuals with major recurrent depression. Based on research evidence supporting MBSR's efficacy in preventing depression relapse (Ramel, Goldin, Carmona, & McQuaid, 2004; Reibel, Greeson, Brainard, & Rosenzweig, 2001), as well as several RCTs reporting the benefits of MBCT for recurrent depression (Collip et al., 2013; Kuyken et al., 2015; Teasdale et al., 2000), the National Institute for Health and Care Excellence (NICE) has highlighted MBCT as a priority for treatment implementation for those with three or more episodes of recurrent major depression (NICE, 2009).

Given the growing prevalence of mental ill health in the West, with one in four UK adults now thought to experience mental illness at some point in their lifetime (Health and Social Care Information Centre, 2009), mindfulness-based interventions are starting to be researched as possible preventative methods, and as a way of enhancing resilience and well-being. A recent meta-analysis studied the efficacy of MBSR for non-clinical samples, reporting small to medium effect sizes for improvements in well-being, positive emotions, and emotion regulation, as well as decreases in stress, negative emotions, and anxiety (Eberth & Sedlmeier, 2012). These changes are smaller than the impact observed in clinical meta-analyses, which note MBSR and MBCT as having moderate to large effects on depression and anxiety symptoms (Hofmann, Sawyer, Witt, & Oh, 2010). The difference in effect sizes between clinical and non-clinical samples is likely due to a qualitative difference in their motivation to practice, and potentially the reduced opportunity to engage in daily practice for non-clinical participants. However, these effects do show that mindfulness practices can impact on general health and well-being, and potentially optimise psychological health.

The impact of mindfulness-based training for adolescents

All the evidence discussed thus far has involved adult populations, reflecting the general trend within the field. However, the suggested benefits of mindfulness-based programmes have more recently encouraged neurodevelopmental researchers, as well as teachers, politicians, and education policy makers to consider the potential of mindfulness training for young people. This is particularly relevant given the increasing rates of mental health problems in adolescents (Office of National Statistics [ONS], 2015) and increasing emphasis of bringing well-being skills into the school curriculum, which is one of the key proposals from the 2015 Children and Young People's Mental Health and Well-being Taskforce (Department of Health, 2015). The relevance of mindfulness for this age group was recently highlighted in an all-party governmental report 'Mindful Nation UK' (Mindfulness All-Party Parliamentary Group [MAPPG], 2015), advising that mindfulness be introduced to promote resilience in schools. What follows is an outline of some of the evidence for why mental health prevention is relevant for young people, particularly in a UK context, and the research that suggests mindfulness-based programmes could benefit them.

The UNICEF Innoncenti Report Card 7 (2007) found that the UK scored in the bottom third for child well-being in developed countries, something which has since been supported by other foundations research (Children's Society, 2015), highlighting an enduring concern. Together with the growing rates of adult mental ill health, these statistics encouraged the UK government to invest more in national well-being (Government Office for Science, 2008), and it commissioned the New Economics Foundation to design the '5 things per day to stay sane' report (Foresight, 2008). One of these recommendations was to ‘Take Notice’ of events inside and all around us, a suggestion closely related to the practice of mindfulness. The fostering of resilience in children and adolescents, as a preventative measure to enhance wellbeing, has also been advocated in later governmental reports (Gutman, Brown, Akerman, & Obolenskaya, 2010).

Reducing levels of denial and avoidant coping behaviours have been shown to promote resilience (Feder, Nestler, & Charney, 2009), and mindfulness is known to cultivate adaptive, experiential acceptance (Baer, Fischer, & Huss, 2005). This supports the potential of mindfulness practice to facilitate emotion regulation in young people, who are strongly effected by their experiences (Davidson et al., 2012). Furthermore, such training would enable young people to more effectively ‘let go’ of unhelpful emotions like anxiety, which can interfere with their working memory, executive control, and attention processing (Ernst, Pine, & Hardin, 2006; Shackman, Maxwell, McMenamin, Greischar, & Davidson, 2011), as well be detrimental to their well-being. We are currently witnessing the declining mental health of our young people, with approximately 10% of UK 5-16 year olds living with a diagnosed mental illness (ONS, 2005), 13.5% of 10-15 year olds reporting high levels of distress as rated by the Strengths and Difficulties Questionnaire (ONS, 2016), and the transition from childhood to adolescence is known to be a particularly sensitive period for well-being, with 2.4% of 10-year olds reporting low life satisfaction in comparison to 8.2% of 16-year olds (Children’s Society, 2015). Moreover, the Crime Survey of England and Wales 2010/11 (ONS, 2012) reported that the large majority of volitional or threatening experiences that youths enact or experience occur at school (56% of violence, and 46% of theft). The education system would therefore seem the ideal place to address issues like compassion, well-being, and motivation. Added pressure is being placed on schools to deliver a more holistic education (Department of Health, 2015). So mindfulness, with its experiential focus on developing self-regulation of attention, mental health, and emotion regulation (Biegal, Brown, Shapiro, & Schubert 2009; Foret et al., 2012), as well as strong links to the enhancement of well-being (Huppert & Johnson, 2010; Jennings, Snowberg, Coccia & Greenberg, 2011) could become an effective tool within this context; contributing to good mental health, and facilitating a healthy learning environment.

Bradshaw, Goldweber, Fishbein, and Greenberg (2012) evaluated the theoretical aspects of developmental neuroscience that could help shape school-based preventative interventions, including our understanding of reward pathways, stress, social-cognitive mechanisms, and executive functioning. They concluded that mindfulness was one of the more promising avenues that could help promote regulatory processes if taught within the education system. Wass, Scerif, and Johnson (2012) have also advocated that cognitive training interventions should be administered to younger audiences in order to generalise any improvements across domains, given the less specialised nature of children's developing neural networks. However, Greenberg and Harris (2012) warn that considerations need to be taken when adapting programmes for younger children, who will have limited attention spans and metacognitive abilities. Moreover, results from mindfulness interventions with younger children have so far been limited. In adults, meta-analysis reports are concluding that most interventions, typically an 8-week course in MBSR (Kabat-Zinn, 1990), MBCT (Segal et al., 2002), or a mindfulness retreat, result in medium to high effect sizes on various measures of mindfulness, well-being, and negative affect (Grossman Niemann, Schmidt, & Walach, 2004; Hofmann et al., 2010). However preliminary studies with children, including two systematic reviews, report only low to moderate effects (Burke, 2010; Black et al., 2009; Flook et al., 2010). In weighing the benefits of delivering cognitive training to those with more neuroplasticity against the assurance of implementing a trial with participants who can fully engage, the adolescent age group would therefore appear the most suitable.

Preliminary results from adolescent training studies are encouraging enough to show that the area deserves rigorous investigation. Broderick and Metz (2009) conducted a non-randomised study comparing high school senior females educated in the 'Learning 2 Breathe' programme against a small control group of younger girls. The intervention group showed reductions in self-reported negative affect and tiredness, as well as increased self-acceptance, relaxation, and emotion regulation. Bennet and Dorjee (2015), using a self-selected sample of 16-18 year olds, found that an 8-week MBSR course was associated with reductions in medical absences from school by 3-month follow-up, and improved academic attainment compared to controls. And Foret et al. (2012) trained 11th grade students (approx. 16-17 years) in a 4-week relaxation curriculum including mindfulness and breathing meditation. After the intervention, pupils reported significant improvements to their stress management skills, perceived stress, and state anxiety. Interestingly, the authors found these promising results in a group where 80% either never logged on to the website for their home practice or only completed it once. By contrast, previous studies with younger pupils like Huppert and Johnson (2010), found that home practice strongly impacted on positive outcomes.

More research has been conducted with adolescent clinical populations; Biegal et al. (2009) for example, reported on a randomized clinical trial (RCT) with young people receiving community mental health support. The eight-week MBSR course for adolescents significantly improved their levels of anxiety, perceived stress, and depression by 3-month follow-up. Furthermore, relative to the ‘treatment as usual’ (TAU) control group, MBSR participants showed diagnostic improvement as rated by a study-blinded clinician. In addition, Bögels, Hoogstaad, van Dun, de Schutter, and Restifo (2008) reported a pilot study of adolescents with externalising disorders e.g. oppositional-defiant / conduct disorder, ADHD, who underwent MBCT training. After the 8-week course, speed and accuracy measures of sustained attention (D2 test) showed significant increases. Improvements were also found in self-reported goals, behaviour, mindful awareness, and subjective happiness. Parental reports were also very positive, but caution must be taken given their investment in the trial. Finally, Sibinga et al. (2011) conducted a feasibility pilot with youths living with, or at risk of, human immunodeficiency virus (HIV). The 26 adolescents who completed the MBSR course showed significant reductions in their levels of hostility and emotional discomfort. This study also included qualitative interviews, a method that is surprisingly infrequent in mindfulness intervention research with adolescents, particularly as such exploratory methods can reveal new variables, mediators, or moderators not otherwise evaluated (Darbyshire, MacDougall, & Schiller, 2005). These interviews detailed personal improvements to their physical health, interpersonal relationships, school achievement, and stress reduction.

Published school-based mindfulness research has thus far only related to psychological and behavioural outcomes. The initial findings suggest potential for positive effects in adolescents, but research is yet to explain these results from a neurodevelopmental perspective. In considering the recommendations of Bradshaw et al. (2012) and the under-developed nature of the adolescent regulatory system (Romer, 2010), it would seem appropriate to investigate the underlying mechanisms of mindfulness in this population (Belsky, Bakermans-Kranenburg, &Van IJzendoorn, 2007). Such research could help guide the tailoring of future mindfulness programmes in schools and inform well-being policy, as is beginning to happen with reports like 'Mindful Nation' (MAPPG, 2015).

Neuroscientific research into mindfulness-based training effects

Mostly over the last decade, researchers have begun to investigate the neurocognitive mechanisms underlying the encouraging behavioural changes found after mindfulness training. Functional magnetic resonance imagining (*f*MRI) studies have shown that engaging in an eight-week mindfulness course can facilitate activation in the insular cortex, which is associated with sensory awareness (Farb, Segal, & Anderson, 2013), as well as the prefrontal cortex (PFC) and anterior cingulate cortex (ACC) when regulating emotional reactivity (Gard et al., 2012) or attention (Allen et al., 2012; Hölzel et al., 2007). Increased grey matter volume has also been noted in the hippocampus of long-term meditators (Hölzel et al., 2008), which is associated with the formulation and retrieval of declarative memories (Squire, 1992). Interestingly, mindfulness practice may also stimulate neural generation within the hippocampus (Hölzel et al., 2011; Luders, Toga, Lepore, & Gaser, 2009), thought to be an impact of enhanced emotion regulation skills. Mindfulness has been linked to reduced stress activation in the amygdala (Hölzel et al., 2010) and meditation practices more generally have been associated with interruption of the hypothalamic-pituitary-adrenal (HPA) axis (Newberg & Iversen, 2003), reducing cortisol levels that can cause hippocampal atrophy (Starkman et al., 1999). Moreover, mindfulness training in participants with social anxiety has shown a down-regulation of the amygdala (Goldin & Gross, 2010), and PFC when responding to negative self-beliefs (Goldin, Ziv, Jazaieri, Hahn & Gross, 2013), possibly indexing reductions in automatic reactivity to stress and automatic cognitive appraisal of negative stimuli within clinical samples.

Neural changes related to mindfulness practice have also been assessed using electroencephalography (EEG) indexes. Davidson et al. (2003) for example, found participants displayed more right-sided alpha asymmetry after MBSR, suggesting that mindfulness training can be associated with markers of approach-orientated behaviour and positive emotions. More investigations however, have used event-related potential (ERP) methodology, reporting improvements in attention and emotion-based processing. Of particular note are the modulations found in the N200, ERN (Error-Related Negativity), and P300 ERP components (Moore, Gruber, Derose, & Malinowski, 2012; Slagter et al., 2007; Teper & Inzlicht, 2013), which are believed to represent stimulus categorisation (Folstein & van Petten, 2008), executive attention and error monitoring (Gehring, Gross, Coles, Meyer, & Donchin, 1993), and goal-oriented information processing (Sutton, Braren, Zubin & John, 1965) respectively. The background to these components will be discussed in more detail in Chapters Two and Three.

Specifically, mindfulness training has been found to increase posterior N200 negativity (more negative amplitudes post-training) when participants completed the Stroop task, suggesting improved stimulus categorisation at the neural level (Moore et al., 2012). Teper and Inzlicht (2013) noted enhanced ERN amplitudes and less false alarms during a Stroop task in meditation practitioners with an average of three years' experience, indexing mindfulness-based advantages for executive attention control. And in terms of P300 modulation, Slagter et al. (2007) noted that mindfulness may improve the efficiency of attention processing; they reported less positive P300 (P3b) mean amplitudes post-training when completing an Attention-Blink task. The attention-blink task measures a participant's ability to detect two salient targets that occur less than 500 ms apart, among a string of other visual stimuli (Raymond, Shapiro, & Arnell, 1992). Less positive P3b was found for the first target, which was also associated with increased response accuracy for the second target, producing a smaller attention-blink. This was interpreted as mindfulness practice enabling participants to more efficiently allocate their attention – reduced attention demands in responding to the first target reserved more resources to detect the second target. These results suggest that mindfulness practice, which may enhance attention efficiency and executive control through it's training of the PFC and ACC (Allen et al., 2012), could be beneficial for those struggling with attention difficulties or ruminative thinking, or for general improvement of cognitive performance.

Mindfulness training's enhancements to attention control are also believed to have secondary benefits for emotion regulation, facilitating less automatic attention allocation when it would be maladaptive e.g. to negative self-statements (Goldin et al., 2013), as well as reducing rumination on negative thoughts or experiences (Jain et al., 2007). ERP studies of affective processing and emotion regulation have shown modulations to the ERN / error Positivity (Pe) complex, believed to index automatic error detection (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991) and the subsequent evaluation of that error (Overbeek, Nieuwenhuis, & Ridderinkhof, 2005) respectively. Specifically, it has been indicated that mindfulness meditation practice can enhance error monitoring without increasing its emotional salience. Teper and Inzlicht (2013) found that long-term meditators showed a more pronounced ERN, but that the Pe waveform did not differ from baseline. These changes were mediated by acceptance, suggesting that participants with greater acceptance also showed enhanced executive control, without change in markers of error-based judgement. The ERN is associated with an updating of working memory once a conflict between optimum and current behaviour is detected, indicating to the ACC that more on-task attention is required (Botvinick et al, 2001). If meditation practice can enhance an individual's ability to regulate attention without increasing error-related arousal (Teper & Inzlicht, 2013), and mindfulness training specifically can down-regulate stress reactivity from the amygdala (Goldin & Gross, 2010), it could be an effective technique for managing emotion, with implications for well-being and illness prevention in young people. In the next chapter I will introduce electroencephalography in more detail, and discuss the utility of event-related brain potentials (ERPs) in researching the neural effects of mindfulness training with adolescents.

References

Allen, M., Dietz, M., Blair, K. S., van Beek, M., Rees, G., Vestergaard-Poulsen, P., Lutz, A., & Roepstorff, A. (2012). Cognitive-affective neural plasticity following active-controlled mindfulness intervention. *The Journal of Neuroscience*, *32(44)*, 15601-15610.

Baer, R. A., Fischer, S., & Huss, D. B. (2005). Mindfulness and acceptance in the treatment of disordered eating. *Journal of Rational-Emotive and Cognitive-Behavior Therapy*, *23(4)*, 281-300.

Belsky, J., Bakermans-Kranenburg, M. J., & Van IJzendoorn, M. H. (2007). For better and for worse differential susceptibility to environmental influences. *Current Directions in Psychological Science*, *16(6)*, 300-304.

Bennett, K., & Dorjee, D. (2015). The impact of a mindfulness-based stress reduction course (MBSR) on well-being and academic attainment of sixth-form students. *Mindfulness, 7(1)*, 105-114.

Biegel, G. M., Brown, K. W., Shapiro, S. L., & Schubert, C. M. (2009). Mindfulness-based stress reduction for the treatment of adolescent psychiatric outpatients: A randomized clinical trial. *Journal of consulting and clinical psychology*, *77(5)*, 855-866.

Bishop, S. R., Lau, M., Shapiro, S., Carlson, L., Anderson, N. D., Carmody, J., Segal, Z. V., Abbey, S., Speca, M., Velting, D., & Devins, G. (2004). Mindfulness: A proposed operational definition. *Clinical psychology: Science and practice*, *11(3)*, 230-241.

Black, D. S., Milam, J., & Sussman, S. (2009). Sitting-meditation interventions among youth: A review of treatment efficacy. *Pediatrics*, *124(3)*, e532-e541.

Bögels, S., Hoogstad, B., van Dun, L., de Schutter, S., & Restifo, K. (2008). Mindfulness training for adolescents with externalizing disorders and their parents. *Behavioural and Cognitive Psychotherapy*, *36(02)*, 193-209.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological review*, *108(3)*, 624-652.

Bradshaw, C. P., Goldweber, A., Fishbein, D., & Greenberg, M. T. (2012). Infusing developmental neuroscience into school-based preventive interventions: Implications and future directions. *Journal of Adolescent Health*, *51(2)*, S41-S47.

Broderick, P. C., & Metz, S. (2009). Learning to BREATHE: A pilot trial of a mindfulness curriculum for adolescents. *Advances in school mental health promotion*, *2(1)*, 35-46.

Burke, C. A. (2010). Mindfulness-based approaches with children and adolescents: A preliminary review of current research in an emergent field. *Journal of Child and Family Studies*, *19(2)*, 133-144.

Children's Society. (2015). *The Good Childhood Report 2015. The subjective well-being of children in the UK*. University of York. Retrieved from http://www.childrenssociety.org.uk/what-we-do/research/well-being

Collip, D., Geschwind, N., Peeters, F., Myin-Germeys, I., van Os, J., & Wichers, M. (2013). Putting a hold on the downward spiral of paranoia in the social world: A randomized controlled trial of mindfulness-based cognitive therapy in individuals with a history of depression. *PloS one*, *8(6)*, e66747.

Darbyshire, P., MacDougall, C., & Schiller, W. (2005). Multiple methods in qualitative research with children: more insight or just more?. *Qualitative research*, *5(4)*, 417-436.

Davidson, R. J., Dunne, J., Eccles, J. S., Engle, A., Greenberg, M., Jennings, P., ... Vago, D. The Mind and Life Education Research Network: MLERN (2012). Contemplative practices and mental training: Prospects for American education. *Child Development Perspectives, 6*, 146–153.

Davidson, R. J., Kabat-Zinn, J., Schumacher, J., Rosenkranz, M., Muller, D., Santorelli, S. F., ... & Sheridan, J. F. (2003). Alterations in brain and immune function produced by mindfulness meditation. *Psychosomatic medicine*, *65(4)*, 564-570.

Department of Health. (2015). *Future in Mind: promoting, protecting and improving our children and young people's mental health and wellbeing.* Retrieved from https://www.gov.uk/government/publications/improving-mental-health-services-for-young-people

Eberth, J., & Sedlmeier, P. (2012). The effects of mindfulness meditation: a meta-analysis. *Mindfulness*, *3(3)*, 174-189.

Ernst, M., Pine, D. S., & Hardin, M. (2006). Triadic model of the neurobiology of motivated behavior in adolescence. *Psychological medicine*, *36(03)*, 299-312.

Falkenstein, M., Hohnsbein, J., Hoormann, J., & Blanke, L. (1991). Effects of crossmodal divided attention on late ERP components. II. Error processing in choice reaction tasks. *Electroencephalography and clinical neurophysiology*, *78(6)*, 447-455.

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (1999). ERP components in Go/Nogo tasks and their relation to inhibition. *Acta Psychologica*, *101(2)*, 267-291.

Farb, N. A., Segal, Z. V., & Anderson, A. K. (2013). Attentional modulation of primary interoceptive and exteroceptive cortices. *Cerebral cortex*, *23(1)*, 114-126.

Feder, A., Nestler, E. J., & Charney, D. S. (2009). Psychobiology and molecular genetics of resilience. *Nature Reviews Neuroscience*, *10(6)*, 446-457.

Flook, L., Smalley, S. L., Kitil, M. J., Galla, B. M., Kaiser-Greenland, S., Locke, J., Ishijima, E., & Kasari, C. (2010). Effects of mindful awareness practices on executive functions in elementary school children. *Journal of Applied School Psychology*, *26(1)*, 70-95.

Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: a review. *Psychophysiology*, *45(1)*, 152-170.

Foret, M. M., Scult, M., Wilcher, M., Chudnofsky, R., Malloy, L., Hasheminejad, N., & Park, E. R. (2012). Integrating a relaxation response-based curriculum into a public high school in Massachusetts. *Journal of adolescence*, *35(2)*, 325-332.

Foresight. The Government Office for Science. (2008). *Foresight Mental Capital and Wellbeing Project: Final Project Report.* Retrieved from http://www.bis.gov.uk/foresight/our-work/projects/current-projects/mental-capitaland-wellbeing

Gard, T., Hölzel, B. K., Sack, A. T., Hempel, H., Lazar, S. W., Vaitl, D., & Ott, U. (2012). Pain attenuation through mindfulness is associated with decreased cognitive control and increased sensory processing in the brain. *Cerebral Cortex*, *22(11)*, 2692-2702.

Gehring, W. J., Goss, B., Coles, M. G., Meyer, D. E., & Donchin, E. (1993). A neural system for error detection and compensation. *Psychological science*, *4(6)*, 385-390.

Goldin, P. R., & Gross, J. J. (2010). Effects of mindfulness-based stress reduction (MBSR) on emotion regulation in social anxiety disorder. *Emotion*, *10(1)*, 83-91.

Goldin, P., Ziv, M., Jazaieri, H., Hahn, K., & Gross, J. J. (2013). MBSR vs aerobic exercise in social anxiety: fMRI of emotion regulation of negative self-beliefs. *Social Cognitive and Affective Neuroscience*, *8(1)*, 65-72.

Government Office for Science. (2008). *Mental capital and wellbeing: making the most of ourselves in the 21st century. Final Project Report.* Retrieved from https://www.gov.uk/government/publications/mental-capital-and-wellbeing-making-the-most-of-ourselves-in-the-21st-century

Greenberg, M. T., & Harris, A. R. (2012). Nurturing mindfulness in children and youth: Current state of research. *Child Development Perspectives*, *6(2)*, 161-166.

Grossman, P., Niemann, L., Schmidt, S., & Walach, H. (2004). Mindfulness-based stress reduction and health benefits: A meta-analysis. *Journal of psychosomatic research*, *57(1)*, 35-43.

Gutman, L., Brown, J., Akerman, R., & Obolenskaya, P. (2010). *Change in wellbeing from childhood to adolescence: risk and resilience* [Wider Benefits of Learning Research Report No. 34].

Health and Social Care Information Centre. (2009). *Adult psychiatric morbidity in England, 2007 – Results of a household survey.* University of Leicester. Retrieved from http://www.hscic.gov.uk/pubs/psychiatricmorbidity07

Hofmann, S. G., Sawyer, A. T., Witt, A. A., & Oh, D. (2010). The effect of mindfulness-based therapy on anxiety and depression: A meta-analytic review. *Journal of consulting and clinical psychology*, *78(2)*, 169-183.

Hölzel, B. K., Carmody, J., Evans, K. C., Hoge, E. A., Dusek, J. A., Morgan, L., Pitman, R. K., & Lazar, S. W. (2010). Stress reduction correlates with structural changes in the amygdala. *Social, Cognitive, and Affective Neuroscience*, *5(1)*, 11-17.

Hölzel, B. K., Ott, U., Gard, T., Hempel, H., Weygandt, M., Morgen, K., & Vaitl, D. (2008). Investigation of mindfulness meditation practitioners with voxel-based morphometry. *Social Cognitive & Affective Neuroscience, 3(1)*, 55-61.

Hölzel, B. K., Ott, U., Hempel, H., Hackl, A., Wolf, K., Stark, R., & Vaitl, D. (2007). Differential engagement of anterior cingulate and adjacent medial frontal cortex in adept meditators and non-meditators. *Neuroscience letters*, *421(1)*, 16-21.

Hölzel, B. K., Carmody, J., Vangel, M., Congleton, C., Yerramsetti, S. M., Gard, T., & Lazar, S. W. (2011). Mindfulness practice leads to increases in regional brain gray matter density. *Psychiatry Research: Neuroimaging*, *191(1)*, 36-43.

Huppert, F. A., & Johnson, D. M. (2010). A controlled trial of mindfulness training in schools: The importance of practice for an impact on well-being. *The Journal of Positive Psychology*, *5(4)*, 264-274.

Jain, S., Shapiro, S. L., Swanick, S., Roesch, S. C., Mills, P. J., Bell, I., & Schwartz, G. E. (2007). A randomized controlled trial of mindfulness meditation versus relaxation training: effects on distress, positive states of mind, rumination, and distraction. *Annals of behavioral medicine*, *33(1)*, 11-21.

Jennings, P. A., Snowberg, K. E., Coccia, M. A., & Greenberg, M. T. (2011). Improving classroom learning environments by cultivating awareness and resilience in education (CARE): Results of two pilot studies. *The Journal of Classroom Interaction*, 37-48.

Kabat-Zinn, J. (1990). Full catastrophe living: Using the wisdom of your body and mind to face stress, pain, and illness. New York: Delacorte.

Kabat-Zinn, J. (1994). Wherever you go, there you are: Mindfulness meditation in everyday life. New York, NY: Hyperion.

Kabat-Zinn, J., Lipworth, L., & Burney, R. (1985). The clinical use of mindfulness meditation for the self-regulation of chronic pain. *Journal of behavioral medicine*, *8(2)*, 163-190.

Kabat-Zinn, J., Wheeler, E., Light, T., Skillings, A., Scharf, M. J., Cropley, T. G., Hosmer, D., & Bernhard, J. D. (1998). Influence of a mindfulness meditation-based stress reduction intervention on rates of skin clearing in patients with moderate to severe psoriasis undergoing photo therapy (UVB) and photochemotherapy (PUVA). *Psychosomatic medicine*, *60(5)*, 625-632.

Kuyken, W., Hayes, R., Barrett, B., Byng, R., Dalgleish, T., Kessler, D., … & Byford, S. (2015). Effectiveness and cost-effectiveness of mindfulness-based cognitive therapy compared with maintenance antidepressant treatment in the prevention of depressive relapse or recurrence (PREVENT): a randomised controlled trial. *The Lancet*, *386(9988)*, 63-73.

Luders, E., Toga, A. W., Lepore, N., & Gaser, C. (2009). The underlying anatomical correlates of long-term meditation: larger hippocampal and frontal volumes of gray matter. *Neuroimage*, *45(3)*, 672-678.

Mindfulness All-Party Parliamentary Group. (2015). Mindful Nation UK. Retrieved from http://www.themindfulnessinitiative.org.uk/

Moore, A. W., Gruber, T., Derose, J., & Malinowski, P. (2012). Regular, brief mindfulness meditation practice improves electrophysiological markers of attentional control. *Frontiers in Human Neuroscience*, *6*, 18.

National Institute of Health and Clinical Excellence. (2009). Depression in adults: recognition and management (update) (Clinical Guideline No. 90). Retrieved from http://www.nice.org.uk/guidance/CG90

Newberg, A. B., & Iversen, J. (2003). The neural basis of the complex mental task of meditation: neurotransmitter and neurochemical considerations. *Medical hypotheses*, *61(2)*, 282-291.

Office for National Statistics. (2005). *Mental Health of Children and Young People in Great Britain: 2004*. Retrieved from https://www.mentalhealth.org.uk/statistics/mental-health-statistics-children-and-young-people#sthash.NhOrGw0U.dpuf

Office of National Statistics. (2012). *Measuring National Well-Being – Children's Well-being, 2012*. Retrieved from http://www.ons.gov.uk/ons/rel/wellbeing/measuring-national-well-being/measuring-children-s-well-being/art-measuring-children-s-well-being.html

Office of National Statistics. (2015). *Insights into children's mental health and well-being*. Retrieved from http://www.ons.gov.uk/ons/rel/wellbeing/measuring-national-well-being/children-and-young-people-s-well-being-in-the-uk--october-2015/art-insights-into-children-s-mental-health-and-well-being.html

Office of National Statistics. (2016). *Measuring national well-being: Life in the UK: 2016*. Retrieved from http://www.ons.gov.uk/peoplepopulationandcommunity/wellbeing/articles/measuringnationalwellbeing/2016#childrens-well-being

Overbeek, T. J., Nieuwenhuis, S., & Ridderinkhof, K. R. (2005). Dissociable components of error processing: on the functional significance of the Pe vis-à-vis the ERN/Ne. *Journal of Psychophysiology*, *19(4)*, 319-329.

Ramel, W., Goldin, P. R., Carmona, P. E., & McQuaid, J. R. (2004). The effects of mindfulness meditation on cognitive processes and affect in patients with past depression. *Cognitive therapy and research*, *28(4)*, 433-455.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of experimental psychology: Human perception and performance*, *18(3)*, 849-860.

Reibel, D. K., Greeson, J. M., Brainard, G. C., & Rosenzweig, S. (2001). Mindfulness-based stress reduction and health-related quality of life in a heterogeneous patient population. *General hospital psychiatry*, *23(4)*, 183-192.

Romer, D. (2010). Adolescent risk taking, impulsivity, and brain development: Implications for prevention. *Developmental psychobiology*, *52(3)*, 263-276.

Segal, Z., Williams, J. M. G., & Teasdale, J. D. (2002). Mindfulness- based cognitive therapy for depression: A new approach to relapse prevention. New York, NY: Guilford Press.

Sibinga, E. M., Kerrigan, D., Stewart, M., Johnson, K., Magyari, T., & Ellen, J. M. (2011). Mindfulness based stress reduction for urban youth. *The Journal of Alternative and Complementary Medicine*, *17(3)*, 213-218.

Siegel, R. D., Germer, C. K., & Olendzki, A. (2009). Mindfulness: What is it? Where did it come from? In *Clinical handbook of mindfulness* (pp. 17-35). Springer New York.

Shackman, A. J., Maxwell, J. S., McMenamin, B. W., Greischar, L. L., & Davidson, R. J. (2011). Stress potentiates early and attenuates late stages of visual processing. *The Journal of Neuroscience*, *31(3)*, 1156-1161.

Shapiro, S. L., Carlson, L. E., Astin, J. A., & Freedman, B. (2006). Mechanisms of mindfulness. *Journal of clinical psychology*, *62(3)*, 373-386.

Slagter, H. A., Lutz, A., Greischar, L. L., Francis, A. D., Nieuwenhuis, S., Davis, J. M., & Davidson, R. J. (2007). Mental training affects distribution of limited brain resources. *PLoS Biology, 5(6)*, 1228-1235.

Squire, L. R. (1992). Declarative and nondeclarative memory: Multiple brain systems supporting learning and memory. *Journal of Cognitive Neuroscience*, *4(3)*, 232-243.

Starkman, M. N., Giordani, B., Gebarski, S. S., Berent, S., Schork, M. A., & Schteingart, D. E. (1999). Decrease in cortisol reverses human hippocampal atrophy following treatment of Cushing’s disease. *Biological psychiatry*, *46(12)*, 1595-1602.

Sutton, S., Braren, M., Zubin, J., & John, E. R. (1965). Evoked-potential correlates of stimulus uncertainty. *Science*, *150(3700)*, 1187-1188.

Teasdale, J. D., Segal, Z. V., Williams, J. M. G., Ridgeway, V. A., Soulsby, J. M., & Lau, M. A. (2000). Prevention of relapse/recurrence in major depression by mindfulness-based cognitive therapy. *Journal of consulting and clinical psychology*, *68(4)*, 615-623.

Teper, R., & Inzlicht, M. (2013). Meditation, mindfulness and executive control: the importance of emotional acceptance and brain-based performance monitoring. *Social Cognitive and Affective Neuroscience*, *8(1)*, 85-92.

Unicef. (2007). *Child poverty in perspective: An overview of child well-being in rich countries* (No. inreca07/19). UNICEF Innocenti Research Centre.

Wass, S. V., Scerif, G., & Johnson, M. H. (2012). Training attentional control and working memory–Is younger, better? *Developmental Review*, *32*(4), 360-387.

Chapter Two – Electroencephalography and Event-Related Potentials

The discovery of electroencephalography (EEG) can be traced back to the research of Hans Berger in 1929. He noted that fluctuations in brain activity could be measured by recording the rhythmic changes in voltage across the scalp, with the use of electrodes and an amplifier to increase the signal. This was later confirmed by other physiology labs (Adrian & Matthews, 1934; Jasper & Carmichael, 1935), and with the development of more sophisticated computer technology in the 1960s, EEG became one of the most evidenced neuroscientific tools. The majority of psychological investigations, however, were interested not in baseline activity but online responses of the brain to a particular environment or stimulus within specific parameters. By recording the changes in scalp-recorded voltage while exposing a participant to a stimulus, you can directly assess the brains response to that specific event (Mohrmann, de Wit, Verhage, Neher, & Sørensen, 2010). Theoretically, these recordings can focus on one of two sources; the first is the action potential, a brief voltage spike that travels from the cell body to the axon terminal of a neuron. The second is the post-synaptic potential, when neurotransmitters bind to receptors on the post-synaptic neuron and trigger the opening and closing of ion channels, leading to a graded change in potential across the cell. However, the brevity of action potentials compared to post-synaptic potentials, which can last for hundreds of milliseconds as the neurotransmitters continue to be taken up into the post-synaptic cell, mean that the second source of activity (post-synaptic potentials) are the most reliably recorded by non-invasive scalp electrodes. The measurement of cumulative, post-synaptic potentials from electrodes attached to the scalp, while the brain responds to a particular stimulus gave rise to the electrophysiological markers called event-related potentials (ERPs). Originally these recordings were termed ‘evoked potentials’ but Herb Vaughn argued that this was not general enough a concept when what was recorded could be participant initiated or stimulus evoked. The term ‘event-related potential’ seemed better suited to explain the trajectory of various positive and negative voltage fluctuations across the time-line after the onset of a stimulus, with individual ERP components associated with a particular event or function and not just the initial ‘invoked’ stimulus (Vaughan, 1969).

The main strengths of ERP recordings are their temporal accuracy, and their ability to detect cumulative brain cell communication (Jasper & Carmichael, 1935) so researchers can directly infer that changes in ERP patterns index brain activity. This is advantageous over other neuroscientific techniques, where a secondary level of assumptions is required. In *f*MRI studies for example, interpretations rely on the assumption that brain activity can be inferred from associated changes in blood flow, as demonstrated by the blood-oxygen level dependant (BOLD) contrast (Ogawa, Lee, Kay, & Tank, 1990). However *f*MRI does have millimetre specific spatial accuracy across the brain, while EEG can only record voltage at the scalp and cannot clearly measure activity deep within the brain or even in certain parts of the cortex, e.g. amygdala or hippocampus. This is because voltage change can only be accurately taken from multiple neurons that summate and thus be recorded at close distance i.e. the scalp. Another condition is that the neural array needs to be spatially aligned, as is the case for most cortical pyramidal cells that run perpendicular to the surface of the cortex. If neuronal activity is not temporally synchronised, excitatory and inhibitory neurotransmitters are running in parallel, or if neurones are aligned at random orientations, then this can lead to a cancellation of cumulative signal across neural cells. Nevertheless, ERP measures are highly appropriate for answering questions relating to continuous, temporally accurate brain responses, in a non-invasive procedure. ERPs are also one of the oldest tools used in neuroscience, and the rich evidence base allows us to build on reliable experimental paradigms and make robust predictions for future testing.

EEG Set-Up

There are various methodological decisions to be made when setting up apparatus for the recording of ERPs. It is also important to note that this project was designed for testing within a school environment, and not the standard EEG lab with access to a faraday cage to limit electrical interference. A portable EEG system allowed us to bring all study equipment to our participants, and test the impact of a mindfulness-based training programme in a more ecologically valid way. The use of a portable system also made this project acceptable to potential schools, as the logistics of transporting study participants to the University for testing appointments within school hours would have been implausible.

It is important to identify which electrode sites to use as the ground and reference points within your EEG set-up. These additional electrodes are required as electrical activity is never measured at just one site, but the potential for current to pass from one point to another i.e. voltage. Therefore, reported ERP activity at a specific electrode corresponds to the potential between this active electrode and the ground electrode – a common reference point on the scalp. The laboratory of Cognitive Neuroscience of Mindfulness and Well Being, from which this project was based, uses FPz as the ground electrode; a standard ground site also used by Brown et al. (2013) and Dorjee et al. (2015). This allows us to confidently replicate and advance relevant literature, as well as build upon our own investigations within the 'Mindful Brain Lab'. However, the ground electrode will still detect static electricity within the environment, as well as reflect its own voltage, therefore we need to remove this interference if we are to accurately record the potential for the active electrode. Including a reference electrode, and using a differential amplifier within the EEG set-up can limit this problem. The reference electrode should have a voltage potential as close to 0 as possible, so for a standard 32-channel set-up (like that used in this project) the mastoid bone was an appropriate and convenient location (also used by Brown et al., 2013; Dorjee et al., 2015; Slagter et al., 2007; Smallwood, Beach, Schooler & Handy, 2008) – it can still be attached via the electrode cap but this bony protrusion behind the ear should not elicit any brain activity of its own. The differential amplifier will record the voltage from active electrode to ground, and the reference to ground. The voltage from reference to ground should be minimal, so anything recorded can be attributed to environmental interference and can then be subtracted from the active-ground voltage in order to gain a true representation of the electrode of interest. Relating to this project, the right mastoid (A2) has been used online, and then combined with the left mastoid (A1) offline using a linear derivation script in Neuroscan edit.

A central parameter impacting on both EEG data collection and data analysis is filtering EEG data. This can typically be done online using the amplifier to filter out extreme high and low frequency bands during recording, and later offline during the data-cleaning phase. There are two standard types of filter employed, the first is a low-pass filter that removes high frequency bands associated with environmental electrical noise, or muscular movements. Frequencies associated with these could interfere with the recording of brain activity voltages that are normally below 50Hz. In contrast, high-pass filters remove interference from low frequency bands, which are typically slow voltage shifts resulting from sweating that creates skin potentials, or gradual changes in the electrode impedance (resistance). Standard ranges of high pass and low pass are 0.01 – 200Hz online, and an offline filter with a zero shift low pass setting of 30Hz, 48dB/Oct slope is typically applied to derive ERP recordings. These ranges were suggested by Luck (2005), given that harsher filtering online cannot be removed later, and offline filtering (particularly high-pass) can temporally distort the waveform and lead to incorrect interpretation of ERPs, if not used cautiously.

Another concern in deriving ERPs is interference from motor and ocular artefacts. It is best to control for motor movements by explaining to participants the importance of remaining still during EEG recording (Picton et al., 2000). However, irregular blinking and occasional movements during EEG recording are inevitable and these artefacts are typically removed manually during the cleaning phase of analysis. An algorithm using ERP data processing software such as Neuroscan edit can also be employed to regress out typical eye-blinks, an important step in the cleaning process given that motor neuron voltages during eye-blinks can be especially disruptive to the signal pattern at frontal electrodes. In order to record ocular movements, additional electrodes should be placed around the eye. The current project measured eye blinks using two electrodes, one above and below the right eye. Recordings can be taken from both eyes, but this was deemed unnecessary given the time restraints of testing in schools and that ocular movements tend to operate in tandem. Further detail of the ERP method and data analysis will be included in the experimental chapters of this thesis.

Particular ERPs of interest

Past mindfulness training research in adults has identified modifications to the N200 and P300 event-related potentials (Moore, Gruber, Derose, & Malinowski, 2012; Slagter et al., 2007). Chapter three will go into more depth relating these components to adolescent brain development, but here I will briefly describe their characteristics.

The N200

One subcomponent of the negative N200 ERP component is the N2c (Folstein & van Petten, 2008), typically identified at posterior scalp sites in the visual modality, has a time-window of approx. 150-300ms, and has been coupled with the P3b in that it is believed to index target-related attention processing (Ritter, Simson, Vaughan, & Macht, 1982). It is a marker of stimulus categorisation, and has previously been found to increase in mean amplitude after 16-weeks of brief mindfulness practice in adults (Moore et al., 2012). This was interpreted as indexing improved sustained attention as more negative N2c was identified across all Stroop trials, suggesting increases in attention control and efficiency via enhanced feature identification.

Another subcomponent, termed the ‘No-Go N2’ by Falkenstein, Hoormann & Hohnsbein (1999) responds to non-target stimuli, and is typically maximal at electrode Fz

(Luck, 2005). It is considered a marker of response inhibition e.g. during an oddball or Go-NoGo task, and can be sensitive to priming (Kopp, Mattler, Goertz & Rist, 1996) and time pressure i.e. shorter response windows (Jodo & Kayama, 1992). Interpretation of this component was more recently updated to also indicate conflict monitoring (van Veen & Carter, 2002) e.g. during the Eriksen flanker task. The conflict theory of the frontal N2, generated by the caudal anterior cingulate cortex (ACC) (Barch, Braver, Sabb, & Noll, 2000; Botvinick, Braver, Barch, Carter & Cohen, 2001), suggests that more negative amplitudes are observed during high conflict situations; for example when an infrequent distractor, similar to a target stimulus, appears and the individual must inhibit a response.

Van Veen and Carter (2002) put forward evidence to suggest that the N2 and error-related negativity (ERN) are a marker of the same conflict identification process within the ACC. A more pronounced N2 indicates this conflict is responded to before a physical response is made (hence it tends to be found in correct trials), while the ERN marks conflict processing after a physical response (most pronounced in error trials, when the incorrect response was not inhibited promptly). Conflict processing is considered an automatic response of the ACC, as both N2 and ERN components have been detected during tasks with unconscious or unnoticed task conflict (Leuthold & Kopp, 1998; Nieuwenhuis, Ridderinkhof, Blom, Band & Kok, 2001). Research has theoretically linked frontal N2 and ERN components as indexing similar conflict monitoring processes (van Veen & Carter, 2002), affording us the opportunity to use meditation-linked ERN modifications as evidence that executive attention improvements may be measured by either ERP component. However, N2-marked enhancements would indicate improved conflict monitoring i.e. to non-target stimuli similar to targets (oddballs) before a response was made, and could index improved attentional efficiency and task accuracy. More negative frontal N2 amplitudes have also been noted in studies of dispositional mindfulness during an affective Go No-Go task (Quaglia, Goodman, &

Brown, 2016), supporting the prediction that similar benefits to executive attention might be found after mindfulness training.

Mindfulness practice effects on the ERN and cognitive improvements in executive attention (Teper & Inzlicht, 2013) also converges with findings in *f*MRI studies examining mindfulness-related changes (Allen et al., 2012; Brefczynski-Lewis, Lutz, & Davidson, 2004; Cahn & Polich, 2006; Hölzel et al., 2007), where increased activation in the ACC has been reported during meditation practice. Linking the training of this brain area, cognitive task improvements, and electrophysiological enhancement informs us about the mechanisms underlying behavioural benefits in attention and emotion regulation post-mindfulness training. It also opens up avenues for developmental research, considering the maturation of the ACC continues into the early 20s *(*Eshel et al., 2007; Velanova, Wheeler, & Luna, 2008). Children and adolescents' increased potential for neural development may allow for greater attention-based improvements following mindfulness training (Davidson et al., 2012; Oberle, Schonert-Reichl, Lawlor, & Thomson, 2012), if it does indeed enhance activity within this frontal brain structure, and train improved conflict monitoring and response inhibition. This argument will be discussed in further detail in Chapter Three.

The P300

The P300 is a family of positive amplitude components that manifest roughly between 300-500ms, but this is dependent on stimulus type, distinctiveness, cognitive load, and participant attention (Kok, 2001; Polich, 2007). The main subcomponent of interest in this thesis is the P3b component, with previous adult intervention research showing modifications after mindfulness practice (e.g. Slagter et al., 2007). It has a central-parietal distribution, and indicates target-based information categorisation, an updating of working memory, and the inhibition of information processing to other incoming stimuli (Polich, 2007; Sutton, Braren, Zubin, & John, 1965). The inhibition theory of the P3b may explain the findings of Slagter et al. (2007) discussed in Chapter One. Mindfulness training was associated with less positive P3b amplitudes to target-1 (T1) during correct trials of the Attention-Blink task. This suggests that sufficient attention was given to identify T1, but mindfulness practice may have trained participants to remain vigilant (‘alerting’ in the three attention network model: Posner & Petersen 1990; Petersen & Posner, 2012) and therefore not signalled for the inhibition of incoming stimulus processing once the current target was identified. By keeping attention resources alert to further targets, these participants were better able to identify and respond to target-2 (T2) within the attention-blink window.

There is still much debate about where the P3b is generated, but recent evidence would suggest that the temporal-parietal junction (TPJ) as well as prefrontal regions like the ACC, are involved (Kok, 2001; Polich, 2007). This is not surprising given the sophisticated nature of the processing P3b is likely to index; integration of activation in several brain areas would be necessary to categorise an incoming stimulus, incorporate this information into working memory, and inhibit the processing of further stimuli. Desimone, Miller, and Chelazzi (1994) attempted to describe the stimulus categorisation mechanism using evidence from primate studies. They suggested that the inferior-temporal cortex may work as an adaptive filter to narrow stimulus attention through familiarity, with prefrontal brain structures operating as a top-down modulator to bias the filter and focus on target-specific features.

As discussed in the previous section, mindfulness practice can enhance activation of the ACC, which may be marked by N2 or ERN modulation. Given the contribution of ACC to P3b generation, changes resulting from mindfulness practice may also be researched using paradigms sensitive to P3b responding, such as the Attention-Blink or oddball paradigms. Interestingly, MRI studies have also found mindfulness effects on the TPJ (Hölzel et al., 2011), another region thought to be involved in the generation of the P3b. Whole brain analysis of participants before and after a mindfulness-based stress reduction (MBSR) course found grey matter concentration increases in the TPJ, as well as left hippocampus, posterior cingulate cortex, and the cerebellum, compared to matched controls (Hölzel et al., 2011). The TPJ is thought to also be involved in social cognition and perspective taking, with its maturation ongoing until late adolescence (Crone, 2013; van den Bos, van Dijk, Westenberg, Rombouts, & Crone, 2011). This further supports the strong potential of studying P3b-invoking ERP paradigms in developmental mindfulness research, particularly considering the relative ease of EEG set-up, the portability of EEG recording equipment, and its low cost compared to neural imaging techniques.

Indeed, forensic research suggests that impaired TPJ and related P3b responses during childhood can be an early indicator of later criminal behaviour (Gao, Raine, Venables, & Mednick, 2013). This is also supported by developmental neuroscientific evidence showing that adolescents with severe anti-social behaviour can display impaired TPJ activity during socially-relevant decision making (van den Bos et al., 2014). Therefore, the impact of mindfulness training on TPJ activity and associated neural plasticity may be highly relevant to the developmental trajectories of younger people. It is possible that introducing mindfulness-based training to children and adolescents could enhance TPJ development, encouraging more sophisticated perspective taking and empathy, which could be recorded via the P3b component in a socially-relevant, affective testing paradigm.

The study of ERPs through specific testing paradigms can highlight training modulations at the neural level, and initial mindfulness intervention studies are already showing some promising results in terms of N200 and P3b-related change, amongst others. The utilisation of ERPs for mindfulness training research in a developmental context seems an exciting, and logical next step in terms of investigating how to best implement mindfulness interventions in order to maximise their potential to enhance attention and emotion regulation functioning in adolescents. This will be discussed in more depth in Chapter Three.

The oddball paradigm and its use in the current project

It has been mentioned above that both the No-Go N2 and P300 components can be measured using oddball and Go/No-Go paradigms. Indeed ERP reviews often use the oddball paradigm for prototypical examples of these components characterisation and functionality (e.g. Folstein & van Petten, 2008; Patel & Azzam, 2005; Polich, 2007), due to its simplicity, extensive evidence base, and it’s applicability across sensory modalities (Patel & Azzam, 2005). The current PhD project endeavoured to investigate the potential of a mindfulness training curriculum to impact on adolescent attention and emotion processing, using ERP markers to index relevant change. Given the exploratory nature of this research, a robust and easily interpretable paradigm like the oddball appeared appropriate. I will now outline the attention task used in the current project, described in Chapter Four, as an example to explain the particular design employed and how it maps onto specific ERP predictions.

The attention task followed a go/no-go oddball design with four simple shapes (three diamonds and one shape deviant non-target star). The standard frequent non-target stimulus (70% of trials) was a dark blue diamond, 15% larger than all other shapes seen during the task. The target stimulus was also a dark blue diamond (10% of trials), but smaller than the standard stimulus. There was a colour deviant non-target oddball (10% of trials), which was the same size and shape as the target, but pale blue in colour. The shape deviant non-target oddball (10% of trials) was a star shaded the same dark blue as target and standard stimuli, and was of equal size to the other task oddballs. A standard oddball may have three conditions – standard, target, and distracter – but we decided to include an additional non-target oddball (colour-deviant) in order to incorporate a more distinctive measure of conflict monitoring that could be separated from novelty processing, which would be signalled by the shape-deviant oddball.

Participants were instructed to respond only when they saw the target stimulus appear, pressing the space bar of a keyboard. No response was required to any other stimuli. Appendices III and IV illustrate the task, which was split into three blocks, each with 130 trials displayed randomly within that block (131 in the last block). Each block contained the same proportion of stimuli – 70% standard non-target, 10% target, 10% colour deviant non-target and 10% shape deviant non-target. All stimuli appeared one at a time in the centre of the computer screen. Participants were informed beforehand of what to expect during the task, but they did not know that a shape deviant non-target would infrequently appear, this was to maximise its novelty and deviance from learned task schema. Overall, participants saw 40 trials of each oddball and 271 standard stimuli.

Specifically, we expected that the standard stimulus and oddball most perceptually similar to the target (colour deviant non-target) would produce a more negative no-go N2, as the component signals pre-response conflict monitoring; processing the perceptual similarities to the target stimulus but the need to inhibit a response. The reason that the standard was expected to also elicit an N2 was because the 15% size difference was still a perceptually difficult distinction between target and standard. The task was created to be difficult because older adolescence is believed to be the peak age for performance on tasks of computerised stimulus categorisation and attention shifting (Cepeda, Kramer & Gonzalez de Sather, 2001). In order to measure potential benefits after mindfulness training, we needed to prevent finding a baseline ceiling effect. By making the standard so visually similar to the target this also meant that participants would need to pay effortful attention throughout the task, this had a secondary benefit of potentially exhausting participants' attentional resources and facilitated our chances of finding improved task accuracy and reduced response variability, with mindfulness practice. According to the Liverpool model, one of the first skills brought about by mindfulness training is attention stability, through focussed-attention practices (Malinowski, 2013). Improvements in executive attention control may also be noted early into the training, as the individual must learn to monitor their attention in order to maintain it on moment-to-moment experience. This led us to anticipate that post-training, mindfulness group participants would show enhancement of N2 negativity to both standard and colour-deviant oddballs, as they learn greater attention control and conflict monitoring skills.

In order to distinguish potential mindfulness training effects on conflict monitoring from processing of novelty, which would also involve stimulus categorisation deviating from the schema in working memory, the perceptually more distinctive shape-deviant oddball was included. The P3a, a frontal P300 amplitude that indexes the orienting of attention to an unexpected stimulus (Polich, 2007), can be measured using an infrequent non-target oddball that would be too repeated to index another novelty component, the novelty N2 (Alho, Woods, Algazi, & Näätänen, 1992; Folstein & van Petten, 2008). Therefore, with 40 shape-deviant trials that participants were not informed of before the start of the task, we should expect to see a positive waveform at frontal electrode cites. Mindfulness practice has been described as an approach that teaches the individual to be open to all experience, without judgement. It is unsure what influence this attitude would have when responding to novel objects in the environment, but a study by Antonova, Chadwick, and Kumari (2015) found that high intensity meditators show less habituation to startling auditory stimuli, while moderate intensity meditators showed faster habituation within the first trial block of the same startle response task. Similarly, Cahn and Polich (2009) noted that vipassana meditation practitioners exhibited dampened P3a startle responses to auditory distracters whilst meditating. No studies to our knowledge have yet investigated the impact that mindfulness training might have to P3a-indexed novelty.

The last stimulus condition within this task was the target, which was anticipated to elicit a more pronounced P3b waveform as this component is known to index goal-orientated attention processing (Polich, 2007). More positive P300 amplitudes have been associated with reduced target categorisation difficulty (Kok, 2001), and less mind wandering (Smallwood, Beach, Schooler, Handy, 2008). Additionally, Mrazek, Smallwood, and Schooler (2012) demonstrated that a brief mindfulness induction can reduce behavioural measures of mind wandering. Therefore, it was predicted that mindfulness training would induce more positive P3b amplitudes to target stimuli throughout the task, indexing sustained attention.

References

Adrian, E. D., & Matthews, B. H. C. (1934). The interpretation of potential waves in the cortex. *The Journal of Physiology, 81(4)*, 440-471.

Alho, K., Woods, D. L., Algazi, A., & Näätänen, R. (1992). Intermodal selective attention. II. Effects of attentional load on processing of auditory and visual stimuli in central space. *Electroencephalography and clinical neurophysiology*, *82(5)*, 356-368.

Allen, M., Dietz, M., Blair, K. S., van Beek, M., Rees, G., Vestergaard-Poulsen, P., ... & Roepstorff, A. (2012). Cognitive-affective neural plasticity following active-controlled mindfulness intervention. *The Journal of Neuroscience, 32(44)*, 15601-15610.

Antonova, E., Chadwick, P., & Kumari, V. (2015). More meditation, less habituation? The effect of mindfulness practice on the acoustic startle reflex. *PloS one*, *10*(5), e0123512.

Barch, D. M., Braver, T., Sabb, F. W., & Noll, D. C. (2000). Anterior cingulate and the monitoring of response conflict: Evidence from an fMRI study of overt verb generation. *Journal of Cognitive Neuroscience, 12(2)*, 298-309.

Berger, H. (1929). Über das elektrenkephalogramm des menschen. *European Archives of Psychiatry and Clinical Neuroscience, 87(1)*, 527-570.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108(3)*, 624-652.

Brefczynski-Lewis, J. A., Lutz, A., & Davidson, R. J. (2004). A neural correlate of attentional expertise in long-time Buddhist practitioners (No. 715.8). *Society for Neuroscience, San Diego*.

Brown, K. W., Goodman, R. J., & Inzlicht, M. (2013). Dispositional mindfulness and the attenuation of neural responses to emotional stimuli. *Social, Cognitive, and Affective Neuroscience, 8(1)*, 93-99.

Cahn, B. R., & Polich, J. (2006). Meditation states and traits: EEG, ERP, and neuroimaging studies. *Psychological Bulletin, 132(2)*, 180-211.

Cahn, B. R., & Polich, J. (2009). Meditation (Vipassana) and the P3a event-related brain potential. *International Journal of Psychophysiology*, *72(1)*, 51-60.

Cepeda, N. J., Kramer, A. F., & Gonzalez de Sather, J. (2001). Changes in executive control across the life span: examination of task-switching performance. *Developmental Psychology*, *37(5)*, 715.

Crone, E. A. (2013). Considerations of fairness in the adolescent brain. *Child Development Perspectives, 7(2)*, 97-103.

Davidson, R. J., Dunne, J., Eccles, J. S., Engle, A., Greenberg, M., Jennings, P., ... & Roeser, R. W. (2012). Contemplative practices and mental training: Prospects for American education. *Child Development Perspectives, 6(2)*, 146-153.

Desimone, R., Miller, E. K., & Chelazzi, L. (1994). The interaction of neural systems for attention and memory. In C Koch & J. L. Davis (Eds.) Large-scale neuronal theories of the brain (pp. 75-91). Cambridge, Massachusetts: MIT Press.

Dorjee, D., Lally, N., Darrall-Rew, J., & Thierry, G. (2015). Dispositional mindfulness and semantic integration of emotional words: Evidence from event-related brain potentials. *Neuroscience Research, 97*, 45-51.

Eshel, N., Nelson, E. E., Blair, R. J., Pine, D. S., & Ernst, M. (2007). Neural substrates of choice selection in adults and adolescents: development of the ventrolateral prefrontal and anterior cingulate cortices. *Neuropsychologia, 45(6)*, 1270-1279.

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (1999). ERP components in Go/Nogo tasks and their relation to inhibition. *Acta Psychologica, 101(2)*, 267-291.

Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: A Review. *Psychophysiology*, *45(1)*, 152-170.

Gao, Y., Raine, A., Venables, P. H., & Mednick, S. A. (2013). The association between P3 amplitude at age 11 and criminal offending at age 23. *Journal of Clinical Child & Adolescent Psychology, 42(1)*, 120-130.

Hölzel, B. K., Carmody, J., Vangel, M., Congleton, C., Yerramsetti, S. M., Gard, T., & Lazar, S. W. (2011). Mindfulness practice leads to increases in regional brain gray matter density. Psychiatry Research: *Neuroimaging, 191(1)*, 36-43.

Hölzel, B. K., Ott, U., Hempel, H., Hackl, A., Wolf, K., Stark, R., & Vaitl, D. (2007). Differential engagement of anterior cingulate and adjacent medial frontal cortex in adept meditators and non-meditators. *Neuroscience Letters, 421(1)*, 16-21.

Jasper, H. H., & Carmichael, L. (1935). *Electrical potentials from the intact human brain. Science, 81*, 51-53.

Jodo, E., & Kayama, Y. (1992). Relation of a negative ERP component to response inhibition in a Go/No-go task. *Electroencephalography and Clinical Neurophysiology, 82(6)*, 477-482.

Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology, 38(3)*, 557-577.

Kopp, B., Mattler, U., Goertz, R., & Rist, F. (1996). N2, P3 and the lateralized readiness potential in a nogo task involving selective response priming. *Electroencephalography and Clinical Neurophysiology, 99(1)*, 19-27.

Leuthold, H., & Kopp, B. (1998). Mechanisms of priming by masked stimuli: Inferences from event related brain potentials. *Psychological Science, 9(4)*, 263-269.

Luck, S. J. (2005). *An Introduction to the Event-Related Potential Technique*. Cambridge, Massachusetts: MIT Press.

Malinowski, P. (2013). Neural mechanisms of attentional control in mindfulness meditation. *Frontiers in Neuroscience*, *7*, 8.

Mohrmann, R., De Wit, H., Verhage, M., Neher, E., & Sørensen, J. B. (2010). Fast vesicle fusion in living cells requires at least three SNARE complexes. *Science, 330(6003)*, 502-505.

Moore, A. W., Gruber, T., Derose, J., & Malinowski, P. (2012). Regular, brief mindfulness meditation practice improves electrophysiological markers of attentional control. *Frontiers in Human Neuroscience, 6*, 18.

Mrazek, M. D., Smallwood, J., & Schooler, J. W. (2012). Mindfulness and mind-wandering: finding convergence through opposing constructs. *Emotion, 12(3)*, 442-448.

Nieuwenhuis, S., Ridderinkhof, K. R., Blom, J., Band, G. P., & Kok, A. (2001). Error-related brain potentials are differentially related to awareness of response errors: Evidence from an antisaccade task. *Psychophysiology, 38(5)*, 752-760.

Oberle, E., Schonert-Reichl, K. A., Lawlor, M. S., & Thomson, K. C. (2012). Mindfulness and Inhbitory Control in Early Adolescence. *The Journal of Early Adolescence, 32(4)*, 565-588.

Ogawa, S., Lee, T. M., Kay, A. R., & Tank, D. W. (1990). Brain magnetic resonance imaging with contrast dependent on blood oxygenation. *Proceedings of the National Academy of Sciences, 87(24)*, 9868-9872.

Patel, S. H., & Azzam, P. N. (2005). Characterization of N200 and P300: selected studies of the event-related potential. *International Journal of Medical Sciences, 2(4)*, 147-154.

Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience, 35*, 73-89.

Picton, T. W., Bentin, S., Berg, P., Donchin, E., Hillyard, S. A., Johnson, R., ... & Taylor, M. J. (2000). Guidelines for using human event-related potentials to study cognition: recording standards and publication criteria. *Psychophysiology, 37(02)*, 127-152.

Polich, J. (2007). Updating P300: an integrative theory of P3a and P3b. *Clinical Neurophysiology, 118(10)*, 2128-2148.

Posner, M. I., & Petersen, S. E. (1990). The attention systems of the human brain. *Annual Review of Neuroscience, 13*, 25–40.

Quaglia, J. T., Goodman, R. J., & Brown, K. W. (2016). Trait Mindfulness Predicts Efficient Top-Down

Attention to and Discrimination of Facial Expressions. *Journal of Personality, 84(3)*, 393-404.

Ritter, W., Simson, R., Vaughan, H. G., & Macht, M. (1982). Manipulation of event-related potential manifestations of information processing stages. *Science, 218(4575)*, 909-911.

Slagter, H. A., Lutz, A., Greischar, L. L., Francis, A. D., Nieuwenhuis, S., Davis, J. M., & Davidson, R. J. (2007). Mental training affects distribution of limited brain resources. *PLoS Biol, 5(6)*, e138.

Smallwood, J., Beach, E., Schooler, J. W., & Handy, T. C. (2008). Going AWOL in the brain: Mind wandering reduces cortical analysis of external events. *Journal of Cognitive Neuroscience, 20(3)*, 458-469.

Sutton, S., Braren, M., Zubin, J., & John, E. R. (1965). Evoked-potential correlates of stimulus uncertainty. *Science, 150(3700)*, 1187-1188.

Van Den Bos, W., van Dijk, E., Westenberg, M., Rombouts, S. A., & Crone, E. A. (2011). Changing brains, changing perspectives the neurocognitive development of reciprocity. *Psychological Science, 22(1)*, 60-70.

Van Den Bos, W., Vahl, P., Güroğlu, B., van Nunspeet, F., Colins, O., Markus, M., ... & Crone, E. A. (2014). Neural correlates of social decision-making in severely antisocial adolescents. *Social, Cognitive, and Affective Neuroscience, 9(12)*, 2059-2066.

Van Veen, V., & Carter, C. S. (2002). The anterior cingulate as a conflict monitor: fMRI and ERP studies. *Physiology & Behaviour, 77(4)*, 477-482.

Vaughan, H. G. Jr. (1969). The relationship of brain activity to scalp recordings of event-related potentials. In E. Donchin & D. B. Lindsley (Eds.), *Average Evoked Potentials: Methods, Results, and Evaluations* (pp. 45-75). Washington, DC: US Government Printing Office.

Velanova, K., Wheeler, M. E., & Luna, B. (2008). Maturational changes in anterior cingulate and frontoparietal recruitment support the development of error processing and inhibitory control. *Cerebral Cortex, 18(11)*, 2505-2522.

Chapter Three – Mindfulness training for adolescents: A neurodevelopmental perspective on investigating modifications in attention and emotion regulation using event-related brain potentials

Text as it appears in: 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.

Abstract

Mindfulness training is increasingly being introduced in schools, yet studies examining its impact on the developing brain are scarce. A neurodevelopmental perspective on mindfulness has been advocated as a powerful tool to enhance our understanding of underlying neurocognitive changes with implications for developmental well-being research and the implementation of mindfulness in education. To stimulate more research in developmental cognitive neuroscience of mindfulness, this paper outlines possible indexes of mindfulness-based change in adolescence with a focus on event-related brain potentials (ERP) markers. We provide methodological recommendations for future studies, and offer examples of research paradigms. We discuss how mindfulness practice could impact on the development of prefrontal brain structures, and enhance attention control and emotion regulation skills in adolescents, impacting in turn on their self-regulation and coping skills. We highlight advantages of ERP methodology in neurodevelopmental research of mindfulness. It is proposed that research using established experimental tasks targeting ERP components such as the Contingent Negative Variability, N200, Error-Related Negativity and error Positivity, P300, and the Late Positive Potential could elucidate developmentally salient shifts in neural plasticity of the adolescent brain induced by mindfulness practice.

Introduction

The term ‘mindfulness’ has been derived from the Buddhist concept of ‘sati’ which refers to refined skills of awareness, attention, and remembering (Siegel, Germer & Olendzki, 2008). In the secular context, Bishop et al. (2004) proposed a two-component model of mindfulness, involving ‘self-regulation of attention’ (maintained on immediate experience) and ‘attitudinal orientation’ (curiosity, openness, and acceptance). They described mindfulness as a form of mental training that develops a reflective rather than reflexive mode of responding to internal and external events. Shapiro, Carlson, Astin, and Freedman (2006) later extended the model to include a third axiom: intention, which links back to the earlier notion of ‘remembering’, in addition to attention and attitude (IAA). They refer to Jon Kabat-Zinn’s description of mindfulness to explain their three axioms *“paying attention* (Attention) *in a particular way* (Attitude): *on purpose* (Intention*), in the present moment, and non-judgementally”* (Kabat-Zinn, 1994, p.4).

Several reviews have summarised the benefits of mindfulness for adult physical and mental health (Grossman, Niemann, Schmidt & Walach, 2004; Brown, Ryan & Creswell, 2007; Eberth & Sedlmeier, 2012), in various clinical populations (Baer, 2003; Hoffman, Sawyer, Witt & Oh, 2010), and more recently in children, both within and outside of a clinical context (Black, Milam & Sussman, 2009; Burke, 2010; Davidson et al., 2012; Greenberg & Harris, 2012; Meiklejohn et al., 2012; Zenner, Herrnleben-Kurz & Walach, 2014). The field of mindfulness research is now moving towards more rigorous clinical trials, and increasingly more studies are targeting the underlying neurocognitive mechanisms (Lutz, Slagter, Dunne & Davidson, 2008; Moore & Malinowski, 2009; Chiesa, Calati & Serretti, 2011; Hölzel et al., 2011; Bradshaw, Goldweber, Fishbein & Greenberg, 2012; Brown, Goodman & Inzlicht, 2013). Indeed, neuroscientific methods can help us understand the intricate relationship between cognition, neural plasticity and mindfulness as a well-being enhancing strategy. Better understanding, particularly from the neurodevelopmental perspective, may also inform the adaptation of interventions for specific populations such as adolescents, by taking into account their neurodevelopmental trajectories.

Davidson et al. (2012) outlined how contemplative practices including mindfulness could benefit young people at the interlinked levels of neural substrates, psychological functioning and behaviour. They discuss recent neurodevelopmental findings that show Social-Emotional Learning (SEL) programmes implemented in regular school curricula improve executive function in children e.g. inhibitory control and working memory (Greenberg & Rhoades, 2008) and emphasize that mindfulness-based approaches could further strengthen SEL-like programmes. Specifically in adolescents, brain areas of executive function i.e. the prefrontal cortex (PFC) where emotion regulation networks overlap with circuitry for attention control (Ochsner & Gross, 2005; Lee, Heller, van Reekum, Nelson & Davidson, 2012) require greater activation than for adults when regulating emotions. Furthermore, high arousal situations impair adolescent decision making abilities much more than in adults (Steinberg, 2005). These contingencies suggest that practices like mindfulness, which enhance executive functioning (Oberle, Schonert-Reichl, Lawlor & Thomson, 2012; Westbrook et al., 2013), could support prefrontal brain structure development in adolescents. Arguably, such training could also enable adolescents' to manage excessive levels of negative emotions like anxiety, which interfere with working memory and attention (Shackman et al., 2006; Shackman, Maxwell, McMenamin, Greischar & Davidson, 2011), and impacts on well-being and academic performance (Kaplan, Liu & Kaplan, 2005). Mindfulness can also encourage a present-moment experiential form of self-awareness (ESA) as opposed to the traditional narrative form (NSA) (Davidson et al., 2012). Perceiving the self through ESA can decrease rumination and self-judgement, which in turn could benefit academic motivation and learning (Roeser & Peck, 2009). Davidson et al. (2012) exemplify this with beliefs about intelligence – perceiving intellect as a fixed trait was associated with higher test anxiety and poorer exam results despite cognitive ability, whereas interventions that portray such constructs as malleable can reduce anxiety and increase persistence and achievement (Dweck, 2008).

In summary, the neurocognitive perspective has great potential to help expand our understanding of developmental mechanisms of mindfulness and their implications for the adaptation and implementation of specific adolescent programmes, particularly in the context of education. The purpose of this paper is to formulate the theoretical foundations for mindfulness research with adolescents, which would take into account both the complexities of training this age group and their neurodevelopmental dispositions. After discussing current mindfulness training programmes for adolescents, we will outline some salient methodological issues, including advantages of ERPs in developmental research on mindfulness. Then we will specifically focus on the potential of neurocognitive ERP markers of attention and emotion regulation to study the effect of mindfulness training in adolescence.

Researching mindfulness-based programmes for adolescents

There are currently several mindfulness-based programmes for children and adolescents available, varying in their degrees of evidence-based support and views about which aspects of mindfulness and related concepts (e.g. compassion, yoga, cognitive behaviour therapy) should be emphasized. These include Wellness Works in School (Kinder Associates LLC, 2002), Still Quiet Place (Saltzman & Goldin, 2008), Meditación Fluir (Justo, 2009), Mindfulness-Based Stress Reduction for Teens (MBSR-T: Biegel, 2009), Mindfulness for Adolescents (Dewulf, 2009), Mindful Schools (Mindful Schools, 2010), MindUp (The Hawn Foundation, 2011), Learning to BREATHE (L2B: Broderick, 2013), and Mindfulness in Schools Project (MiSP: Kuyken et al., 2013). For a thorough discussion of the different programmes and their outcomes, see Meiklejohn et al. (2012). One overarching feature of these programmes is their Western cultural focus, which needs to be carefully considered if these programmes are to be adapted for use in non-Western countries and cultures. This may impact on the format and underlying intentions of implementation such as enhancement of attention, well-being and academic performance in the Western context in contrast to encouragement of cognitive flexibility and creativity in some Asian cultures. Given the nascent nature of these programmes, there is a lack of strong research evidence for many of them, most having only one peer-reviewed study to support their efficacy. One of the methodologically strongest studies conducted so far was by Biegel, Brown, Shapiro and Schubert (2009), who evaluated the MBSR-T intervention with young people receiving community mental health support. The study followed a randomised controlled design including a post-treatment follow-up and diagnostic assessments by a study-blind clinician. The participants in the training group significantly improved on levels of anxiety, perceived stress, and depression by 3-month follow-up and also showed diagnostic improvements. Hopefully, more future studies will apply as robust a design as this trial, while also integrating neurocognitive assessments which have not so far been employed.

It is also important to consider the contribution of participant specific variables to the outcomes of studies with adolescents. For example, the significant findings in Biegel et al. (2009) could have been impacted by the clinical nature of the sample - a variable which needs to be taken into account in future research with non-clinical populations in schools where the ceiling effect may decrease the likelihood of finding improvements. Indeed, Gould, Dariotis, Mendelson & Greenberg (2012) reported just this, finding that baseline depression scores moderated mindfulness-training effects in urban youths. This highlights the need for measures that would be sensitive enough to detect changes in both clinical and non-clinical groups – which is where neurocognitive assessments can be particularly helpful. In addition to the clinical-nonclinical differences, personality traits have been found to impact on the outcomes of mindfulness training with adolescents. Specifically, Huppert and Johnson (2010) reported that agreeableness and openness significantly correlated with improvements in wellbeing after MiSP training. And non-reactivity has been reported to directly moderate the beneficial effects of mindful observing on anxiety and depression (Desrosiers, Vine, Curtiss & Klemanski, 2014). Age may also play a role, Schonert-Reichl and Lawlor (2010) found in their early validation study of MindUp (previously known as Mindfulness Education) that the course was more effective with younger students.

Two other issues for consideration are the amount of home-practice necessary for a significant effect, and the required qualifications of programme trainers. One of the most prevalent adult-based mindfulness training programmes is Mindfulness-Based Stress Reduction (MBSR: Kabat-Zinn, 1990), which involves eight 2.5-hour sessions and asks participants to individually practice for 45-minutes daily. These requirements are reduced in most youth mindfulness programmes, but there is still a strong emphasis on regular practice, if only for 5-10 minutes per day. It is currently not clear how the amount of home practice impacts on outcomes with this population. Foret et al. (2012) trained 11th grade students (16-17 years) in a 4-week relaxation curriculum including mindfulness and breathing meditation. After the intervention, pupils reported significant improvements to their stress management skills, perceived stress, and state anxiety. These promising results were found in a group where 80% either never logged on to the website for their home practice or only completed it once. However, Huppert and Johnson (2010) found that home practice was a significant contributing factor to mindfulness and wellbeing effects after MiSP training. The latter intervention was run with a younger (14-15 years), all-male cohort. It is possible that younger adolescents who are less matured neurologically and behaviourally, or boys, who are known to have a slower developmental trajectory (Brumback, Arbel, Donchin & Goldman, 2012), need this additional practice. Methodologically, home-practice is a pivotal issue given that it may have a significant impact on intervention effects (Zenner et al., 2014), but is difficult to accurately record. Researchers have typically relied upon self-report measures, but the use of ID-locked online home practices (e.g. Foret et al., 2012) or a similar tracking system is a potential solution. More reliable measures would enable us to fully review the extent of home-practice contributions, and allow programme designers to balance intervention efficacy with time-effectiveness.

In terms of trainer qualification requirements, few studies rigorously report on the mindfulness training and qualifications of the programme teachers. Most mindfulness-based programmes for adolescents involve external trainers, normally the programme developers, communicating the mindfulness course to pupils (e.g. Broderick & Metz, 2009; Huppert & Johnson, 2010; Kuyken et al. 2013; Raes, Griffith, Van der Gucht & Williams, 2013). But if mindfulness programmes prove effective enough to be considered for broad implementation into school curricula, mindfulness training and delivery will need to become more self-sustaining. Most education boards cannot afford to pay external trainers long-term, but without upholding the fidelity of the programme any attempts at training young people may be fruitless. An alternative model would involve training school teachers in mindfulness, supporting them to develop a personal practice and then train them in the delivery of mindfulness-based curricula (*e.g. model described and used at the Centre for Mindfulness Research and Practice; Mindfulness in Education, 2014*). It seems that a compromise between these two delivery approaches could be met, in order to achieve a programme that all schools could practically accommodate without weakening the therapeutic outcomes.

Methodological issues of neurodevelopmental research on mindfulness with adolescents

Bradshaw et al. (2012) evaluated the theoretical aspects of developmental neuroscience that could help shape school-based preventative interventions - developmental research on reward pathways, stress, social-cognitive mechanisms, and executive functioning seem particularly relevant here. They concluded that mindfulness–based programmes could help promote regulatory processes if taught within the education system. However, preliminary studies with children, including two systematic reviews, only report low-moderate effects (Black et al., 2009; Burke, 2010; Flook et al., 2010). In comparison, meta-analysis reports in adults evaluating the 8-week courses in MBSR (Kabat-Zinn, 1990) or Mindfulness-Based

Cognitive Therapy (MBCT: Segal, Williams & Teasdale, 2002), found medium to high effect sizes on various measures of mindfulness, well-being, negative affect etc. (Grossman et al., 2004; Hofmann, Sawyer, Witt & Oh, 2010). This could, in part, result from the developmentally appropriate reductions to course length and depth, as well as practice frequency and duration seen in child mindfulness programmes. In this context, the adolescent age group may be a more advantageous research population than younger children, bridging the gap between adult and child mindfulness-based curricula. Adolescence can also be seen as a late catchment point for neuro-cognitive interventions within the context of prefrontal development (Spear, 2013), with mindfulness training particularly targeting attention monitoring and control systems of the prefrontal cortex (Hölzel et al*.,* 2011).

Spear (2013) also advocated for adolescent-related governmental policy to take more consideration of developmental neuroscience. This was based on the emerging consensus amongst researchers that adolescents' perception of rewarding and aversive stimuli is strongly biased towards the former, and that the role of context is highly influential over their decision-making abilities. Spear (2013) reviewed recent *f*MRI research and non-human animal models that demonstrated adolescents are susceptible to 'hot cognitions', where the still maturing prefrontal cortex can process cognitive tasks at adult-levels of performance, but can be overridden by more matured subcortical brain regions of the dopaminergic, mesolimbic reward pathway, like the ventral striatum. This shift in activation can result in greater risk-taking behaviours (Gardner & Steinberg, 2005). Spear (2013) ends by questioning whether developmental neuroscience could help introduce interventions that actively support the development of prefrontal brain regions, thus balancing adolescent perceptions of reward and punishment in order to prevent extreme risk-taking. Mindfulness-based training could be a helpful intervention in this context, particularly if it can be sustainably implemented in schools.

The introduction of developmental neurocognitive approaches into mindfulness training and research requires careful consideration of the suitable research tools. Investigations of neurocognitive mechanisms in adults have so far mostly relied on functional and structural magnetic resonance imaging (MRI) (see Hölzel et al., 2011) and to a lesser extent on ERPs, which are averaged brain waves in response to certain categories of stimuli such as oddballs or affective pictures (Fabiani, Gratton & Coles, 2000). Each of the two methods has its pros and cons, with MRI having superior spatial resolution and thus being more suitable for research questions about localization, and ERPs providing millisecond temporal accuracy of neurocognitive processing which is advantageous for questions tapping into automatic versus controlled processing. Another strength of MRI is its longer-standing use in mindfulness research, where the grounding for further developments is already established. While less frequently used in mindfulness research so far, ERP methodology has the advantage of being less costly and theoretically more firmly established after more than 60 years of research. Importantly, ERP research has identified functionally specific indexes of neurocognitive processing, so called ERP components, which can be used in the assessment of attention control and efficiency, inhibition, semantic processing and error judgement. In addition, ERPs can be particularly helpful in the investigation of skill acquisition effects where functional MRI findings focusing on localization may mask functionally salient changes in processing efficiency induced by learning (Dorjee & Bowers, 2012). Nevertheless, developmental factors must be taken into account if using either approach. ERP components have typically been described in adult populations, whereas the limited child research has indicated different scalp localisations and time courses in the still developing brain. Please refer to *Table 1* where these differences are also known to apply in adolescence. The following ERP components seem particularly relevant to neuro-cognitive research on mindfulness with adolescents:

1. Contingent negative variation (CNV), a slow-building negative waveform that emerges in the period between a warning and imperative stimulus. It has a frontal/ central distribution, and signals preparatory motor activity, sensory anticipation, and the activation of attention (Walter, Cooper, Aldridge, McCallum & Winter, 1964).
2. The visual-N200 (N2) is a negative deflection with a frontal/ central distribution, and signals task-specific inhibition (Falkenstein, Hoormann & Hohnsbein, 1999) and

conflict monitoring (Ladouceur, Dahl & Carter, 2007). It can also be detected at occipital sites (Fabiani et al., 2000).

3. The P300 (P3 family of positive components) is elicited in response to salient stimulus events, thus allocating mental resources to attention and memory operations associated with stimulus processing (Polich, 2007).

   Two subcomponents of the P300, the P3a and P3b, have been distinguished. While the P3a has a fronto-central distribution and is associated with automatic attention capture (Polich, 2007), the P3b has a centro-parietal distribution and has been linked to stimulus categorisation and processing, as well as an updating of working memory (Sutton, Braren, Zubin & John, 1965).

4. Error Related Negativity (ERN) is a negative deflection over fronto-central sites, used to assess automatic responses to an error that deviates from goal-directed behaviour (Falkenstein, Hohnsbein, Hoormann & Blanke, 1991). This is followed by error Positivity (Pe), which is sensitive to the subsequent appraisal of that errors severity (Overbeek, Nieuwenhuis & Ridderinkhof, 2005).
5. The Late Positive Potential (LPP) is considered a neural marker of emotional arousal, reflecting the preferential processing and encoding of motivationally relevant stimuli. It is a slow-building positive waveform, with a central/ posterior distribution (Brown et al., 2013).
6. The Late Positive Complex (LPC) is a positive, broad peaking waveform with a parietal distribution. It has been associated with deep processing (Rellecke, Sommer & Schacht, 2012), memory recall (Schaefer, Pottage & Rickart, 2011) and affective rumination (Sitges et al., 2007).

We will discuss each of these components in relation to effects of mindfulness on attention and emotion processing in adolescents in the following sections.

Mindfulness training effects on attention

Attention is a key modulator of cognitive processing, enabling us to select task relevant stimuli and inhibit irrelevant information, sustain focus on cognitive performance, divide attention, and stay vigilant when needed. One theory of attention that is commonly used in mindfulness research proposes that there are three largely independent attention networks (Posner & Petersen 1990; Peterson & Posner, 2012). The *orienting network* supports selecting relevant sensory input, and shifting attention towards a goal-related stimulus (disengaging and re-engaging attention). The *alerting network* refers to a level of arousal and vigilance i.e. the ability to maintain sensitivity to external stimuli. This can be further separated into phasic alertness, which is task specific, and intrinsic alertness that refers to more general trait levels of arousal. And *executive attention*, which monitors and resolves any conflicts arising between thought, emotion, or action (Raz & Buhle, 2006). Executive attention is typically measured using tasks involving an incompatibility between different aspects of a task otherwise known as ‘conflict’, like the classic Stroop task where an individual must ignore the written word e.g. RED and instead identify the colour ink that word is written in e.g. blue (Stroop, 1935). Conflict monitoring is believed to be one key aspect of executive attention, computing task parameters, evaluating conflict, updating new or unlearned responses, regulating thoughts and emotions, and blocking habitual responding (Raz & Buhle, 2006). While a body of research supports both functional and neural separation of these networks, there is also evidence that it can be difficult to methodologically separate the attention networks because they often operate in parallel (MacLeod et al., 2010). The majority of studies regarding attention performance and mindfulness practice have discussed improvements in terms of the three attention networks (Chan & Woollacott, 2007; Jha, Krompinger & Baime, 2007; Chiesa, Calati & Serretti, 2011; Malinowski, 2013; Tang, Hölzel & Posner, 2015), and in order to evaluate past literature consistently we will also apply this approach. However, there are other frameworks within the broader attention literature, with the Integrated Competition hypothesis being another common explanation supported by neurocognitive findings (Desimone & Duncan, 1995; Duncan, Humphreys & Ward, 1997). For a more in depth discussion of the ERP literature on attention please refer to Luck (2014) or Picton et al. (2000).

In addition to task-specific attention improvements, we will give special consideration to past research and ERP markers of mind wandering. This is defined as the withdrawal of attention from task-relevant stimuli, which subsequently reduces the capacity of working memory. Mind wandering involves brain regions responsible for orienting, goal-directed behaviour, and executive attention (Smallwood, Beach, Schooler & Handy, 2008). It has previously been linked to reductions in learning, task performance, and clinical issues such as depression (Mooneyham & Schooler, 2013; Deng, Li & Tang, 2014), and is therefore a process of particular interest to schools given that mind wandering is known to occur most often in educational contexts (Unsworth, McMillan, Brewer & Spillers, 2012).

ERP markers of attention and experimental paradigms for mindfulness research with adolescents

The CNV

The Contingent Negative Variation represents attention activation, motor preparation, and a proactive response to suggested targets. It has a frontal/ central distribution and has been linked to activation in the anterior cingulate cortex (ACC), prefrontal cortex (PFC), and supplementary motor area (SMA) (Nagai et al., 2004; Bares, Nestrasil & Rektor, 2007). These brain regions have also been associated with increased activation during meditation in trained practitioners (Hölzel et al., 2007), which may signal mindfulness practice benefits to mental alertness (Posner, 2008). Tasks like the Attention Network Test (ANT: Fan, McCandliss, Sommer, Raz & Posner, 2002) identify this orienting attention ability through measuring the response when spatial cues appear before an impending target. Jha, Krompinger and Baime (2007) demonstrated that orienting of attention is significantly improved in adults after an 8-week MBSR course.

The CNV might be a sensitive ERP component to detect possible facilitation of attention ‘priming’, with Bostanov, Keune, Kotchoubey and Hautzinger (2012) demonstrating that mindfulness practice can increase CNV negativity in depressed adult populations. Interestingly, Killikelly and Szucs (2013) showed how proactive response activation towards an imminent target, which correlated with more negative CNV amplitudes, is reduced in even older adolescents compared to young adults. Adolescents’ suggested lack of orientation and proactive planning abilities, associated with less negative CNV (and less efficient frontal lobe executive functioning), has potential consequences for risk-taking behaviours. It also means that testing paradigms aimed at manipulating the CNV will likely show poorer baseline functioning in adolescent participants in comparison to adults. Nevertheless, this converging evidence on developmental CNV modulation in adolescents (Killikelly & Szucs, 2013) and its modifiability through mindfulness training in depressed populations (Bostanov et al., 2012) who also show dampened pre-testing CNV responses, recommends this to be a sensitive tool for understanding the underlying mechanisms of mindfulness-based change. More negative CNV amplitudes could be expected after mindfulness training in adolescents, reflecting anticipatory mobilisation of attentional resources.

The N200

Response inhibition is a strong contributor to performance in tasks of executive attention like the Stroop (Stroop, 1935), Go No-Go (Donders, 1969), D2 (Brickenkamp, 1962), and conflict sub-task of the ANT and can be monitored through N200 (N2) negativity. Moore, Gruber, Derose and Malinowski (2012) employed the Stroop Task with mindfulness novices before and after an 8-week programme (and at 16-week follow-up), which involved an initial 2-hour guided session and regular 10-15 minute practices 5-days per week. No behavioural effects were found, but N2 amplitudes showed a significant Group x Time interaction (at occipito-parietal electrode clusters), which reflected more negative amplitudes in the meditation group by follow-up. There was also a significant decrease in meditators’ P3b amplitudes during incongruent trials. The authors suggested that N2 amplitude changes indicated improvements in detection and inhibition, which subsequently led to less attentional resources being required for object recognition reflected in less positive P3b amplitudes. In other words, efficiently allocating cognitive resources to early detection left mental resources for maintaining task vigilance. In this context the N2 can thus be interpreted as a direct index of response inhibition, and indicate the facilitation of improved orienting (attention shift) and alerting (vigilance) skills after mindfulness training. The non-significant group effect for performance highlights that changes in the alerting system may be subtle, needing prolonged practice before enhanced attention leads to significantly more accurate task performance. This favours neurocognitive methods of testing like ERPs, which may identify early mechanisms of change. Ortner, Kilner and Zelazo (2007) also reported that university students practicing mindfulness were better able to disengage from unpleasant stimuli, in comparison to those in a passive control or relaxation group. However there was no difference between groups when observing neutral or pleasant stimuli, suggesting that mindfulness practice does not uniformly disengage people from experience, rather it prevents interference by negative stimuli. Future testing methods may be to correlate N2 and P3b amplitudes, as well as performance accuracy, using an odd-ball or Sustained Attention to Response Task (SART; Robertson, Manly, Andrade, Baddeley & Yiend, 1997).

With regard to adolescents, studies show that they have difficulty in shifting attention away from emotive stimuli (e.g. Shackman et al., 2011). Being taught how to effectively re-engage their attention through mindfulness could improve concentration levels at school, where social, emotional and academic stressors are widespread and distracting. Bogels, Hoogstad, van Dun, de Schutter and Restifo (2008) found that after an MBCT course, adolescents with externalising disorders showed significant improvements on speed and accuracy measures of sustained attention (D2 Test of Attention: Brickenkamp, 1962), with further improvements by 8-week follow-up. Caution is needed when generalising findings from clinical samples, but these results suggest that mindfulness can enhance sustained attention in this age group. In terms of typical development, Chapman, Woltering, Lamm and Lewis

(2010) mapped out N2 development in participants ranging from 8-17 years. They detected more negative amplitudes and shorter latencies in adolescents that suggest more efficient and mature processing, akin to adult levels. Therefore, similar to what has been reported in adult populations, more negative N2 amplitudes could be expected after mindfulness training in clinical and non-clinical adolescent populations, reflecting enhanced patterns of automatic attention capture and inhibition.

The P300

The attention-blink paradigm (Raymond, Shapiro & Arnell, 1992) is another measure of orienting and alerting performance. This measures an individual's ability to disengage from Target-1 (T1) and stay vigilant for detecting Target-2 (T2), both presented quickly (less than 500 ms apart) in a visual sequence of numbers and letters. In relation to mindfulness, Slagter et al. (2007) found significantly better T2 detection in participants after a 3-month mindfulness meditation retreat and a selective reduction in T1-elicited P3b amplitudes on the no-blink (successful T2 detection) trials. These results suggest that reducing attentional resources to T1 through meditation training increased an individual's chances of remaining vigilant and detecting T2. In terms of relating this to adolescents, Brumback et al. (2012) demonstrated that the maturity of P300 amplitude and latency develops earlier in females i.e. reduced P300 positivity and shorter latency. This suggests that male students may have more potential to improve attention performance after training, but also that baseline differences in mixed gender groups should be controlled for. Research with adolescents specifically using the attention-blink paradigm (Ray Li, Chen, Lin & Yang, 2005) reported that impulsivity was associated with lower T2 detection. Improvements in adults (Slagter et al., 2007) would therefore suggest that mindfulness training might be particularly beneficial for adolescents with high impulsivity, with practice benefits reflected in greater T2 detection and associated P3b amplitude decreases to T1.

The P3b reduction found after mindfulness training by Moore et al. (2012) during inhibition trials in the Stroop task reflects conflict monitoring and inhibitory performance in addition to alerting discussed in the previous section. And MBCT has also been shown to enhance executive control abilities in healthy adults (Chambers, Lo & Allen, 2008). Moore et al. (2012) showed no corresponding drop in task accuracy when P3b amplitudes decreased, suggesting a reduction in the amount of attentional resources required for executive control. However, Moore and Malinowski (2009) reported in a cross-sectional study with meditation naive participants compared to intermediate Buddhist students (who had at least completed the 6-week intensive course) that meditation students did perform significantly better in Stroop and D2 tasks. These improvements indicate better inhibitory control, cognitive flexibility, and quality of performance that might reflect the more intense nature of their meditation training. Other executive function tests use dual-task paradigms such as the n-back (Watter, Geffen & Geffen, 2001) and task switching (Kieffaber & Hetrick, 2005), which also modulate the P300. In dual-task paradigms, increases in task difficulty (including task switching) result in more positive P300 amplitudes and prolonged latencies (Kramer, Wickens & Donchin, 1985). Palluel, Nougier and Olivier (2010) identified 14-15 years as the maturational turning point in dual-task performance, so adults levels of performance should be anticipated in older adolescents unless affective stimuli are incorporated that prompt subcortical brain regions to interfere with executive functioning (Spear, 2013).

In contrast to the increased efficiency of attention resulting from mindfulness training, mind wandering is marked by a lack of efficient attention allocation. This can have a detrimental impact on education, both on the effective learning process and academic performance. For example, during revision periods an awareness of an individual’s optimum attention span and an ability to catch themselves mind wandering could maximise productivity, and their sense of achievement. A person’s susceptibility to mind wander can be measured using simple, over-learned tasks like the Sustained Attention to Response Task (SART; Robertson et al., 1997), where behavioural performance correlates with self-reported mind wandering and P3b waveforms. Improvements in dual-task performance (which is essentially the internal environment that mind wandering creates) have been associated with activity in the ACC (Dreher & Grafman, 2003), one of the key brain areas linked to mind wandering (Ros et al., 2013) and mindfulness practice (Hölzel et al., 2007). Less mind wandering correlates with greater P3b mean amplitude to non-targets preceding a correctly inhibited response to target during the SART, suggesting more consistent attention processing throughout (Smallwood et al., 2008). This contrasts with the reduced P3b that is observed after mindfulness training in other attention-based tasks, thus highlighting the importance of context in neurocognitive theory and testing. Mind wandering has been shown to reduce after brief mindfulness practice in adults (Mrazek, Smallwood and Schooler, 2012), and similar effects could be expected in adolescents, positively impacting on the effectiveness of their learning. Moreover, it would be very relevant to investigate whether temporary improvements such as those reported by Mrazek et al. (2012) can, with regular mindfulness training, translate into stable trait-like reductions in mind wandering.

Mindfulness training effects on emotion regulation

Emotions are multi-faceted phenomena involving cognitive appraisal of a situation, physiological responses, emotional experience (feelings) and a tendency to respond (Scherer, 2000). The ability to manage emotions is described as emotion regulation (Gross & Thompson, 2007). Typically, emotions compete for attention with other cognitive processes that are demanded by a situation, and the prefrontal systems of attention control enable the inhibition, shifting of attention, and monitoring of emotions that underlies emotion regulation (Ochsner, Bunge, Gross & Gabrieli, 2002). This malleability by attention processes makes emotion regulation (ER) subject to maturation changes throughout development.

The links between attention control and ER have consequences for the adolescent population, since adolescents typically display poorer inhibition and more impulsive, risk-taking behaviours. Specifically, Ernst, Pine and Hardin's (2006) Triadic Model of Motivated Behaviour illustrates how the adolescent reward-driven system (ventral striatum) may be exerting more control over their behaviour than the harm-avoidant (amygdala) and regulatory control system (medial/ ventral PFC) that is still developing. In addition, reward regions of the brain are more strongly activated when young people take risks in the company of their peers (Steinberg, 2010), confirming the strong impact of peer pressure on this population. Gambling tasks like that of Van Leijenhorst et al. (2010) exemplify how the adolescent ACC, which balances emotions with objective judgement, exerts less control over behaviour than the reward-orientated ventral striatum. This leads to riskier decisions based on the different developmental trajectories of these neural systems.

The connection between attention control and ER through the ACC is paramount to where mindfulness can influence ER strategies (Dywan, Mathewson, Choma, Rosenfeld & Segalowitz, 2008). It is possible that mindfulness practice could encourage connections between the relevant prefrontal structures in adolescents, stabilising arousal and reducing harmful risk-taking, as advocated more broadly in support of mental training by Atkins, Bunting, Bolger and Dougherty (2012). Relevant evidence for this comes from adult *f*MRI research, for example Grant, Courtemanche and Rainville (2011) found that proficient meditators display less activation in brain regions of executive functioning (lateral and medial PFC, ACC) whilst attending to pain. This may represent a selective reduction in unhelpful cognitive elaboration, translating into more effortless ER. Petter, McGrath, Chambers and Dick (2014) have reported similar behavioural findings, with mindfulness practice attenuating pain responses in typical adolescents. The influence of mindfulness practice on ER strategy is complex however, and *f*MRI research shows a shift in ER strategies with more extensive mindfulness experience. Taylor et al. (2011) reported that actively engaging in mindful meditation during negative picture displays caused a bilateral deactivation of the amygdala for beginners, while long-term practitioners showed a deactivation in the left lateral PFC. Meditators may initially reappraise in order to modify maladaptive emotional responses, but progressively an all-accepting attitude leaves appraisal unnecessary (Teper, Segal & Inzlicht, 2013). Mapping the development of ER in adolescents will therefore need to take into account neurocognitive changes in relation to length and quality of practice. Task design and stimuli used will also influence the predictions made. During studies of pain tolerance it is most adaptive to disengage from the incoming stimulus and therefore less activation of the PFC may be recorded. Whereas during an active ER task, e.g. Creswell, Way, Eisenberger & Lieberman (2007), individuals must first appraise stimuli for valence and then actively down-regulate the emotional response this had upon the amygdala.

The next section will review previous ERP research, outline specific testing paradigms, and suggest what neural markers sensitive to emotion regulation could be studied within the adolescent population.

ERP markers of emotion processing and experimental paradigms for mindfulness research with adolescents

The P300

In comparison to MRI research, the utilisation of ERPs to interpret emotion regulation is still emerging. However, the applications of the P300, described by Polich (2007) as having associations to executive attention, memory updating and retrieval (P3b in particular), the dopaminergic reward system, and the PFC and ACC, all point to its relevance for ER. Particularly the P3b component has been linked to cognitive processing during emotion discrimination tasks, showing sensitivity to modulation by stimulus valence and intensity (Cavanagh & Geisler, 2006), as well as arousal (Briggs & Martin, 2009). The P300 has been shown to detect mindfulness effects in cognitive attention tasks like the attention-blink and Stroop task with neutral stimuli (e.g. Slagter et al., 2007; Moore et al., 2012), indicating that it may also prove a sensitive marker for changes to affective orientation linked to the efficiency of attention processing.

The ERN/ Pe

ER strategies associated with the ACC can be examined through the error-related negativity (ERN) ERP component, which is followed by error positivity (Pe) – both elicited in trials where participants make and review an error (vanVeen & Carter, 2002). There is some discussion over the specific role of the ERN, as Endrass, Reuter and Kathmann (2007) found no difference in ERN responses whether the error was noticed by the individual or not, while the Pe indicated more conscious error awareness. The ERN may be considered a neural correlate of conflict monitoring, signalling the need to increase cognitive control and modulate behaviour (Botvinick, Braver, Barch, Carter & Cohen, 2001). A more negative ERN has been associated with general anxiety (Hajcak, McDonald & Simons, 2003) and negative mood (Hajcak, McDonald & Simons, 2004). The Pe component was unaffected during the anxiety study, and less positive Pe waveforms were reported in Hajcak et al. (2004) for the high negative affect group. This latter result was thought to indicate less salience for the individual when they made an error. Interestingly, a cross-sectional study of non-meditators following either a guided mindfulness practice CD or educational talk demonstrated that the mindfulness induction also impacted on reducing Pe mean amplitudes during error trials in a flanker task (Larson, Steffen & Primosch, 2013). This finding is particularly significant for older adolescents, who typically respond to errors with more positive Pe amplitudes, signalling stronger affective responses than either adults or children (Ladouceur et al., 2007). It could be expected that the kind, accepting attitude of mindfulness contributed to a less positive Pe coupled with adequate response to error (ERN), in contrast to the apathetic Pe reduction seen in people with high negative affect. This is where sensitive self-report measures of error judgements in conjunction with ERP testing might be able to identify the mediating cause behind Pe modulation after mindfulness practice. The long-term effects of meditation on ERN and Pe have been tested by Teper and Inzlicht (2013), with ERN negativity positively correlating with meditation practice without an amplitude increase in Pe. Accurately responding to errors (ERN) without the upsurge in emotion response (Pe) might allow adolescents to learn from their mistakes without self-punishment, a mechanism with clear links to reductions in risk-taking and self-harm that can otherwise result from hyper-critical self-beliefs and negative affect (Klonsky, 2007).

The LPP

Another promising component already tested in adults is the late positive potential (LPP), thought to index attention to emotional stimuli. More LPP positivity is typically found to unpleasant, high-arousal stimuli (Brown et al., 2013) interpreted as reflecting the ‘negativity bias’ of rapid amygdala activation and processing to threatening stimuli (LeDoux, 1995). Importantly, ‘top-down’ projections from the PFC can influence LPP responses, for example, Hajcak and Nieuwenhuis (2006) reported amplitude reduction when unpleasant stimuli were deliberately re-appraised more positively. This is aligned with reductions in amygdala activation and increases in PFC responses seen after mindfulness training (Goldin & Gross, 2010; Goldin, Jazaieri, Hahn & Gross, 2013). Indeed, Brown et al. (2013) found a strong inverse correlation between dispositional mindfulness and the LPP amplitude elicited by high arousal, unpleasant stimuli in a passive picture viewing task. No research linking the LPP to mindfulness training has been conducted with adolescents, but it is known that LPP responses do not reach adult levels of modulation until late adolescence (Zhang et al., 2012). Peak emotional ratings of pictures and LPP amplitudes have been reported in young adolescents (Zhang et al., 2013), corresponding to the undeveloped nature of their ER abilities. It would be interesting to investigate whether mindfulness training can impact on the strength of emotional responses reflected in the LPP modulation in a young adolescent population.

The CNV combined with LPC

The last waveform of interest is the CNV, in conjunction with a late target stimulus-related ERP component, the Late Positive Component (LPC). During a negative emotion ‘priming’ task, more negative CNV amplitudes to the warning stimulus followed by a reduced LPC could represent early preparation (Walter et al., 1964) followed by a reduction of secondary processing and rumination regarding that stimulus (Sitges et al., 2007). This ERP pattern could be used to map improvements in participants' regulation through initial attention deployment and preparation (CNV), as seen in mindfulness research with depressed populations (Bostanov et al., 2012), followed by a withdrawal of appraisal and reduction in rumination (LPC). There is little research on the potential of the LPC to signal adaptive ER but tasks with affective stimuli manipulating an increase or reduction in rumination seem most suitable to test possible modulations of the LPC by mindfulness practice, with more positive LPC amplitudes reflecting less adaptive (more ruminative) processing. Support for this approach comes from Rellecke et al. (2012), where LPC amplitude increased when participants wilfully focussed their attention on affective facial stimuli, indicating the individual's voluntary control over higher cognitive emotion processing. Interestingly, a dispositional study of Australian adolescents reported that higher levels of rumination exacerbate the relationship between self-reported life hassles and depression and anxiety, whereas higher mindfulness levels alleviated these same links (Marks, Sobanski & Hine, 2010). Training young people in mindfulness techniques may therefore work to protect them against the damaging effects of rumination on well-being while dealing with everyday stressors. Potential future studies could examine whether such effects are detectable when measuring LPC and CNV ERP neural markers.

Conclusions

We have argued that the neurodevelopmental perspective belongs to the frontiers of future research on mindfulness in adolescents, and ERP methodology could prove particularly useful in this context. What is needed is an integrative approach where (a) mindfulness programmes are informed by neurodevelopmental trajectories and allow for adaptation in order to target developmentally salient challenges, such as disengaging from affectively salient stimuli or the lessening of peer pressure influences in adolescents; and (b) evaluations of mindfulness curricula focus on the aspects of neurocognitive function targeted by that particular mindfulness programme. For example, an investigation of more negative N2 amplitudes in response to interfering stimuli after mindfulness training, which would reflect more efficient disengagement linked to the development of an accepting attitude. Experiments utilizing ERPs can be particularly helpful here because of their functional sensitivity to shifts in attention control, the low cost of EEG equipment, and its portability which enables more naturalistic experimental testing in schools beyond the restrictive lab environment. To enable broader utilization of ERPs in developmental intervention studies on mindfulness, there is a need for more basic research on reliable ERP markers. This is particularly relevant to investigations of ER since studies in both adults and children are scarce. The initial research points to modulations of the LPP by emotion regulation strategies (Hajcak & Nieuwenhuis, 2006) and by trait mindfulness (Brown et al., 2013), but in the absence of longitudinal and developmental studies it is not clear how mindfulness as a unique ER strategy could modify the LPP component. It is also possible that with more mindfulness practice the mindful ER strategy would lead to modulation of ERP components (such as the P300) peaking earlier than the LPP. This would be due to shifts in more automatic responding to emotionally salient stimuli as suggested by adult *f*MRI research with beginners and long-term meditation practitioners (Taylor et al., 2011). Given the paucity of available research on ER with ERPs, measures of attention control and efficiency may be the most prudent outcomes to begin researching developmentally, as the ERP findings of mindfulness training in adults allow for more confident predictions; i.e. more negative N2 (Moore et al., 2012) and less P300 positivity (Slagter et al., 2007).

In addition, researchers and mindfulness trainers need to work together attuning mindfulness programmes for developmentally and population (e.g. gender) specific features, such as adjustments to the frequency and length of home practices. Collaborations are needed in the evaluation process, to include converging assessments from self-reports and neurocognitive measures in combination with behavioural assessments from teachers and parents (where appropriate). And ideally, such research would inform education policy, focusing on investigating changes in variables that are high on school policy agendas such as metacognition, attention, and well-being. An example would be to study changes in adolescent mind wandering after mindfulness training, which would investigate shifts in self-reported mind wandering together with modifications in target detection accuracy and the P3b amplitudes reflecting attention efficiency. These findings could be linked to well-being assessments and behavioural reports of pupil's self-regulation from teachers, as well as academic attainment records. The neurocognitive evidence would be key in this multidisciplinary approach since only neurodevelopmental experimental paradigms can address focused questions about the endogenous trajectories of change in emotion regulation and attention with school based mindfulness programmes. In this way, neurocognitive research can provide pivotal evidence for education policy makers. A similar approach has been applied by the Neville lab to assess the neurocognitive basis of poor attention performance in children from lower socio-economic status (SES) backgrounds. Their findings guided focused interventions, which enhanced attention abilities in children from lower SES families (Stevens, Fanning, Coch, Sanders & Neville, 2008).

To conclude, it is our hope that the considerations and research suggestions outlined in this paper will inspire more researchers to adopt an integrative neurodevelopmental approach to the study of mindfulness, particularly using ERP methodology. This will in turn boost our understanding of underlying mechanisms and help us fully harness the potential of mindfulness practice to improve well-being and support the neurocognitive development of adolescents.

ERP components of interest and corresponding research summary table

Event Related Potential	Definition	Experimental Paradigm / Task	Adolescent Patterns	Adult Patterns	Predictions for adolescents trained in mindfulness practices
Contingent Negative Variation (CNV)	A slow-building negative waveform that emerges in the period between a warning and imperative stimuli. It has a frontal/ central distribution, and signals preparatory motor activity, sensory anticipation, and the activation of attention (Walter et al., 1964).	• Priming task with informative and non-informative warning stimuli (primes)	• Killikelly & Szucs (2013) proactive response activation towards an imminent target, which correlates with more negative CNV amplitudes, is dampened in older adolescents compared to young adults.	• Bostanov et al. (2012) - mindfulness practice leads to a more negative CNV in depressed adult populations, who have dampened pre-intervention CNV activity before the intervention.	• The CNV can detect facilitation of anticipatory attention processes after mindfulness interventions, as indicated by converging evidence on developmental CNV modulation in adolescents (Killikelly & Szucs, 2013) and its modifiability through mindfulness training in depressed populations (Bostanov et al., 2012). • More negative CNV amplitudes could be expected after training.
Visual-N2	The visual-N2 is a negative deflection with frontal/ central distribution, and it signals task-specific inhibition (Falkenstein et al., 1999) and conflict monitoring (Ladouceur et al., 2007). The N2 can also be detected at occipital	• Inhibition or detection task • Stroop Test (Stroop, 1935) • Go, No-Go Task (Donders, 1969) • D2 (Brinckenkamp, 1962) • Attention Network Test – conflict	• Ladouceur, Dahl, & Carter (2007) mapped out N2 development in conflict monitoring tasks. They found more negative amplitudes in older adolescents and adults compared to younger teens during incongruent trials. This suggests more efficient and	• Moore et al. (2012) - more negative N2 response after mindfulness training in Stroop task. This modulation has also been linked to reduced P3 positivity, suggesting that stronger inhibition reduces the cost of attentional resources on goal-irrelevant stimuli.	• More negative N2 amplitudes could be expected after mindfulness training in adolescent populations, reflecting more mature patterns of inhibition (Ladouceur et al., 2007). • N2 amplitudes should correlate with P3 responses and performance accuracy in odd-ball or SART (Robertson et al., 1997) paradigms, given that increased N2 may result in a reduction of P3b amplitude

	sites (Fabiani et al., 2000).	monitoring task (Fan et al., 2002) • Odd-ball paradigms	mature processing in older adolescents, comparable to adult levels.		while maintaining or increasing task accuracy and vigilance. • Possible links between N2 modulation and well-being since better inhibition has partially mediated increased well-being in adults (Sauer et al., 2011).
P300 **Specific interest in P3b sub-component*	The P300 (P3-family of positive components) is elicited in response to salient stimulus events, thus allocating mental resources to attention and memory operations associated with stimulus processing (Polich, 2007). The P3b specifically has a centro-parietal distribution and is linked to stimulus categorisation and processing, as well as updating working memory (Sutton et al., 1965).	• Focussed attention and executive tasks • Dual-task paradigms e.g. n-back (Watter et al., 2001) and task-switching (Kieffaber & Hetrick, 2005) • Attentional-Blink Paradigm (Raymond et al., 1992) • Stroop (Stroop, 1935) • Odd-ball paradigm • Sustained Attention to Response Task (SART: Robertson et al., 1997)	• Brumback et al. (2012) the developmental maturity of P300 amplitude and latency responses during a visual odd-ball task develops sooner in females (i.e. shorter P300 latency and less positive P300 waveforms). This suggests that males have a slower developmental trajectory, and executive attention in particular is still developing well into older adolescence.	• Slagter et al. (2007) - improved T2 detection after mindfulness training in the Attention-Blink task. Performance was associated with reduced T1-elicited P3b amplitude over time, suggesting more efficient orientating and alerting. • Moore et al. (2012) - P3b amplitude reduction during Stroop task on incongruous targets after mindfulness training. This suggests a reduced cost on attention resources for target inhibition. • Smallwood et al. (2008) less mind wandering correlates with greater P3b mean amplitudes during the SART, suggesting more consistent attention processing. Mind wandering has also been shown to reduce after mindfulness practice (Mrazek et al., 2012) suggesting that P3b	• Attention-blink paradigm is a possible ERP marker to map the development of orientating and alerting performance in adolescents, and could be particularly useful in relation to high impulsivity (Ray Li et al., 2005), reflected in improvements to T2 detection and associated decreases in P3b to T1. • Paulluel et al. (2010) 14-15 years is the turning point for dual-task performance. So adult levels of performance could be anticipated in older adolescents, reflected in reduced P300 amplitudes in Stroop or task-switching paradigms. • Where post-intervention P3b amplitude is reduced, a corresponding increase is anticipated for early components e.g. CNV or N2, signalling better preparation, detection, or inhibition. • Similar mind wandering effects could be anticipated in

				amplitudes would be a useful psycho-physiological marker of mind wandering reduction after mindfulness training.	adolescents as in adults (Smallwood et al., 2008; Mrazek et al., 2012), impacting learning and academic performance.
Error Related Negativity (ERN) and error Positivity (Pe)	ERN is a negative deflection over fronto-central sites, signifying attention to an error deviating from goal-directed behaviour (Falkenstein et al., 1991). This is followed by error Positivity (Pe), which is sensitive to the subsequent appraisal of error severity (Overbeek et al., 2005).	• Any task requiring accuracy, with higher likelihood of errors that can be detected or alerted to • Stroop Task (Stroop, 1935) • Flanker Task (Eriksen & Eriksen, 1974)	• Ladouceur et al. (2007) reported that Pe amplitudes showed a developmental peak in older adolescents, responding to errors with more positive amplitudes than either young adolescent or adult participants.	• Long-term effects of meditation on ERN and Pe have been tested by Teper and Inzlicht (2013). ERN negativity positively correlated with meditation practice, and emotional acceptance, without an amplitude increase in Pe, following Stroop task errors. • Larson et al. (2013), a cross-sectional study of non-meditators following either a guided mindfulness CD or educational talk. Mindfulness induction corresponded with reduced Pe mean amplitudes after errors on the Eriksen Flanker Task.	• Accurately identifying errors (more negative ERN) without the upsurge in emotional response (no change or less positive Pe amplitude), might allow adolescents to learn from their mistakes without self-punishment. This mechanism could have links to reducing hyper-critical self-judgment that can otherwise result in extreme risk-taking and self-harm (Klonsky, 2007).
Late Positive Potential (LPP)	A slow-building positive waveform, with a central /posterior distribution. Considered to be a neural marker of emotional arousal, reflecting preferential processing and encoding of motivationally	• Passive viewing or hearing of affective stimuli • Affect labelling task • Affect induction / regulation tasks (e.g. Hajcak & Nieuwenhuis, 2006)	• LPP response modulation does not reach adult levels until late adolescence (Zhang et al., 2012). Developmental increases indicate more adaptive attention processing.	• Brown et al. (2013) found a strong inverse correlation between dispositional mindfulness and the LPP amplitude elicited by high arousal, unpleasant stimuli in a passive IAPS picture-viewing task.	• Mindfulness training may impact on the strength of emotional responses, reflected in LPP amplitude reduction (possibly linked to less arousal and better emotion regulation), in the young adolescent population (Zhang et al., 2013).

	relevant stimuli (Brown et al., 2013).		• Zhang et al., (2013), peak emotional ratings of pictures and LPP amplitudes reported in young adolescents, corresponding to the undeveloped nature of their ER abilities.		
Late Positive Complex (LPC)	Positive, broad-peaking waveform with a parietal distribution. It is associated with deep processing (Rellecke et al., 2012), memory recall (Schaefer et al., 2011), and affective rumination (Sitges et al., 2007).	• Passive viewing or hearing affective stimuli • Negative emotion 'priming' tasks, combining CNV and LPC neural markers to map regulation through initial attention deployment (CNV), followed by reduction in rumination (LPC). • Affect labelling task	• Marks et al. (2010) found that higher levels of rumination exacerbate the relationship between self-reported life hassles and depression and anxiety, whereas higher dispositional mindfulness can alleviate these same links.	• Rellecke, Sommer & Schacht (2012) LPC mean amplitude increases were induced only when participants intentionally focussed attention on affective facial stimuli, indicating individual's voluntary control over higher cognitive emotion processing.	• Initial correlational studies measuring dispositional mindfulness, trait rumination and the LPC in adolescents could provide useful insights – increased rumination and decreased mindfulness should be linked to less positive LPC amplitudes. • Training adolescents in mindfulness techniques may protect them against the damaging effects of rumination on well-being (Marks et al., 2010), reflected in reduced LPC. • Future studies could test the process of change in ER using LPC and CNV ERP neural markers.

References

Atkins, S. M., Bunting, M. F., Bolger, D. J., & Dougherty, M. R. (2012). Training the adolescent brain: Neural plasticity and the acquisition of cognitive abilities. In V. F. Reyna, S. B. Chapman, M. R. Dougherty & J. Confrey (Eds.), *The Adolescent Brain: Learning, Reasoning, and Decision Making* (pp. 211-242). Washington, DC: American Psychological Association.

Baer, R. A. (2003). Mindfulness Training as a Clinical Intervention: A Conceptual and Empirical Review. *Clinical Psychology: Science and Practice, 10(2)*, 125-143.

Bares, M., Nestrasil, I., & Rektor, I. (2007). The effect of response type (motor output versus mental counting) on the intracerebral distribution of the slow cortical potentials in an externally cued (CNV) paradigm. *Brain Research Bulletin, 71,* 428-435.

Biegel, G. M. (2009). The Stress Reduction Workbook for Teens: Mindfulness skills to help you deal with stress. California: New Harbinger Publications.

Biegel, G. M., Brown, K. W., Shapiro, S. L., & Schubert, C. M. (2009). Mindfulness-Based Stress Reduction for the Treatment of Adolescent Psychiatric Outpatients: A Randomised Clinical Trial. *Journal of Consulting and Clinical Psychology, 77(5)*, 855-866.

Bishop, S. R., Lau, M., Shapiro, S., Carlson, L., Anderson, N. D., Carmody, J., Segal, Z. V., Abbey, S., Speca, M., Velting, D., & Devins, G. (2004). Mindfulness: A proposed operational definition. *Clinical Psychology: Science and Practice, 11(3)*, 230-241.

Black, D. S., Milam, J., & Sussman, S. (2009). Sitting-Meditation Interventions Among Youth: A Review of Treatment Efficacy. *Pediatrics, 124(3)*, 532-541.

Bogels, S., Hoogstad, B., van Dun, L., de Schutter, S., & Restifo, K. (2008). Mindfulness training for adolescents with externalising disorders and their parents. *Behaviour and Cognitive Psychotherapy, 36(2),* 193-209.

Bostanov, V., Keune, P. M., Kotchoubey, B., & Hautzinger. M. (2012). Event-related brain potentials reflect increased concentration ability after mindfulness-based cognitive therapy for depression: A randomized clinical trial. *Psychiatry Research, 199*, 174-180.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological review, 108(3),* 624-652.

Bradshaw, C. P., Goldweber, A., Fishbein, D., & Greenberg, M. T. (2012). Infusing Developmental

Neuroscience Into School-based Preventative Interventions: Implications and Future Directions. *Journal of Adolescent Health, 51(2),* S41-S47.

Brickenkamp, R. (1962). Aufmerksamkeits-Belastungs-Test (Test d2). Göttingen: Hogrefe.

Briggs, K. E., & Martin, F. H. (2009). Affective picture processing and motivational relevance: arousal and valence effects on ERPs in an oddball task. *International Journal of Psychophysiology*, *72(3),* 299-306.

Broderick, P. C. (2013). Learning to Breathe: A mindfulness curriculum for adolescents to cultivate emotion regulation, attention, and performance. California: New Harbinger Publications.

Broderick, P. C. & Metz, S. (2009). Learning to BREATHE: A pilot trial of a mindfulness curriculum for adolescents. *Advances in School Mental Health Promotion. 2(1)*, 35-46.

Brown, K. W., Goodman, R. J., & Inzlicht, M. (2013). Dispositional mindfulness and the attenuation of neural responses to emotional stimuli. *Social, Cognitive, Affective Neuroscience, 1(8)*, 93-99.

Brown, K. W., Ryan, R. M., & Creswell, J. D. (2007). Mindfulness: Theoretical Foundations and Evidence for its Salutary Effects. *Psychological Inquiry, 18(4)*, 211-237.

Brumback, T. Y., Arbel, Y., Donchin, E., & Goldman, M. S (2012). Efficiency of responding to unexpected information varies with sex, age, and pubertal development in early adolescence. *Psychophysiology, 49(10)*, 1330-1339.

Burke, C. A. (2010). Mindfulness-Based Approaches with Children and Adolescents: A Preliminary Review of Current Research in an Emergent Field. *Journal of Child and Family Studies*, *19(2)*, 133-144.

Cavanagh, J., & Geisler, M. W. (2006). Mood effects on the ERP processing of emotional intensity in faces: A P3 investigation with depressed students. *International Journal of Psychophysiology*, *60(1)*, 27-33.

Chambers, R., Lo, B. C. Y., & Allen, N. B. (2008). The impact of intensive mindfulness training on attentional control, cognitive style, and affect. *Cognitive Therapy and Research*, *32(3)*, 303-322.

Chan, D., & Woollacott, M. (2007). Effects of level of meditation experience on attentional focus: is the efficiency of executive or orientation networks improved? *The Journal of Alternative and Complementary Medicine, 13(6),* 651-658.

Chapman, H. A., Woltering, S., Lamm, C., & Lewis, M .D. (2010). Hearts and minds: Coordination of neurocognitive and cardiovascular regulation in children and adolescents. *Biological Psychology, 84(2)*, 296-303.

Chiesa, A., Calati, R., & Serretti, A. (2011). Does mindfulness training improve cognitive abilities? A systematic review of neuropsychological findings. *Clinical Psychology Review, 31(3)*, 449-464.

Creswell, J. D., Way, B. M., Eisenberger, N. I., & Lieberman, M. F. (2007). Neural Correlates of Dispositional Mindfulness During Affect Labeling. *Psychosomatic Medicine, 69,* 560–565.

Davidson, R. J., Dunne, J., Eccles, J. S., Engle, A., Greenberg, M., Jennings, P., Jha, A., Jinpa, T., Lantieri, L., Meyer, D., Roeser, R. W., & Vago, D. [The Mind and Life Education Research Network: MLERN]. (2012). Contemplative Practices and Mental Training: Prospects for American Education. *Child Development Perspectives, 6(2)*, 146-153.

Deng, Y. Q., Li, S., & Tang, Y. Y. (2014). The relationship between wandering mind, depression and mindfulness. *Mindfulness, 5(2)*, 124-128.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual review of neuroscience, 18(1)*, 193-222.

Desrosiers, A., Vine, V., Curtiss, J., & Klemanski, D. H. (2014). Observing nonreactively: A conditional process model linking mindfulness facets, cognitive emotion regulation strategies, and depression and anxiety symptoms. *Journal of affective disorders*, *165*, 31-37.

Dewulf, D. (2009). *Mindfulness voor jongeren*. Tielt, Belgium: Lannoo.

Donders, F. C. (1969). On the speed of mental processes. *Acta Psychologica, 30*, 412-431.

Dorjee, D., & Bowers, J. S. (2012). What can *f*MRI tell us about the locus of learning?. *Cortex*, *48(4),* 509-514.

Dreher, J. C., & Grafman, J. (2003). Dissociating the roles of the rostral anterior cingulate and the lateral prefrontal cortices in performing two tasks simultaneously or successively. *Cerebral Cortex*, *13(4),* 329-339.

Duncan, J., Humphreys, G., & Ward, R. (1997). Competitive brain activity in visual attention. *Current opinion in neurobiology, 7(2)*, 255-261.

Dweck, C. (2008). Can personality be changed? The role of beliefs in personality and change. *Current*

Directions in Psychological Science, *17(6)*, 391-394.

Dywan, J., Mathewson, K. J., Choma, B. L., Rosenfeld, B., & Segalowitz, S. J. (2008). Autonomic and electrophysiological correlates of emotional intensity in older and younger adults. *Psychophysiology, 45(3)*, 389-397.

Eberth, J., & Sedlmeier, P. (2012). The Effects of Mindfulness Meditation: A Meta-Analysis. *Mindfulness, 3(3)*, 174-189.

Endrass, T., Reuter, B., & Kathmann, N. (2007). ERP correlates of conscious error recognition: aware and unaware errors in an antisaccade task. *European Journal of Neuroscience, 26(6)*, 1714-1720.

Ernst, M., Pine, D. S., & Hardin, M. (2006). Triadic model of the neurobiology of motivated behaviour in adolescence. *Psychological Medicine, 36(3)*, 299-312.

Fabiani, M., Gratton, G., & Coles, M. G. H. (2000). Event-related brain potentials: Methods, Theory, and Applications. In J. T. Cacioppo, L. G. Tassinary, & G. G. Bernston [Eds.] *Handbook of Psychophysiology, 2nd Edition* (pp. 53-84). United States of America: Cambridge University Press.

Falkenstein, M., Hohnsbein, J., Hoormann, J., & Blanke, L. (1991). Effects of cross-modal divided attention on late ERP components. Error processing in choice reaction tasks. *Electroencephalography and Clinical Neurophysiology, 78*, 447-455.

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (1999) ERP components in Go/Nogo tasks and their relation to inhibition. *Acta Psychologica, 101*, 267-291.

Fan, J., McCandliss, B.D., Sommer, T., Raz, A., Posner, M.I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14(3)*, 340–347.

Flook, L., Smalley, S. L., Kitil, M. J., Galla, B. M., Kaiser-Greenland, S., Locke, J., Ishijima, E., & Kasari, C. (2010). Effects of Mindfuln Awareness Practices on Executive Functions in Elementary School Children. *Journal of Applied School Psychology, 26(1)*, 70-95.

Foret, M. M., Scult, M., Wilcher, M., Chudnofsky, R., Malloy, L., Hasheminejad, N., & Park, E. R. (2012). Integrating a relaxation response-based curriculum into a public high school in Massachusetts. *Journal of Adolescence, 35(2)*, 325-332.

Gard, T., Hölzel, B.K., Sack, A.T., Hempel, H., Lazar, S.W., Vaitl, D., & Ott, U. (2012). Pain mitigation through mindfulness is associated with decreased cognitive control and increased sensory processing in the brain. *Cerebral Cortex, 22(11)*, 2692-2702.

Gardner, M., & Steinberg, L. (2005). Peer influence on risk taking, risk preference, and risky decision making in adolescence and adulthood: an experimental study. *Developmental psychology*, *41(4)*, 625.

Goldin, P. R., & Gross, J. J. (2010). Effects of mindfulness-based stress reduction (MBSR) on emotion regulation in social anxiety disorder. *Emotion*, *10(1)*, 83-91.

Goldin, P., Ziv, M., Jazaieri, H., Hahn, K., & Gross, J. J. (2013). MBSR vs aerobic exercise in social anxiety: fMRI of emotion regulation of negative self-beliefs. *Social cognitive and affective neuroscience*, 8*(1)*, 65-72.

Gould, L. F., Dariotis, J. K., Mendelson, T., & Greenberg, M. (2012). A SCHOOL-BASED MINDFULNESS INTERVENTION FOR URBAN YOUTH: EXPLORING MODERATORS OF INTERVENTION EFFECTS. *Journal of Community Psychology*, *40*(8), 968-982.

Grant, J. A., Courtemanche, J., & Rainville, P. (2011). A non-elaborative mental stance and decoupling of executive and pain-related cortices predicts low pain sensitivity in Zen meditators. *Pain*, *152(1)*, 150-156.

Greenberg, M. T., & Harris, A. R. (2012). Nurturing Mindfulness in Children and Youth: Current State of Research. *Child Development Perspectives, 6(2)*, 161-166.

Greenberg, M. T., & Rhoades, B. L. (2008). State of science review: Self regulation and executive function – What can teachers and schools do? London: Office of Science and Innovation, Foresight Project: Mental Capital and Mental Wellbeing.

Gross, J. J., & Thompson, R. A. (2007). Emotion Regulation: Conceptual Foundations. In J. J. Gross (Ed.), Handbook of Emotion Regulation, (pp. 3-24). New York: Guildford Press.

Grossman, P., Niemann, L., Schmidt, S., & Walach, H. (2004). Mindfulness-based stress reduction and health benefits: A meta-analysis. *Journal of Psychosomatic Research, 57(1)*, 35-43.

Hajcak, G., McDonald, N., & Simons, R. F. (2003). Anxiety and error-related brain activity. *Biological Psychology, 64(1-2)*, 77-90.

Hajcak, G., McDonald, N., & Simons, R. F. (2004). Error-related psychophysiology and negative affect. *Brain and Cognition, 56(2)*, 189-197.

Hajcak, G., & Nieuwenhuis, S. (2006). Reappraisal modulates the electrocortical response to unpleasant pictures. *Cognitive, Affective & Behavioural Neuroscience*. Vol 6*(4)*, p. 291-297.

Hofmann, S. G., Sawyer, A. T., Witt, A. A., & Oh, D. (2010). The Effect of Mindfulness Based Therapy on Anxiety and Depression: A Meta-Analytic Review. *Journal of Clinical Psychology*, *78(2)*, 169-183.

Hölzel, B. K., Lazar, S. W., Gard, T., Schuman-Olivier, Z., Vago, D. R., & Ott, U. (2011). How Does Mindfulness Meditation Work? Proposing Mechanisms of Action From a Conceptual and Neural Perspective. *Perspectives on Psychological Science, 6(6)*, 537-559.

Hölzel, B.K., Ott, U., Hempel, H., Hackl, A., Wolf, K., Stark, R., & Vaitl, D. (2007). Differential engagement of anterior cingulate and adjacent medial frontal cortex in adept meditators and non-meditators. *Neuroscience Letters*, *421(1)*, 16–21.

Huppert, F. A., & Johnson, D. M. (2010). A controlled trial of mindfulness training in schools: The importance of practice for an impact on well-being. *Journal of Positive Psychology*, *5(4)*, 264-274.

Jha, A. P., Krompinger, J., & Baime, M. J. (2007). Mindfulness training modifies subsystems of attention. *Cognitive, Affective, & Behavioural Neuroscience, 7(2)*, 109-119.

Justo, C. F. (2009). Efectos de un programa de meditación sobre los niveles de creatividad verbal de un grupo de alumnos/as de Bachillerato. *Revista Suma Psicológica*, *16*(2), 113-120.

Kabat-Zinn, J. (1990). Full catastrophe living: Using the wisdom of your body and mind to face stress, pain, and illness. New York: Delacorte.

Kabat-Zinn, J. (1994). Wherever you go, there you are: Mindfulness meditation in everyday life. New York:Hyperion.

Kaplan, D. S., Liu, R. X., & Kaplan, H. B. (2005) School related stress in early adolescence and academic performance three years later: the conditional influence of self expectations. *Social Psychology of Education, 8(1)*, 3-17.

Kieffaber, P. D., & Hetrick, W. P. (2005). Event-related potential correlates of task switching and switch costs. *Psychophysiology, 42(1),* 56-71.

Killikelly, C., & Szucs, D. (2013). Delayed development of proactive response preparation in adolescents: ERP and EMG evidence. *Developmental Cognitive Neuroscience, 3*, 33-45.

Kinder Associates LLC. (2002). Programme information retrieved 05/12/2013: http://www.wellnessworksinschools.com/

Klonsky, E. D. (2007). The functions of deliberate self-injury: A review of the evidence. *Clinical Psychology Review*, *27(2),* 226-239.

Kramer, A. F., Wickens, C. D., & Donchin, E. (1985). Processing of stimulus properties: evidence for dual-task integrality. *Journal of Experimental Psychology and Human Perception Performance, 11(4)*, 393-408.

Kratz, O., Studer, P., Malcherek, S., Erbe, K., Moll, G. H., & Heinrich, H. (2011). Attention processes in children with ADHD: An event-related potential study using the attention network test. *International Journal of Psychophysiology, 81(2)*, 82-90.

Kuyken, W., Weare, K., Ukoumune, O. C., Vicary, R., Motton, N., Burnett, R., Cullen, C., Hennelly, S., & Huppert, F. (2013). Effectiveness of the Mindfulness in Schools Programme: Non-randomised controlled feasibility study. *The British Journal of Psychiatry, 203(2)*, 126-131.

Ladouceur, C. D., Dahl, R. E., & Carter, C. S. (2007). Development of action monitoring through adolescence into adulthood: ERP and source localisation. *Developmental Science, 10(6)*, 874-891.

Larson, M. J., Steffen, P. R., & Primosch, M. (2013). The impact of a brief mindfulness meditation intervention on cognitive control and error-related performance monitoring. *Frontiers in Human Neuroscience, 7(308)*. doi: 10.3389/fnhum.2013.00308.

LeDoux, J. E. (1995). Emotion: Clues from the brain. *Annual Review of Psychology, 46(1)*, 209-235.

Lee, H., Heller, A. S., van Reekum, C. M., Nelson, B., & Davidson, R. J. (2012). Amygdala-prefrontal coupling underlies individual differences in emotion regulation. *NeuroImage, 62(3)*, 1575-1581.

Luck, S. J. (2014). An introduction to the event-related potential technique (2nd ed.). MIT press.

Lutz, A., Slagter, H. A., Dunne, J. D., & Davidson, R. J. (2008). Attention regulation and monitoring in meditation. *Trends in Cognitive Sciences, 12(4)*, 163-169.

MacLeod, J. W., Lawrence, M. A., McConnell, M. M., Eskes, G. A., Klein, R. M., & Shore, D. I. (2010). Appraising the ANT: Psychometric and theoretical considerations of the Attention Network Test. *Neuropsychology, 24(5)*, 637-651.

Malinowski, P. (2013). Neural mechanisms of attentional control in mindfulness meditation. *Frontiers in Neuroscience, 7*, 8.

Marks, A. D., Sobanski, D. J., & Hine, D. W. (2010). Do dispositional rumination and/or mindfulness moderate the relationship between life hassles and psychological dysfunction in adolescents? *Australian and New Zealand Journal of Psychiatry*, *44(9),* 831-838.

Meiklejohn, J., Phillips, C., Freedman, L., Griffin, M. L., Biegel, G., Roach, A., Frank, J., Burke, C., Pinger, L., Soloway, G., Isberg, R., Sibinga, E., Grossman, L., & Saltzman, A. (2012). Intergrating Mindfulness Training into K-12 Education: Fostering the Resilience of Teachers and Students. *Mindfulness, 3(4)*, 291-307.

Mindful Schools non-profit organisation. (2010). Programme information retrieved 05/12/2013 from: http://www.mindfulschools.org/

Mindfulness in Education. (2014). Retrieved 27/02/2014 from: http://www.bangor.ac.uk/mindfulness/education.php.en

Mooneyham, B. W., & Schooler, J. W. (2013). The costs and benefits of mind-wandering: a review. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale, 67(1)*, 11-18.

Moore, A., Gruber, T., Derose, J., & Malinowski, P. (2012). Regular, brief mindfulness meditation practice improved electrophysiological markers of attentional control. *Frontiers in Human Neuroscience, 6(18)*. doi: 10.3389/fnhum.2012.00018.

Moore, A., & Malinowski, P. (2009). Meditation, mindfulness and cognitive flexibility. *Consciousness and Cognition*, *18(1)*, 176-186.

Mrazek, M. D., Smallwood, J., & Schooler, J. W. (2012). Mindfulness and mind-wandering: finding convergence through opposing constructs. *Emotion*, *12(3),* 442.

Nagai, Y., Critchley, H. D., Featherstone, E., Fenwick, P. B. C., Trimble, M. R., & Dolan, R. J. (2004). Brain activity relating to the contingent negative variation: an fMRI investigation. *NeuroImage*, *21,* 1232-1241.

Oberle, E., Schonert-Reichl, K. A., Lawlor, M. S., & Thomson, K. C. (2012). Mindfulness and inhibitory control in early adolescence. *Journal of Early Adolescence*, *32(4)*, 565-588.

Ochsner, K. N., Bunge, S. A., Gross, J. J., & Gabrieli, J. D. E. (2002). Rethinking Feelings: An *f*MRI study of the cognitive regulation of emotion. *Journal of Cognitive Neuroscience*, *14(8)*, 1215-1229.

Ochsner, K. N., & Gross, J. J. (2005). The cognitive control of emotion. *Trends in Cognitive Sciences*, *9(5)*, 242-249.

Ortner, C. N. M., Kilner, S. J., & Zelazo. P. D. (2007). Mindfulness meditation and reduced emotional interference on a cognitive task. *Motivation and Emotion, 31(4)*, 271-283.

Overbeek, T. J. M., Nieuwenhuis, S., & Ridderinkhof, K. R. (2005). Dissociable components of error processing: On the functional significance of the Pe vis-avis the ERN/Ne. *Journal of Psycho-Physiology, 19,* 319-329.

Palluel, E., Nougier, V., & Olivier, I. (2010). Postural control and attentional demand during adolescence. *Brain Research*, *1358*, 151-159.

Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience, 35*, 73-89.

Petter, M., McGrath, P. J., Chambers, C. T., & Dick, B. D. (2014). The Effects of Mindful Attention and State Mindfulness on Acute Experimental Pain among Adolescents. *Journal of Pediatric Psychology*, 39*(5)*, 521-531.

Picton, T. W., Bentin, S., Berg, P., Donchin, E., Hillyard, S. A., Johnson, R., Miller, G. A., Ritter, W., Ruchkin, D. S., Rugg, M. D., & Taylor, M. J. (2000). Guidelines for using human event-related potentials to study cognition: recording standards and publication criteria. *Psychophysiology, 37(2)*, 127-152.

Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology*, *118(10)*, 2128-2148.

Posner, M. I. (2008). Measuring alertness. *Annals of the New York Academy of Sciences*, *1129(1),* 193-199.

Posner, M. I., & Petersen, S. E. (1990). The attention systems of the human brain. *Annual Review of Neuroscience, 13*, 25-40.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception & Performance, 18(3)*, 849-860.

Raes, F., Griffith, J. W., Van der Gucht, K., & Williams, J. M. G. (2013). School-based prevention and reduction of depression in adolescents: A cluster-randomized controlled trial of a mindfulness group program. *Mindfulness*, 1-10.

Ray Li, C. S., Chen, S. H., Lin, W. H., & Yang, Y. Y. (2005). Attentional blink in adolescents with varying levels of impulsivity. *Journal of psychiatric research*, *39(2),* 197-205.

Raz, A., & Buhle, J. (2006). Typologies of attentional networks. *Nature Reviews Neuroscience, 7(5)*, 367-379.

Rellecke, J., Sommer, W., & Schacht, A. (2012). Does processing of emotional facial expressions depend on intention? Time-resolved evidence from event-related brain potentials. *Biological psychology*, *90(1),* 23-32.

Robertson, I. H., Manly, T., Andrade, J., Baddeley, B. T., & Yiend, J. (1997). Oops!: Performance correlates of everyday attentional failures in traumatic brain injured and normal subjects. *Neuropsychologia, 35(6)*, 747-758.

Roeser, R. W., & Peck, S. C. (2009). An Education in Awareness: Self, Motivation, and Self Regulated Learning in Complemplative Perspective. *Educational Psychology, 44(2)*, 119-136.

Ros, T., Théberge, J., Frewen, P. A., Kluetsch, R., Densmore, M., Calhoun, V. D., & Lanius, R. A. (2013). Mind over chatter: plastic up-regulation of the fMRI salience network directly after EEG neurofeedback. *Neuroimage. 65,* 324-335.

Saltzman, A., & Goldin, P. (2008). Mindfulness based stress reduction for school-aged children. In: S.C. Hayes & L. A. Greco (eds.). Acceptance and mindfulness interventions for children, adolescents, and families (pp. 139-161). California: Context Press / New Harbinger.

Schaefer, A., Pottage, C. L., & Rickart, A. J. (2011). Electrophysiological correlates of remembering emotional pictures. *NeuroImage, 54(1)*, 714-724.

Scherer, K. R. (2000). Psychological models of emotion. In J. Borod (Eds.), *The neuropsychology of emotion* (pp. 137–162). Oxford/New York: Oxford University Press.

Schonert-Reichl, K. A., & Lawlor, M. S. (2010). The effects of a mindfulness-based education program on pre-and early adolescents' well-being and social and emotional competence. *Mindfulness*, *1(3),* 137-151.

Segal, Z., Williams, J. M. G., & Teasdale, J. D. (2002). Mindfulness-based cognitive therapy for depression: A new approach to relapse prevention. New York: The Guildford Press.

Shackman, A. J., Maxwell, J. S., McMenamin, B. W., Greischar, L. L., & Davidson, R. J. (2011). Stress potentiates early and attenuates late stages of visual processing. *Journal of Neuroscience, 31(3)*, 1156-1161.

Shackman, A. J., Sarinopoulos, I., Maxwell, J. S., Pizzagalli, D. A., Lavric, A., & Davidson, R. J. (2006). Anxiety selectively disrupts visuospatial working memory. *Emotion*, *6(1)*, 40-61.

Shapiro, S. L., Carlson, L. E., Astin, J. A., & Freedman, B. (2006). Mechanisms of Mindfulness. *Journal of Clinical Psychology*, *62(3)*, 373-386.

Siegel, R. D., Germer, C. K., & Olendzki, A. (2008). Chapter from: Didonna, F. (Editor). *Clinical Handbook of Mindfulness.* New York: Springer. Distributed by permission by The National Institute for the Clinical Application of Behavioural Medicine.

Sitges, C., Garcia-Herrera, M., Pericas, M., Collado, D., Truyols, M., & Montoya, P. (2007). Abnormal brain processing of affective and sensory pain descriptors in chronic pain patients. *Journal of Affective Disorders, 104,* 73-82.

Slagter, H. A., Lutz, A., Greischar, L. L., Francis, A. D., Nieuwenhuis, S., Davis, J. D., & Davidson, R. J. (2007). Mental training affects distribution of limited brain resources. *PLoS Biology, 5(6)*, 1228-1235.

Smallwood, J., Beach, E., Schooler, J. W., & Handy, T. C. (2008). Going AWOL in the Brain: Mind Wandering Reduces Cortical Analysis of External Events. *Journal of Cognitive Neuroscience*, *20(3)*, 458-469.

Spear, L. P. (2013). Adolescent Neurodevelopment. *Journal of Adolescent Health, 52(2)*, S7-S13.

Steinberg, L. (2010). A behavioural scientist looks at the science of adolescent brain development. *Brain and Cognition*, *72(1)*, 160-164.

Steinberg, L. (2005). Cognitive and affective development in adolescence. *Trends in Cognitive Sciences*, *9(2)*, 69-74.

Stevens, C., Fanning, J., Coch, D., Sanders, L., & Neville, H. (2008). Neural mechanisms of selective auditory attention are enhanced by computerized training: Electrophysiological evidence from language-impaired and typically developing children. *Brain Research, 1205*, 55-69.

Stroop, J. R. (1935) Studies of interference in serial verbal reactions. *Journal of Experimental*

Psychology, 18(6), 643-662.

Sutton, S., Braren, M., Zubin, J., & John, E. R. (1965). Evoked-potential correlates of stimulus uncertainty. *Science, 150(3700)*, 1187-1188.

Tang, Y. Y., Hölzel, B. K., & Posner, M. I. (2015). The neuroscience of mindfulness meditation. *Nature Reviews Neuroscience, 16*, 213-225.

Taylor, V. A., Grant, J., Daneault, V., Scavone, G., Breton, E., Roffe-Vidal, S., Courtmanche, J., Lavarenne, A. S., & Beauregard, M. (2011). Impact of mindfulness on the neural responses to emotional pictures in experienced and beginner meditators. *NeuroImage, 57(4)*, 1524-1533.

Teper, R., & Inzlicht, M. (2013). Meditation, mindfulness and executive control: the importance of emotional acceptance and brain-based performance monitoring. *Social, Cognitive, and Affective Neuroscience*, *8(1)*, 85-92.

Teper, R., Segal, Z., & Inzlicht, M. (2013). Inside the mindful mind: How mindfulness enhances emotion regulation through improvements in executive control. *Current Directions in Psychological Science*, *22(6)*, 449-454.

The Hawn Foundation. (2011). Programme information retrieved 05/12/2013: http://thehawnfoundation.org/mindup/

Unsworth, N., McMillan, B. D., Brewer, G. A., & Spillers, G. J. (2012). Everyday attention failures: An individual differences investigation. *Journal of experimental psychology: learning, memory, and cognition, 38(6)*, 1765-1772.

Van Leijenhorst, L., Gunther Moor, B., Op de Macks, Z. A., Rombouts, S. A. R. B., Westenberg, P.M., & Drone, E. A. (2010). Adolescent risky decision making: Neurocognitive development of reward and control regions. *NeuroImage, 51,* 345-355.

vanVeen, V., & Carter, C. S. (2002). The timing of action-monitoring processes in the anterior cingulate cortex. *Journal of cognitive neuroscience*, *14(4),* 593-602.

Walter, W. G., Cooper, R., Aldridge, V. J., McCallum, W. C., & Winter, A. L. (1964). Contingent negative variation: An electric sign of sensori-motor association and expectancy in the human brain. *Nature*, *203*, 380-384.

Watter, S., Geffen, G. M., & Geffen, L. B. (2001). The n-back as a dual-task: P300 morphology under divided attention. *Psychophysiology*, *38(6),* 998-1003.

Westbrook, C., Creswell, J. D., Tabibnia, G., Julson, E., Kober, H., & Tindle, H. A. (2013). Mindful attention reduces neural and self-reported cue-induced craving in smokers. *Social cognitive and affective neuroscience*, *8(1),* 73-84.

Zenner, C., Herrnleben-Kurz, S., & Walach, H. (2014). Mindfulness-based interventions in schools-A systematic review and meta-analysis. *Frontiers in Psychology*, *5*, article 603, 1-20.

Zhang, W., Lu, J., Fang, H., Pan, X., Zhnag, J., & Wang, D. (2012). Late positive potentials in affective picture processing during adolescence. *Neuroscience Letters, 510(2)*, 88-92.

Zhang, W., Lu, J., Ni, Z., Liu, X., Wang, D., & Shen, J. (2013). Harm avoidance in adolescents modulates late positive potentials during affective picture processing. *International Journal of Developmental Neuroscience, 31(5)*, 297-302.

Chapter Four – Mindfulness training with adolescents enhances metacognition and the inhibition of irrelevant stimuli: Evidence from event-related brain potentials

Text as it appears in*: Sanger, K. L., & Dorjee, D. (2016). Mindfulness training with adolescents enhances metacognition and the inhibition of irrelevant stimuli: Evidence from event-related brain potentials. *Trends in Neuroscience and Education, 5(1)*, 1-11.

*Additional figure showing attention task stimuli can be seen in Appendix IV

Abstract

With the increased interest in school-based mindfulness interventions, there have been repeated calls to investigate neurodevelopmental markers of change. This non-randomised study of 16-18 year olds with wait-list control group examined possible enhancements to brain indexes of attention processing after school-based mindfulness training using event-related potentials (ERPs) (N=47 for self-report; N=40 for ERPs). Results showed significantly more negative N2 amplitudes after training, in response to irrelevant frequent stimuli and colour-deviant non-target oddball stimuli in a visual oddball paradigm. Improvements in negative thought controllability were associated with more negative N2 amplitudes post-training across groups, and mindfulness training was associated with reductions in students' hypercritical self-beliefs. There were no group differences on task performance, but regression analysis indicated that programme satisfaction explained 16% of the variance in improved target accuracy. Together these results suggest that a school-based mindfulness curriculum can enhance older adolescents' task-relevant inhibitory control of attention and perceived mental competency.

Introduction

Mindfulness interventions involve guided training of present-moment awareness with a kind and accepting attitude (Kabat-Zinn, 1994). The benefits of mindfulness-based interventions for cognitive processing are well documented in both clinical (Hofman, Sawyer, Witt, & Oh, 2010) and non-clinical (Eberth & Sedlmeier, 2012) adult populations. These encouraging results have inspired educators, policy makers, and researchers alike to foster mindfulness-based programmes in schools, with developmentally adapted courses. However, the evidence base for school-based programmes is still being established. The initial results in older children and adolescents show reductions in perceived stress, depression, and anxiety, as well as improvements in emotion regulation and executive control (Huppert & Johnson, 2010; Kuyken et al., 2013; Metz et al., 2013; Oberle, Schonert-Reichl, Lawlor, & Thomson, 2011).

Two important factors emphasised in education policy are well-being (World Health Organisation [WHO], 2011) and metacognition (Meyer, Haywood, Sachdev, & Faraday, 2008). Well-being in children and adolescents is a growing concern, with one in ten young people thought to have a diagnosed mental illness, including emotional, attention, and conduct disorders (Green, McGinnity, Meltzer, Ford, & Goodman, 2005). And beliefs about cognitive ability have been associated with poorer test performance despite an individual's aptitude (Dweck, 2008), suggesting an important contribution of metacognition to academic achievement. Initial evidence suggests that school-based mindfulness training may improve well-being (Huppert & Johnson, 2010; Kuyken et al., 2013; Bluth et al., 2015). To our knowledge, no research has investigated links to metacognition, but studies in adults with depression have reported that Mindfulness-Based Cognitive Therapy (MBCT) can increase metacognitive awareness, and such enhancements have been linked to decreased rates of relapse (Teasdale et al., 2002). Metacognition is also related to mind wandering, referring to an individual's attention shifts away from goal-orientated focus, often without awareness (Smallwood & Schooler, 2006). Mind wandering has been shown to reduce after mindfulness practice in adults (Mrazek, Smallwood, & Schooler, 2012) and a negative relationship was found between mind wandering and well-being in young people (Mrazek, Philips, Franklin, Broadway, & Schooler, 2013).

Mindfulness training is often promoted as a well-being enhancing strategy, though a recent systematic review concluded that the strongest effects of school-based mindfulness programmes are on cognitive performance, with emotion and resilience improvements showing only moderate change overall (Zenner, Herrnleben-Kurz, & Walach, 2014). This might result from the nature of introductory mindfulness programmes in schools, where the overt emphasis is on attention and awareness training through focussed meditation, and there is, understandably, less emotional and experiential group reflection (inquiry) than in adult courses. However, recent considerations surrounding the mechanisms of mindfulness-based changes suggest that improvements in emotion processing are the result of enhanced attention processing (Malinowski, 2013). This has also been demonstrated experimentally, where mindful attention moderated the relationship between depressive affect and negative cognitions (Gilbert & Christopher, 2010). Therefore, it seems important to investigate how mindfulness practice improves attention in young people, given that this mechanism might have primary (attention) and secondary (emotion processing) outcomes. It is possible that the changes in affective processing induced by school-based programmes only become evident after continued mindfulness practice.

Adolescence is a late catchment period for frontal brain development (Spear, 2013), particularly the prefrontal cortex (PFC) and anterior cingulate cortex (ACC) that are centrally involved in error processing, attention monitoring, and control (Velanova, Wheeler, & Luna, 2008). Young peoples' impulsivity, for example, directly relates to the undeveloped nature of these frontal regions (Casey, Jones, & Hare, 2008).

Inappropriate impulsivity is associated with a lack of inhibition, a central part of executive attention through which we monitor and control attentional processes (Horn, Dolan, Elliot, Deakin, & Woodruff, 2003). Importantly, mindfulness training has been shown to increase markers of response inhibition and improve selective attention in adults (Jensen, Vangkilde, Frokjaer, & Hasselbalch, 2012). The PFC and ACC have also been modulated by mindfulness practice, with improvements being found in previous adult magnetic resonance imaging (MRI) and ERP research e.g. (Hölzel et al., 2007; Moore, Gruber, Derose, & Malinowki, 2012). It is yet to be determined whether similar gains would be observed in adolescents, but despite their reduced inhibition skills, adolescents' still developing prefrontal regions and attention control processes might present a larger potential for neural plasticity, resulting in more impactful and pronounced effects.

Given the links between impulsivity and adolescent risk-taking behaviours (Ernst, Pine, & Hardin, 2006), and the added scope for executive attention enhancement in the adolescent population, neuro-cognitive investigations of mindfulness training are of particular interest. In this context, electroencephalographic (EEG) methodologies can be particularly useful for school-based programme research, given their relatively low cost, portability, millisecond temporal accuracy, and reliance on well-established ERP components that index attention functioning (Sanger & Dorjee, 2015). Of particular relevance is the N200 (N2) ERP component, which can be elicited in conflict tasks and is a sensitive marker of response inhibition (Falkenstein, Hoormann, & Hohnsbein, 1999; Ladouceur, Dahl, & Carter, 2007). More negative N2 responses post-mindfulness training indicate better target detection and inhibition of automatic responses, as shown in previous adult research (Moore et al., 2012). In terms of target-related information processing, the P300 (specifically the P3b) component is typically assessed, showing modulation as the result of cognitive load (Raney, 1993), although whether this results in a decrease or increase in P3b amplitude depends on the exact task parameters e.g. more positive P300 amplitudes have been associated with reduced target categorisation difficulty (Kok, 2001), and less mind wandering (Smallwood, Beach, Schooler, & Handy, 2008). However, Moore et al. (2012) reported that more negative N2 was associated with a subsequent drop in P3b positivity on correct task trials, signifying more efficient attention processing after mindfulness training. Similar P3b reductions, indexing improved attention efficiency have also been reported in studies of extensive meditation training (Slagter et al., 2007). Another sub-component of the P300 is the P3a, thought to index attention capture to unexpected stimuli (Polich, 2007). Previous research has found that during meditation practice, P3a-indexed reactivity to unexpected and distracting stimulus is reduced, again indicating at least state-based improvements in attention allocation efficiency (Cahn & Polich, 2009). No studies to date have examined mindfulness training effects on inhibition and attention efficiency in adolescents.

The current study investigated the impact of mindfulness training, delivered as part of the school curriculum, on N2 and P300 ERP markers of attention in adolescents. To assess whether mindfulness impacts metacognition, we also examined changes in self-reported mental competency beliefs. These evaluations were conducted before and after a mindfulness-based course, running over one school term in the Personal, Social and Health Education (PSHE) classroom slot, for sixth form students (16-18 years). Sixth form (UK year groups 12 and 13) refers to AS and A-Level students; the highest high school qualifications. Specifically, we hypothesised that mindfulness training would benefit attention performance through increased response inhibition to non-targets as indicated by more negative N2 to non-target stimuli (particularly for non-target stimuli perceptually similar to targets - see methods for detailed predictions), and more positive P3b amplitudes throughout, indexing sustained attention during a visual oddball task. We also expected decreases in P3a to the non-target condition included to assess changes in automatic attention capture (shape deviant non-target). Reductions in self-reported mind wandering during the task, and improvements in metacognitive beliefs were also expected.

Methods

The study was approved by the Ethics Committee in the School of Psychology at Bangor University, prior to study commencement.

Participants

Participants were recruited from four schools across North Wales, two for the training group and two matched wait-list controls. Sixth form students from all four schools were recruited via presentations explaining the study, and sign-up sheets were then displayed in sixth form common rooms. Participants could volunteer solely for questionnaires, or questionnaires plus ERP recordings during an experimental attention task. Another task focussing on emotion regulation was also part of the testing session, but results are reported elsewhere. For those participating in the ERP section of the study, a time-slot was allocated in January – February (pre-training) and in April – June (post-training) during one of their study periods so as not to interrupt subject lessons. Training group participation was open to all those enrolled on the mindfulness-based course, and open to the entire sixth form for control school students. This resulted in N = 47 (training group = 22) students who completed the computerised odd-ball attention task and questionnaire measures at both time-points, and a subset of 40 participants (training group = 19) with pre-post ERPs. Two intervention group students completed the questionnaires and computerised attention tasks, however they were determined ineligible for study analysis inclusion. One student attended only one session of the mindfulness course, and the other performed at 14% target accuracy during the odd-ball task at baseline, suggesting a lack of comprehension. From the N = 45 remaining, two participants withdrew from EEG testing but completed the computerised task and questionnaires, and three were removed from ERP analysis due to low trial sweep count and too many artefacts in the EEG files.

The average age of participants in the training group was 16.6 years (SD = 0.6) and in the control group 17.1 years (SD = 0.6). This is a representative average for the sixth form cohort. There were significant group differences in age ($t(43) = -2.742$, $p = .009$), as more A-level (year 13) students volunteered in the control schools, equating to them being 6-months older than training group students on average. However the difference between 16 and 17 year olds in developmental terms is minimal (Paulluel, Nougier, & Olivier, 2010; Waxer & Morton, 2011). Chi squared analyses were run for gender, as well as previous experience of mindfulness, and whether participants already practiced stress relief or mental skills training techniques at baseline. No group differences were found on any of these measures (all *ps* > .05). The same was true of participants included in the ERP analysis, where only age showed a significant difference between groups ($t(38) = -2.476$, $p = .018$). A summary of means and standard deviations (SD) can be seen in Table 1.

Students were not paid for their participation, but did gain first-hand experience of neuroscientific testing procedures and benefited from additional volunteer hours for their university applications and curriculum vitas. Neuroscience of mindfulness talks, delivered by the first author (KS) were additionally offered to all schools involved.

				Socio-demographics for all participants (N = 45)			
	Age: Mean (SD)	**Unplanned Absences: Mean (SD)**	**GP Visits: Mean (SD)**	**Gender ratio (F:M)**	**% with stress relief training**	**% with mental skills training**	**% with mindfulness knowledge**
Training Group	16.6 (0.6)	4.0 (3.6)	1.1 (2.4)	10:10	55	30	0
Control Group	17.1 (0.6)	4.8 (5.3)	0.5 (1.0)	17:8	64	32	8
				Socio-demographics for ERP participants (N = 40)			
	Age: Mean (SD)	**Unplanned Absences: Mean (SD)**	**GP Visits: Mean (SD)**	**Gender ratio (F:M)**	**% with stress relief training**	**% with mental skills training**	**% with mindfulness knowledge**

Training Group	16.6 (0.6)	3.9 (3.7)	1.1 (2.4)	9:10	57.9	31.6	0
Control Group	17.0 (0.6)	4.4 (5.2)	0.4 (0.9)	13:8	66.7	38.1	9.5

Table 1: Socio-demographics across participant groups at baseline

Measures

The following self-report measures were included:

The Five-Facet Mindfulness Questionnaire (FFMQ) [39] was used to assess changes in mindfulness score pre-post training, and has been effectively used with adolescents (Ciesla, Reilly, Dickson, Emenuel, & Updegraff, 2012). It has 39-items and contains five subscales; 'Observing, Describing, Acting with Awareness, Non-Judging, and Non-Reacting'. The final score can be calculated as FFMQ-Total for all questions, or separated out into subscales. All subscales and total-FFMQ were used in this study. The internal consistencies (Cronbach α) for these facets have been reported as 0.83 for FFMQ-O, 0.91 for FFMQ-D, 0.87 for FFMQ-AwA, 0.87 for FFMQ-NJ, and 0.75 for FFMQ-NR (Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006). A higher score indicates a more mindful disposition.

The Meta-Cognitions Questionnaire – Adolescent Version (MCQ-A; Cartwright-Hatton et al., 2004) recorded changes in students' perceptions of their mental abilities and behaviours. It consists of 30-items split into five subscales, and uses a 4-point Likert scale similar to the adult version. It can be scored as a sum of all questions or split into its subscales, the total and subscales were used in this study. The reliability of the MCQ-A is fair, with subscales reporting internal consistencies of 0.88 for Positive Beliefs, 0.84 for Uncontrollability and Danger, 0.81 for Cognitive Confidence, 0.66 for Superstition, Punishment, and Responsibility (SPR), and 0.79 for Cognitive Self-Consciousness. The reliability for the measure as a total score was reported as 0.91 (Cartwright-Hatton et al., 2004). A lower score indicates healthier metacognition, with items for Positive Beliefs and Cognitive Confidence asked negatively e.g. “I need to worry in order to work well” is an item on the Positive Beliefs subscale.

A mind wandering measure was designed for the study to record the amount of state mind wandering participants experienced during the attention task. This included a 6-point Likert scale responding to the question “During *block X* how much did you mind wander?” where a higher score indicated more mind wandering. Participants were asked to rate their mind wandering after each of the three attention task blocks.

An acceptability measure was designed for the study, asking mindfulness trained students to rate their enjoyment of the curriculum, and how frequently they practiced at home. Course enjoyment was measured on a 7-point Likert scale (1 = Not at all to 7 = Very much) and home practice was measured on a 4-point Likert scale (1 = Never to 4 = Every day). Mindfulness course attendance was also measured.

Computerised Task

The attention task followed an oddball design with four simple shapes – three diamonds and one shape deviant non-target star. The standard frequent non-target stimulus (70% of trials) was a dark blue diamond, 15% larger than all other shapes seen during the task. The target stimulus was also a dark blue diamond (10% of trials), but smaller than the standard stimulus. There was a colour deviant non-target oddball (10% of trials), which was the same size and shape as the target, but pale blue in colour. The shape deviant non-target oddball (10% of trials) was a star shaded the same dark blue as target and standard stimuli, and was of equal size to the other task oddballs. Participants were instructed to respond only when they saw the target stimulus appear, pressing the space bar of a keyboard. No response was required to any other stimuli. Task stimuli were split into three blocks, each with 130 trials displayed randomly within that block (131 in the last block). Each block contained the same proportion of stimuli – 70% for the frequent non-target, 10% for the target, 10% for the colour deviant non-target and 10% shape deviant non-target. All stimuli appeared one at a time in the centre of the computer screen, and presentation order was random within each of the three blocks. Participants were informed beforehand of what to expect during the task, but they did not know that a shape deviant non-target would infrequently appear. The shape-deviant non-target, and colour deviant non-target oddballs were included to separate the effects of inhibition (N2) and automatic attention orienting (P3a). Specifically, we expected that the standard stimulus, and oddball most perceptually similar to the target (colour deviant non-target) would produce a more negative N2 than the perceptually more distinctive non-target oddball (shape deviant). With regards to the P3a, we predicted more positive P3a amplitudes in response to the shape deviant non-target, which participants did not anticipate appearing in the task.

Overall, participants saw 40 trials of each oddball and 271 standard stimuli. Stimuli were displayed for 900 ms, with an inter-stimulus interval of 700 ms. It took 10.5 minutes to complete the task, with breaks between each block where students were asked to rate their levels of mind wandering.

Mindfulness-based School Training Programme

An age appropriate mindfulness-based school curriculum (.b Foundations), designed for adults and educators was delivered. This course was chosen instead of the standard ‘.b’ curriculum intended for secondary school pupils to reflect the maturity of the age group targeted for this intervention. The .b Foundations programme was created by the Mindfulness in Schools Project (MiSP; http://mindfulnessinschools.org/) team and draws strongly from Mark Williams and Daniel Penman’s ‘Mindfulness:

Finding Peace in a Frantic World' (Williams & Penman, 2011). The course was delivered over eight 50-minute weekly sessions plus an initial orientation session, taught by students' regular teachers within the PSHE curriculum slot. This is a relatively new model of delivering mindfulness-based courses in schools, which have typically been taught by external mindfulness trainers. The implementation model involved a long-term commitment from teachers, who first completed a prolonged period of mindfulness instruction themselves. This consisted of the .b Foundations course taught over six weeks, three months of individual practice to establish comprehension, and then 14-hours training in how to deliver the .b Foundations course to sixth form students. Teachers only proceeded to this last training phase if they wished to continue, and showed a sufficient personal mindfulness practice as assessed by an experienced mindfulness trainer. Supervision from the trainer was also given during the student course period. Control schools were offered the same training after data collection was completed.

Procedures

This experiment used a non-randomised pre-post intervention study design, with wait-list control group, assessing training feasibility as well as underlying neurocognitive mechanisms. Participants were tested individually during school hours, scheduled within personal study periods, using a portable EEG system consisting of acquisition and stimulus presentation laptops, Neuroscan NuAmp amplifier, and EEG cap. Quiet testing spaces were provided on school premises. At baseline all procedures were explained to participants, and informed consent was obtained before the start of testing. EEG volunteers were asked to come to their appointments with clean, dry hair and not to apply hair products or conditioner. During the set-up period, students could complete the FFMQ and MCQ-A as part of a battery of questionnaires. If these were not completed during the set-up time, students took these measures away in a plain envelop and were asked to return them to the experimenter on the next school day. Students only completing questionnaires were handed sealed envelopes with the battery of assessments. Consent forms were enclosed along with information sheets and contact details of the PI if they had any follow-up questions. Completed forms were requested to be handed back to the PI within one week.

EEG signal was recorded with 36 Ag/AgCl electrodes, with the right mastoid as the reference site and Fpz as the ground. Data was obtained with Neuroscan NuAmp amplifiers, utilizing a sampling rate of 1 kHz. Two electrodes, situated above and below the right eye, recorded ocular movements. Additionally, two electrodes were placed on either forearm to record heart rate variability, and results of this analysis will be reported elsewhere. The impedance of all electrodes was kept at less than 7 kΩ. Online, the EEG signal was filtered with a bandpass filter range of 0.01 – 200 Hz, and an additional filter was applied offline with a zero shift low pass setting of 30 Hz, 48 dB/Oct slope. ERP data was cleaned manually by rejecting motor and irregular ocular artefacts, after which an algorithm in Neuroscan Edit software was employed to regress out eye-blinks, and later to remove residual artefacts. The data was epoched into 1100 ms segments starting at -100 ms, and baseline corrected using the signal 100 ms before stimulus onset. Finally, averages for each condition and participant, as well as grand averages across participants for each condition and group were computed.

The attention task was preceded by a short practice block (seven standard trials and one of each odd-ball). Between each block the experimenter asked participants to rate how much they noticed themselves mind wandering during the preceding block, ranging from “Not at all” to “All the time”. Clean towels, sensitive skin wipes, and individually labelled hair brushes were supplied for participants so that they could remove most of the electrolyte gel before returning to class.

Data Analysis

Pre-post questionnaire measures were analysed using mixed factorial ANOVAs with a 2(time: pre, post) x 2(group: training, control) design. Significant effects were followed up with paired sample t-tests. Outliers more than 2 standard deviations from the mean for that measure were removed prior to analysis, and any violations of sphericity were corrected for, using the Greenhouse-Geisser correction.

ERP analysis was carried out in the same way, with ANOVAs assessing mean amplitude and latency data for electrodes of interest. Initial ANOVAs were run with factors of 4(condition: target, colour deviant non-target, shape deviant non-target, standard non-target) x 2(time) x 2(group) x n(electrode) for the N2, P3a, and P3b components. Where significant main effects of condition and interactions were found, separate ANOVAs with factors of time, group, and electrode were conducted. All analysable trials were included in the ERP analyses, as discarding incorrect trials would also remove any ERP differences resulting from mind-wandering, which was a core interest in this study. Removal of incorrect trials would radically shift the scope and predictions of the study. This is because higher amplitudes in the current task, associated with higher accuracy and sustained attention, were linked to less mind wandering based on previous literature (Smallwood et al., 2008). By contrast, with incorrect trials removed, lower amplitudes would be considered to reflect more efficient attention processing (e.g., Moore et al., 2012; Slagter et al., 2007), and would not measure mind wandering.

Correlation and step-wise multiple regression was used to assess the moderating effects of course engagement, as there have been contrasting findings regarding the impact of practice frequency (Foret et al., 2012; Huppert & Johnson, 2010). MCQ-A data was additionally correlated with ERP responses to verify the efficacy of this measure as an index of attention control and mental responsiveness.

The electrode sites of interest were based on previous literature, and visual inspection of peak activity in Neuroscan Edit. Mean amplitudes were used in all ERP analyses. The following clusters of electrodes were selected for analyses for each of the components based on previous literature and maximal signal: N2 - AFz, Fz, F3 and F4, in the time window 270-330 ms; P3a - Cz, C4, CPz, CP2, and CP4, in the time window 370-430 ms; P3b - CP1, CP2, Cz, and CPz across the time window 330-490 ms.

Results

Acceptability

One intervention participant did not complete this questionnaire, leaving the training group sample as n = 19. Students reported to have generally enjoyed the course, giving it an average of 65% (5 out of 7). Furthermore, 58% reported practicing often or every day during the programme and 84% were considering keeping up the practice in future. Class attendance records were also checked, with students on average attending 82% of the 8-week course.

Five-Facet Mindfulness Questionnaire

One control participant did not complete this questionnaire, bringing the total sample to N = 44. The mixed ANOVA for FFMQ-Total reported no significant main effects of time (F(1,42) = .5, p = .47, η^2 = .01), group (F(1,42) = .1, p = .80, η^2 = .002) or significant time*group interaction (F(1,42) = .1, p = .83, η^2 = .001). No subscale main effects or interactions were significant (all ps > .1).

Mind Wandering

The mixed ANOVA for mean self-reported mind wandering over the three attention trial blocks reported no significant main effects of time ($F(1,43) = .4$, $p = .52$, $\eta^2 = .01$), group ($F(1,43) = 1.3$, $p = .26$, $\eta^2 = .03$), or significant interaction effect ($F(1,43) = 1.4$, $p = .24$, $\eta^2 = .03$). Mind wandering was also assessed for those students included in the ERP analysis. This subset of participants resulted in non-significant main effects of time ($F(1,38) = .8$, $p = .38$, $\eta^2 = .02$), and group ($F(1,38) = .9$, $p = .35$, $\eta^2 = .02$), but there was a significant time*group interaction ($F(1,38) = 5.1$, $p = .03$, $\eta^2 = .12$). The follow-up t-tests revealed a significant increase in control group mind wandering over time ($t(20) = -2.7$, $p = .014$, $d = .59$).

Meta-Cognitions Questionnaire – Adolescent Version

One participant from the intervention group and four from the control group did not complete the MCQ-A, leaving the final sample for this questionnaire as N = 40. Additionally two outliers from the intervention group with values above 2 SD from the mean were removed, resulting in a sample of N = 38. The MCQ-A Total ANOVA showed a general reduction in scores over time ($F(1,36) = 6.3$, $p = .02$, $\eta^2 = .13$), non-significant group main effect ($F(1,36) = .8$, $p = .37$, $\eta^2 = .02$), and significant time*group interaction ($F(1,36) = 6.1$, $p = .02$, $\eta^2 = .13$). Follow-up paired samples t-tests reported this to be due to a significant decrease in MCQ-A Total score in the training group ($t(16) = 2.7$, $p = .02$, $d = .64$) with the control group not showing a significant change ($p > .1$). On visual inspection it appeared that there was a discrepancy between training and control groups at baseline, as can be seen in Figure 1. However, independent t-test confirmed that after removal of the two outlier participants this group difference was non-significant ($t(36) = 1.7$, $p = .09$).

The Positive Beliefs subscale showed an overall increase over time ($F(1,36) = 8.0$, $p = .008$, $\eta^2 = .17$), non-significant main effect of group ($F(1,36) = .001$, $p = .98$, η^2

< .001) and marginally significant interaction (F(1,36) = 4.0, p = .054, η^2 = .08). Paired t-tests showed this to be due to a significant increase on the Positive Beliefs subscale for control group participants pre-post (t(20) = -3.2, p = .004, d = .70), indicating that they increased in their reliance on worry and anxiety in order to motivate action. There was no change on this scale in the training group (p > .1). For the Uncontrollability, and Cognitive Confidence subscales, ANOVA results showed no significant main effects or interactions (all ps > .1). The Superstition, Punishment, and Responsibility (SPR) subscale reported general decrease in scores over time (F(1,36) = 15.7, p < .001, η^2 = .27), non-significant main effect of group (F(1,36) = 2.0, p = .16, η^2 = .05), and significant time*group interaction (F(1,36) = 6.0, p = .02, η^2 = .10). Follow-up t-tests confirmed this to be due to a significant reduction in SPR score for the training group (t(16) = 4.7, p < .001, d = 1.15) with no change observed in the control group (p > .1). Cognitive Self-Consciousness showed an overall reduction in score over time (F(1,36) = 6.3, p = .02, η^2 = .14), but no significant effect of group (F(1,36) = 2.3, p = .14, η^2 = .06) or significant interaction (F(1,36) = 1.4, p = .25, η^2 = .03) was obtained.

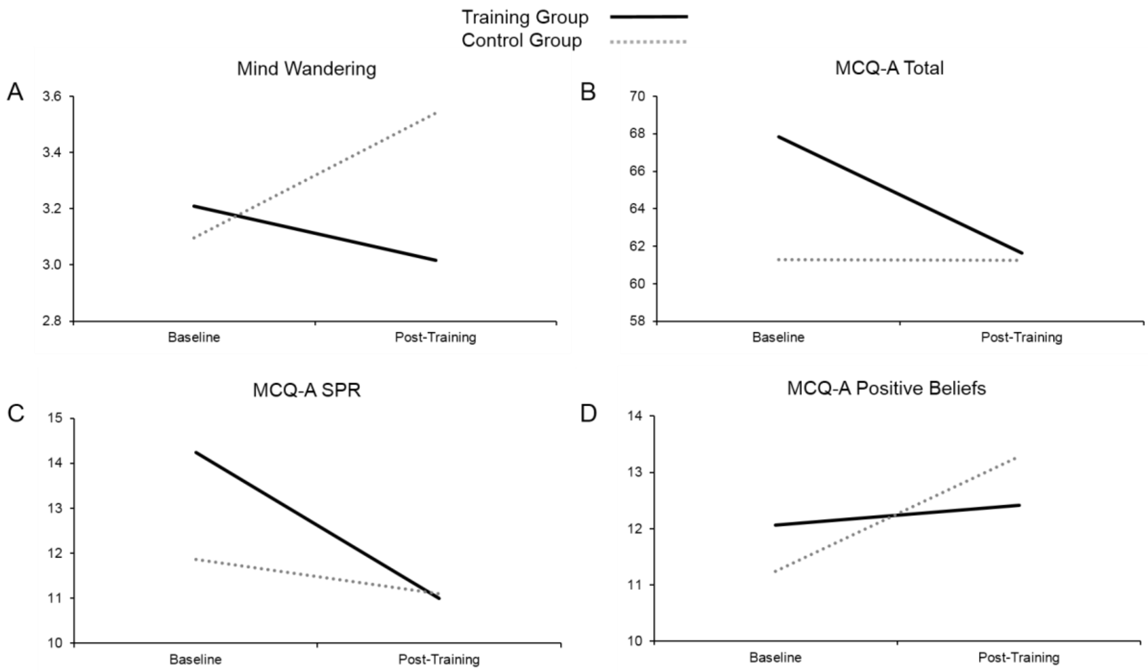

Figure 1: Mean pre-post changes in self-report measures between groups:

Mind wandering (A), MCQ-A Total (B) and MCQ-A SPR (C) significant p < .05; MCQ-A Positive Beliefs (D) p = .054

Questionnaire means (SD)				
	Pre-Training Group	**Post-Training Group**	**Pre-Control Group**	**Post-Control Group**
FFMQ-Total	118.6 (14.6)	119.3 (13.4)	119.4 (16.1)	120.7 (15.1)
FFMQ-O	24.0 (5.5)	24.1 (4.8)	23.9 (5.2)	23.3 (4.9)
FFMQ-D	25.1 (5.8)	23.8 (4.0)	25.4 (6.6)	25.4 (5.8)
FFMQ-AwA	23.9 (5.5)	23.5 (4.6)	23.8 (6.8)	23.3 (5.8)
FFMQ-NJ	26.1 (6.2)	27.6 (5.9)	26.6 (6.4)	28.1 (5.8)
FFMQ-NR	19.6 (3.3)	20.4 (3.3)	19.8 (4.5)	20.6 (3.5)
MindWandering (N=45)	3.2 (0.8)	3.1 (0.9)	3.3 (0.9)	3.5 (0.8)
MindWandering (N=40)	**3.2 (0.8)**	**3.0 (0.8)**	**3.1 (0.8)**	**3.5 (0.9)**
MetaCog-Total	**69.5 (11.6)**	**65.1 (15.4)**	**61.3 (12.1)**	**61.2 (13.8)**
MetaCog-PosBeliefs	**12.3 (4.0)**	**13.4 (4.2)**	**11.2 (4.0)**	**13.3 (4.3)**
MetaCog-Uncontrollability	15.2 (3.9)	13.8 (4.8)	12.9 (4.1)	12.4 (4.2)
MetaCog-CognitiveConfidence	12.8 (3.8)	11.7 (4.2)	11.7 (4.1)	12.3 (5.7)
MetaCog-SPR	**14.5 (3.0)**	**11.8 (3.5)**	**11.9 (3.1)**	**11.1 (3.0)**
MetaCog-SelfConsciousness	14.8 (3.1)	14.4 (4.2)	13.6 (2.9)	12.1 (2.4)
Mindfulness Course Attendance %	NA	81.9 (0.2)	NA	NA
Mindfulness Course Satisfaction %	NA	65.0 (0.3)	NA	NA

Table 2: Means and standard deviations across participant groups for questionnaire measures. Significant results (p < .05) highlighted in bold.

Attention Task Performance

Table 3 summarises attention task performance; no false alarms to the shape deviant non-target were recorded so this is not included in the table. For target accuracy, there were non-significant main effects of time ($F(1,43) = .2$, $p = .7$, $\eta^2 = .01$), group ($F(1,43) = 2.4$, $p = .13$, $\eta^2 = .05$), and a non-significant time*group interaction ($F(1,43) = 1.7$, $p = .20$, $\eta^2 = .04$). Regarding false alarms to the colour deviant non-target, the main effect of time was significant ($F(1,40) = 25.5$, $p < .001$ $\eta^2 = .39$) showing a general reduction in false alarms over time, while the main effect of group and the time*group interaction were non-significant (all *ps* > .05). False alarm data are reported after the removal of three outliers. ANOVA results for all other performance related measures, i.e. reaction time, reaction time variability, and false alarm responses to the standard stimulus were non-significant (all *ps* > .05).

Oddball task performance mean percentages % (SD)										
	Pre- Target RT	**Post- Target RT**	**Pre- Target Accuracy**	**Post- Target Accuracy**	**Pre- Target Omissions**	**Post- Target Omissions**	**Pre- False Alarms to Colour-Deviant**	**Post- False Alarms to Colour-Deviant**	**Pre- False Alarms to Standard**	**Post- False Alarms to Standard**
Training Group	520.2 ms (46.4)	527.6 ms (51.5)	83.5 (11.0)	86.0 (9.1)	16.5 (11.0)	14.0 (9.1)	5.1 (5.4)	1.6 (2.0)	3.2 (6.5)	1.6 (3.2)
Control Group	519.1 ms (47.2)	522.5 ms (49.9)	89.4 (8.8)	88.2 (10.5)	10.6 (8.8)	11.8 (10.5)	4.8 (6.2)	1.4 (4.2)	2.9 (5.9)	1.2 (1.4)

Table 3: Mean performance percentages and SDs across participant groups for the oddball task

Training group participants' self-reported enjoyment of the course significantly correlated with target accuracy difference, calculated by subtracting baseline accuracy from the post-test accuracy rates (*r* = .45, *p* = .05), *see figure 2*. No significant correlations were reported with course attendance (*r* = .28, *p* = .23) or amount of home practice (*r* = .22, *p* = .36). This was supported by step-wise multiple regression, where only course enjoyment explained enough of the variance to be included in the model. The adjusted R^2 reported that student's enjoyment of the mindfulness course accounted for 16% of the variance in training group target accuracy improvement over time.

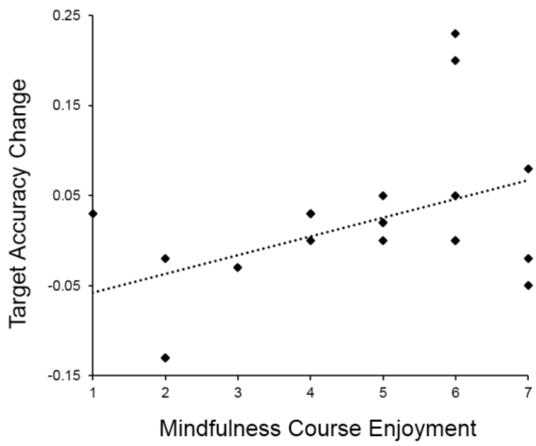

Figure 2: Significant positive correlation between changes in target accuracy and self-reported mindfulness course enjoyment within the training group (r = .45)

ERP Analysis

Table 4 shows the mean number of trials included in the averaged ERP analysis per task condition, with the averages for oddball conditions ranging from 38.3 to 39.5.

Mean (SD) trials per condition for ERP analysis								
	Pre-Target	**Pre-Colour Deviant**	**Pre-Shape Deviant**	**Pre-Standard**	**Post-Target**	**Post-Colour Deviant**	**Post-Shape Deviant**	**Post-Standard**
Training Group	38.4 (3.0)	38.3 (3.0)	38.3 (2.8)	259.4 (18.6)	39.4 (0.7)	39.3 (1.1)	39.5 (0.8)	267.6 (6.0)
Control Group	39.5 (0.7)	38.8 (1.4)	39.2 (1.3)	265.9 (5.0)	39.0 (2.2)	38.8 (1.9)	38.5 (2.5)	260.3 (13.7)

Table 4: Mean number of trials per condition included in averaged ERP analysis across participant groups

N200 Analysis

To evaluate the predicted differences in response inhibition across the non-target conditions, mean amplitude analysis for the N2 component was conducted at frontal electrodes AFz, Fz, F3 and F4 within the time window 270-330 ms. The EEG signal was maximal at Fz, and this electrode was therefore used to derive peak latencies. An initial ANOVA assessed the independence of task conditions, using a 2(time: pre, post) x 4(condition: standard, colour deviant, shape deviant, target) x 4(electrode: AFz, F3, F4, Fz) x 2(group: training, control) design. This showed a significant main effect of condition ($F(2.5, 93.3) = 10.4$, $p < .001$, $\eta^2 = .12$), and condition*group interaction ($F(2.5, 93.3) = 4.2$, $p = .013$, $\eta^2 = .05$) suggesting that mean amplitude varied between groups dependent on stimulus type. All other main effects and interactions were non-significant (all *p*s > .1). Since one outlier was identified (with means 2 SD outside of group mean), the ANOVA was re-run using n = 39 to ensure that the original results were not skewed by this participant's data. This revealed a significant main effect of condition ($F(3, 111) = 9.9$, $p < .001$, $\eta^2 = .11$), as well as condition*group ($F(2.5, 91.3) = 5.6$, $p = .001$, $\eta^2 = .06$) and time*condition*electrode*group ($F(6, 221.7) = 2.3$, $p = .039$, $\eta^2 < .01$) interactions. No other main effects or interactions were significant (all *p*s > .1). The significant main effect of condition and interactions were further investigated in separate ANOVAs for each of the conditions.

Shape deviant non-target: The results of the mixed factorial ANOVA showed a significant main effect of group ($F(1,37) = 4.3$, $p = .05$, $\eta^2 = .10$), suggesting that the intervention group overall expressed more pronounced N2 negativity to shape-deviant oddballs. All other main effects and interactions were non-significant (all *p*s > .05). There were no significant effects for the ANOVA on latency, and no correlations with MCQ-A (all *ps* > .1).

Colour deviant non-target: The ANOVA showed a marginal Time*Electrode*Group interaction ($F(3, 111) = 2.1$, $p = .10$, $\eta^2 < .01$) only (no other significant main effects or interactions, all *p*s > .1). Reviewing the descriptive statistics for the data identified an outlier (individual mean amplitudes outside of 2 SD for the group), so the analysis was re-ran with n = 38, revealing a marginally stronger Time*Electrode*Group interaction ($F(3, 108) = 2.2$, $p = .09$, $\eta^2 < .01$). No other main effects or interactions were significant (all *ps* > .1). As previous adult mindfulness-training studies have found N2 modulations during attention tasks (Moore et al., 2012), this marginal effect was followed-up for each electrode. More N2 negativity was found post-test in the training group at electrode F4 ($t(18) = 2.0$, $p = .06$, $d = .46$) only, while no modulation was seen in controls at any electrode ($p > .1$). There were no significant main effects or interactions for N2 latency (all *ps* > .1). Correlation analysis was used to assess any converging evidence from MCQ-A change alongside N2 modulation. Pre-post difference scores on the Uncontrollability and Danger (*r* = .35, *p* = .04) and marginally Cognitive Confidence (*r* = .32, *p* = .06) subscales of the MCQ-A were found to positively correlate with N2 mean amplitude change, indicating that more negative N2 post-training was also associated with an obtained drop in perceived uncontrollability and improved cognitive confidence. Within the training group specifically, correlation analysis also investigated potential contributions to N2 modulation by self-reported course enjoyment, attendance, and home practice, but no significant effects were found.

Standard non-target: Analysis for this condition was of interest since N2-marked inhibition to the standard stimulus would be expected after mindfulness training, and improvement over time would indicate more efficient attention processing. There was a significant time*group (F(1,37) = 6.9, p = .01, η^2 = .1) interaction effect. No other significant main effects or interactions were found (all *ps* > .1). Therefore a follow-up paired sample t-test was performed on averaged electrode mean amplitudes pre-post, revealing the ANOVA effect to be due to significantly more negative N2 amplitudes over time in the training group (t(18) = 3.3, p = .004, d = .76). There were no significant changes in the control group (*p* > .1). Additionally, there were no significant main effects or interactions for latency or correlations with MCQ-A change scores (all *p*s > .1).

Target: As expected the ANOVA for target stimulus revealed a main effect of electrode only (F(3, 111) = 2.9, p = .04, η^2 = .01). No main effects or interactions were revealed for latency, or correlations with MCQ-A (all *p*s > .1).

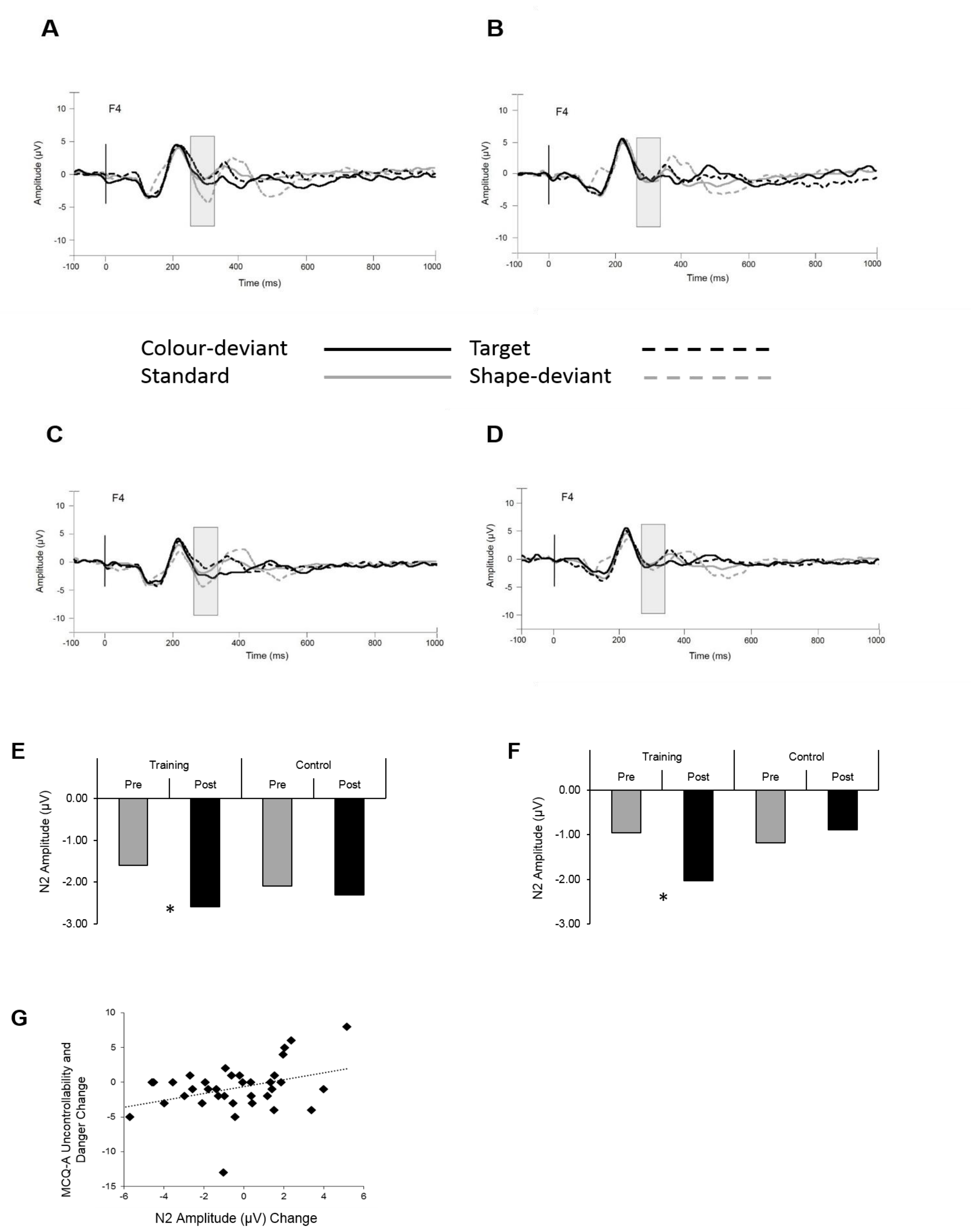

Figure 3: Graphs A-D show general average waveforms highlighting the N2 time window. Graph E represents the N2 mean amplitude change for the distractor condition with marginal modulation in the training group (p = .09), and graph F shows N2 mean amplitude change for the frequent stimulus condition showing significant change in the training group (p = .01). The

correlation plot (G) shows the significant positive correlation (p < .05) between N2 mean amplitude change to distractor stimuli and improved score on the MCQ-A Uncontrollability and Danger subscale.

P3a Analysis

The EEG signal for the P3a was maximal at CP4 (where latency was derived). Mean amplitudes across a right-sided central parietal cluster Cz, C4, CPz, CP2, and CP4 were examined between 370-430 ms. A 2(time: pre, post) x 4(condition: standard, colour deviant, shape deviant, target) x 5(electrode: Cz, C4, CPz, CP2, CP4) x 2(group: training, control) ANOVA was run. We found a significant main effect of time indicating significant decrease in amplitudes by post-test ($F(1,38) = 5.3$, $p = .03$, $\eta^2 = .01$), and significant difference in mean amplitudes between conditions ($F(3,114) = 15.8$, $p < .001$, $\eta^2 = .16$). There was also a significant time*condition interaction ($F(1,93.5) = 2.9$, $p = .04$, $\eta^2 = .01$). Follow up analyses showed that, as expected, the mean amplitudes were maximal for the shape deviant non-target oddball, and similarly, most of the variation over time was in response to the shape deviant stimulus. However, there were no interactions with time or group (all ps > .1) so no further analysis was undertaken. The ANOVA for latency showed no significant main effects or interactions (all *ps* > .1).

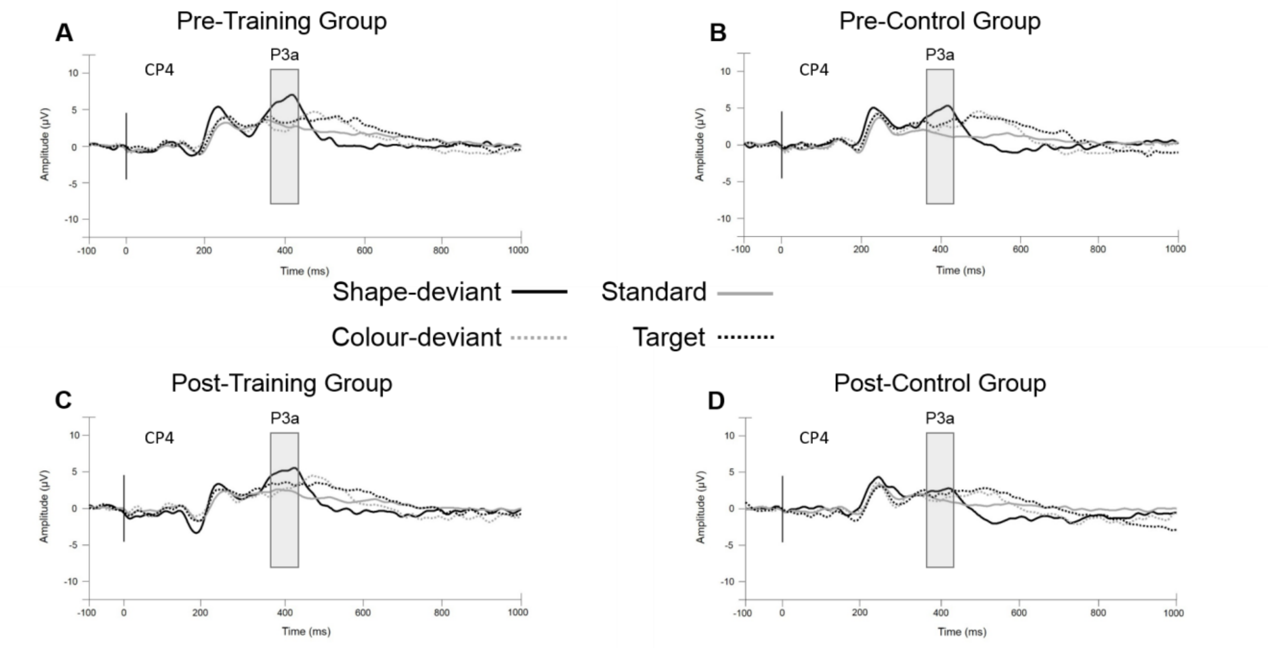

Figure 4: Graphs A–D show general average waveforms highlighting the P3a time-window (370-430 ms).

P3b Analysis

Mean amplitude analysis focused on a right-sided central, parietal cluster of electrodes – CP1, CP2, Cz, and CPz between 330-490 ms. The signal was maximal at CPz, which was used to derive peak latencies. The 2(time: pre, post) x 4(condition: standard, colour deviant, shape deviant, target) x 4(electrode: CP1, CP2, Cz, CPz) x 2(group: training, control) ANOVA showed a significant main effect of time, indicating a decrease in mean amplitude over time ($F(1,38) = 6.2$, $p = .02$, $\eta^2 = .02$), and significant main effect of condition pointing to neural response differences between conditions ($F(3,77.5) = 7.4$, $p = .001$, $\eta^2 = .09$). There was also a significant condition*electrode ($F(6,227.5) = 4.9$, $p < .001$, $\eta^2 < .01$) interaction. No other effects were significant (all *p*s > .01). As no significant interactions included time or group there was no suggestion of training impacting P3b modulation, and follow-up analysis was not conducted. The ANOVA for latency showed no significant main effects or interactions (all *ps* > .1).

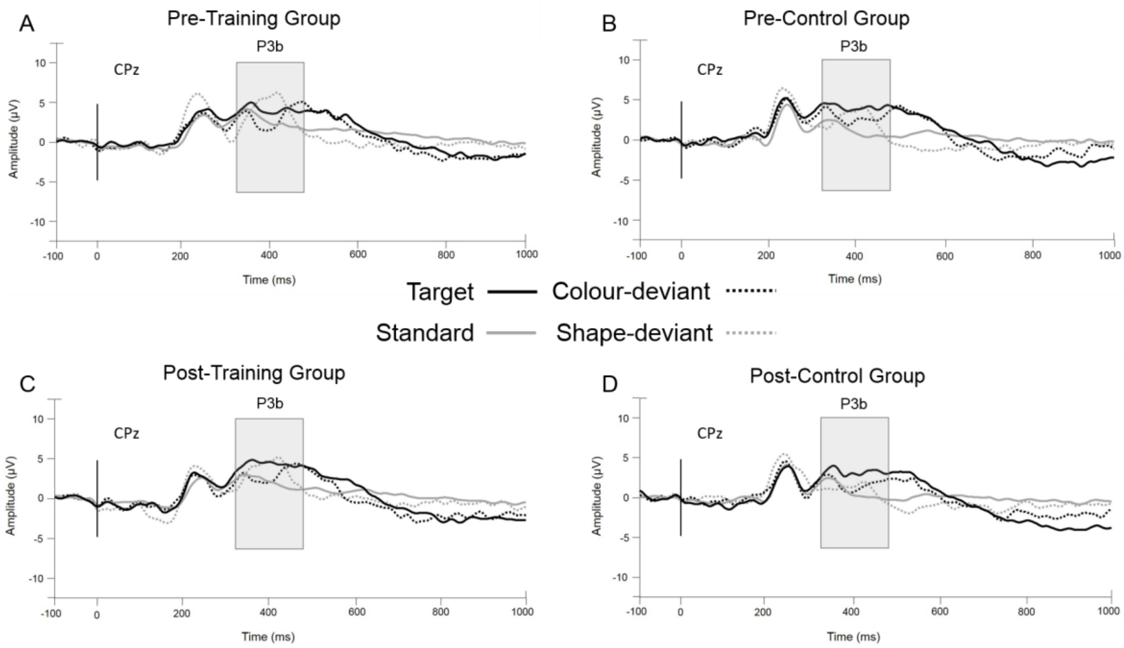

Figure 5: Graphs A–D show general average waveforms highlighting the P3b time-window (330-490 ms).

Discussion

To our knowledge, this was the first investigation of the impacts of mindfulness-based training for adolescents in school using neuroscientific methodology. The results showed that a mindfulness-based programme delivered as part of the standard curriculum was acceptable for 16-18 year old students. Importantly, we found that mindfulness training was associated with significantly more pronounced N2 negativity in response to colour deviant and standard non-target stimuli, in a visual oddball paradigm. Moreover, N2 modulation was associated with changes in mental uncontrollability and cognitive confidence as measured by the MCQ-A metacognition questionnaire, showing converging evidence that N2 modulation can index cognitive control processes. Training-based improvements were also noted in self-reported mind wandering and metacognitive beliefs. We found that ERP participants in the control group had more concentration lapses at post-test, and relied more on worry-based motivations to work. By contrast, mindfulness training was associated with reductions in superstitious and self-punishing beliefs about thought content, indicated by a lower score on the SPR subscale of the MCQ-A.

Overall, our findings suggest that mindfulness training for adolescents, delivered by schoolteachers, can have a positive impact on attention processing. Indeed, the pattern of non-significant change in response time and accuracy, coupled with a significant increase in N2 negativity to non-target standard and colour deviant stimuli, is similar to the findings of Moore et al. (2012) in adults undergoing 16-weeks of brief mindfulness training. Interestingly, the current study found the N2 change to be specific to colour deviant and standard non-target conditions. This would be expected, since these conditions require response inhibition from the participant. This pattern of N2 modulation suggests that adolescents trained in mindfulness-based practices were able to discriminately inhibit responses to task-irrelevant oddball stimuli. No change over time was identified to the shape deviant non-target, which was likely due to the distinctive perceptual difference of the stimulus, resulting in less demanding inhibition of a response. Older adolescence is considered the peak age for orienting attention skill (Cepeda, Kramer, & Gonzalez de Sather, 2001), which encapsulates our ability to shift attention between stimuli. This could account for the training group's learning to selectively inhibit responses to irrelevant stimuli after mindfulness practice, instead of increasing N2-marked response inhibition to all stimuli as was reported in an adult study of conflict monitoring after mindfulness training (Moore et al., 2012).

The selective disengagement from task-irrelevant stimuli noted in mindfulness-trained students could be pertinent to emotion regulation skills in adolescents, though we have not directly assessed this in the current study. Risk-taking behaviours are most prolific in adolescents, and while this can be advantageous for personal development, young people can make hasty decisions when emotionally influenced by peer pressure, known as 'hot cognitions' (Spear, 2013). The noted improvements in the training group's inhibitory responses, indicated by more N2 negativity, may extend to more emotion-based interference like peer pressure or engagement with negative, ruminative thoughts, as N2 modulation has previously been associated with emotion and attention regulation (Heil, Osman, Wiegelmann, Rolke, & Hennighausen, 2000; Kanske & Kotz, 2010; Pliszka et al., 2007; Schmajuk, Liotti, Busse, & Woldorff, 2006; Sumich, Castro, & Kumari, 2014). Indeed, we found an association between the increases in N2 negativity and the uncontrollability subscale of the MCQ-A, which measures an individual's concern about rumination on worry. Therefore, more prolonged mindfulness training may enable adolescents to filter out unhelpful influences and support them to re-allocate their attention resources, thus enabling more balanced decision-making, as suggested in adults (Malinowski, 2013).

In addition to N2 marked changes in attention, this study found that mindfulness training may positively impact on students' metacognitive beliefs. The mindfulness group reported a significant reduction in metacognitive concerns, with the Superstition, Punishment, and Responsibility subscale in particular showing this decrease. Together with the significant increase in control students' reported reliance on worry, i.e. higher scores on the Positive Beliefs subscale post-test, this suggests that mindfulness may have a 'befriending' effect on how students' relate to their own mind. The training group reported becoming kinder and more accepting of their thoughts, and unlike controls they did not increase in their belief that worry motivates action. This is particularly relevant in the context of the post-test timing of the study, since data collection occurred during the run-up to summer exams, and academic pressures would have been high. This could explain the reliability on worry that control participants expressed, and mindfulness practice may have buffered the training group against this effect. A similar pattern emerged in the mind wandering data, where control students reported increases in their lapses of concentration. This increase was not found in mindfulness-trained students, who maintained their ability to stay present.

Finally, our results indicated that although attention task performance did not change between groups, a significant correlation was found in the training group between self-reported enjoyment of the programme and changes in target response accuracy. No such correlations were found with home practice or class attendance, which have previously been associated with benefits to student well-being (Huppert & Johnson, 2010). This new link suggests that it might not necessarily be the frequency of mindfulness practice that brings about attention change in adolescents, but the quality of the engagement with practice. This finding could have strong implications for the design of developmentally adapted courses, highlighting the need to ensure that programme delivery is relevant and engaging for students, not merely longer or more frequently administered. More qualitative research to investigate this would be insightful, to gain recommendations on how programme enjoyment can be maximised in schools.

Limitations and future directions

The study also had some limitations. The correlation between target accuracy and mindfulness course enjoyment may have been confounded by motivation. It is possible that those students who most enjoyed the mindfulness-based programme were also more motivated to perform well on the computerised task. A similar effect could have contributed to the observed effect on mind wandering. However, the lack of between group improvements in overall target accuracy and response time suggest that this was not the case. Nevertheless, future studies controlling for participant motivation need to be conducted. The changes in metacognition should also be interpreted with caution, as while the groups were not statistically different at baseline (p = .09), there was a marginal variance, and therefore inadvertent selection bias may have impacted the results.

The current study, similar to the majority of neuroscience studies on mindfulness, did not include follow-up measurements due to the complexity of EEG data acquisition. However, future research on school-based mindfulness programmes would benefit from including follow-up measurements to assess the possibility of emotion regulation effects being subsequent to improvements in attention processing, as others and we have hypothesised. It is also an open question whether the observed effects are sustained after programme completion.

We did not find the predicted changes in P300 (P3a or P3b) mean amplitude post-training, however the strongest N2 effects were found in response to standard non-targets. Considering that this increased N2 response was sustained over 271 trials, it may be that initial mindfulness training effects impact sustained automatic attention, rather than later information processing that would be indicated by P3b modulations. A lack of P3a effect may have been due to the strong perceptual contrast between the shape deviant stimulus and other task conditions. Future studies could experiment with different ways to study the ‘startle’ effect after mindfulness training, perhaps using different sensual modalities like sound. Finally, the current study did not investigate links between modulations in N2 and impulsivity, which would be of direct relevance to adolescent risk-taking behaviour.

Conclusions

This was the first study in adolescents to document benefits to attention processing and metacognition resulting from mindfulness-based training in school, using event-related potentials. This initial evidence of mindfulness practice encouraging adolescents to more efficiently inhibit irrelevant stimuli, together with enabling them to reduce critical self-judgment, may have implications for academic performance and learning; which would also be relevant to education policy. Indeed, our findings provide further support to the hypothesis that mindfulness practice can contribute to the development of metacognitive awareness and well-being in young adults, potentially supporting their self-efficacy and academic success. As demonstrated in this study, neuroscience research has a strong role to play in helping us further understand the potential and limitations of mindfulness in an educational context.

References

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.

Bluth, K., Campo, R. A., Pruteanu-Malinici, S., Reams, A., Mullarkey, M., & Broderick, P. C. (2015). A School-Based Mindfulness Pilot Study for Ethnically Diverse At-Risk Adolescents. *Mindfulness*, 1-15, DOI: 10.1007/s12671-014-0376-1.

Cahn, B. R., & Polich, J. (2009). Meditation (Vipassana) and the P3a event-related brain potential. *International Journal of Psychophysiology*, *72*(1), 51-60.

Cartwright-Hatton, S., Mather, A., Illingworth, V., Brocki, J., Harrington, R., & Wells, A. (2004). Development and preliminary validation of the Meta-cognitions Questionnaire—Adolescent Version. *Journal of Anxiety Disorders, 18(3)*, 411-422.

Casey, B. J., Jones, R. M., & Hare, T. A. (2008). The adolescent brain. *Annals of the New York Academy of Sciences*, *1124*(1), 111-126.

Cepeda, N. J., Kramer, A. F., & Gonzalez de Sather, J. (2001). Changes in executive control across the life span: examination of task-switching performance. *Developmental Psychology*, *37*(5), 715.

Ciesla, J. A., Reilly, L. C., 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 & Adolescent Psychology, 41(6)*, 760-770.

Dweck, C. S. (2008). Can personality be changed? The role of beliefs in personality and change. *Current Directions in Psychological Science*, 17(6), 391-394.

Eberth, J., & Sedlmeier, P. (2012). The effects of mindfulness meditation: a meta-analysis. *Mindfulness*, *3*(3), 174-189.

Ernst, M., Pine, D. S., & Hardin, M. (2006). Triadic model of the neurobiology of motivated behaviour in adolescence. *Psychological Medicine*, 36(3), 299-312.

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (1999) ERP components in Go/Nogo tasks and their relation to inhibition. *Acta Psychologica, 101*, 267-291.

Foret, M. M., Scult, M., Wilcher, M., Chudnofsky, R., Malloy, L., Hasheminejad, N., & Park, E.

R. (2012). Integrating a relaxation response-based curriculum into a public high school in Massachusetts. *Journal of adolescence, 35(2)*, 325-332.

Gilbert, B. D., & Christopher, M. S. (2010). Mindfulness-based attention as a moderator of the relationship between depressive affect and negative cognitions. *Cognitive Therapy and Research*, 34(6), 514-521.

Green, H., McGinnity, A., Meltzer, H., Ford, T., & Goodman, R. (2005). Mental health of children and young people in Great Britain, 2004. Macmillian Palgrave, Hampshire.

Heil, M., Osman, A., Wiegelmann, J., Rolke, B., & Hennighausen, E. (2000). N200 in the Eriksen-task: Inhibitory executive process? *Journal of Psychophysiology, 14(4)*, 218-225.

Hofmann, S. G., Sawyer, A. T., Witt, A. A., & Oh, D. (2010). The effect of mindfulness-based therapy on anxiety and depression: A meta-analytic review. *Journal of consulting and clinical psychology*, *78*(2), 169-183.

Hölzel, B. K., Ott, U., Hempel, H., Hackl, A., Wolf, K., Stark, R., & Vaitl, D. (2007). Differential engagement of anterior cingulate and adjacent medial frontal cortex in adept meditators and non-meditators. *Neuroscience letters*, 421(1), 16-21.

Horn, N. R., Dolan, M., Elliott, R., Deakin, J. F. W., & Woodruff, P. W. R. (2003). Response inhibition and impulsivity: an fMRI study. *Neuropsychologia*, *41*(14), 1959-1966.

Huppert, F. A., & Johnson, D. M. (2010). A controlled trial of mindfulness training in schools: The importance of practice for an impact on well-being. *The Journal of Positive Psychology*, 5(4), 264-274.

Jensen, C. G., Vangkilde, S., Frokjaer, V., & Hasselbalch, S. G. (2012). Mindfulness Training Affects Attention – Or Is It Attentional Effort? *Journal of Experimental Psychology: General*, *141*(1), 106-123.

Kabat-Zinn, J. (1994). Wherever you go, there you are: Mindfulness meditation in everyday life. New York: Hyperion.

Kanske, P., & Kotz, S. A. (2010). Modulation of early conflict processing: N200 responses to emotional words in a flanker task. *Neuropsychologia, 48(12)*, 3661-3664.

Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology, 38(3)*, 557-577.

Kuyken, W., Weare, K., Ukoumunne, O. C., Vicary, R., Motton, N., Burnett, R., Cullen, C., Hennelly, S., & Huppert, F. (2013). Effectiveness of the Mindfulness in Schools Programme: non-randomised controlled feasibility study. *The British Journal of Psychiatry*, 203(2), 126-131.

Ladouceur, C. D., Dahl, R. E., & Carter, C. S. (2007). Development of action monitoring through adolescence into adulthood: ERP and source localisation. *Developmental Science, 10(6)*, 874-891.

Malinowski, P. (2013). Neural mechanisms of attentional control in mindfulness meditation. *Frontier in Neuroscience*, 7, 8.

Metz, S. M., Frank, J. L., Reibel, D., Cantrell, T., Sanders, R., & Broderick, P. C. (2013). The effectiveness of the Learning to BREATHE program on adolescent emotion regulation. *Research in Human Development*, 10(3), 252-272.

Meyer, B., Haywood, N., Sachdev D., & Faraday,S. (2008) Independent Learning: Literature Review. Research Report DCSF-RR051. Department for Children, Schools and Families. Learning and Skills Network. DCSF Publications, Nottingham.

Moore, A., Gruber, T., Derose, J., & Malinowski, P. (2012). Regular, brief mindfulness meditation practice improved electrophysiological markers of attentional control. *Frontiers in Human Neuroscience*, 6, 18.

Mrazek, M. D., Phillips, D. T., Franklin, M. S., Broadway, J. M., & Schooler, J. W. (2013). Young and restless: Validation of the Mind-Wandering Questionnaire (MWQ) reveals disruptive impact of mind-wandering for youth. *Frontiers in Psychology*, *4*.

Mrazek, M. D., Smallwood, J., & Schooler, J. W. (2012). Mindfulness and mind-wandering: finding convergence through opposing constructs. *Emotion*, 12(3), 442-448.

Oberle, E., Schonert-Reichl, K. A., Lawlor, M. S., & Thomson, K. C. (2011). Mindfulness and inhibitory control in early adolescence. *The Journal of Early Adolescence*, 32(4), 565-588.

Palluel, E., Nougier, V., & Olivier, I. (2010). Postural control and attentional demand during adolescence. *Brain Research, 1358*, 151-159.

Pliszka, S. R., Liotti, M., Bailey, B. Y., Perez III, R., Glahn, D., & Semrud-Clikeman, M. (2007). Electrophysiological effects of stimulant treatment on inhibitory control in children with attention-deficit/hyperactivity disorder. *Journal of Child and Adolescent Psychopharmacology, 17(3)*, 356-366.

Polich, J. (2007). Updating P300: an integrative theory of P3a and P3b. *Clinical Neurophysiology*, *118*(10), 2128-2148.

Raney, G. E. (1993). Monitoring changes in cognitive load during reading: an event-related brain potential and reaction time analysis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*(1), 51-69.

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, Behavioural Neuroscience*. DOI: 10.3758/s13415-015-0354-7.

Schmajuk, M., Liotti, M., Busse, L., & Woldorff, M. G. (2006). Electrophysiological activity underlying inhibitory control processes in normal adults. *Neuropsychologia, 44(3)*, 384-395.

Slagter, H. A., Lutz, A., Greischar, L. L., Francis, A. D., Nieuwenhuis, S., Davis, J. M., & Davidson, R. J. (2007). Mental training affects distribution of limited brain resources. *PLoS biology*, *5*(6), e138.

Smallwood, J., Beach, E., Schooler, J. W., & Handy, T. C. (2008). Going AWOL in the brain: Mind wandering reduces cortical analysis of external events. *Journal of Cognitive Neuroscience, 20(3)*, 458-469.

Smallwood, J., & Schooler, J. W. (2006). The restless mind. *Psychological bulletin*, *132*(6), 946-958.

Spear, L. P. (2013). Adolescent neurodevelopment. *Journal of Adolescent Health*, 52(2), S7 S13.

Sumich, A., Castro, A., & Kumari, V. (2014). N100 and N200, but not P300, amplitudes predict paranoia/suspiciousness in the general population. *Personality and Individual Differences, 61*, 74-79.

Teasdale, J. D., Moore, R. G., Hayhurst, H., Pope, M., Williams, S., & Segal, Z. V. (2002). Metacognitive awareness and prevention of relapse in depression: empirical evidence. *Journal of consulting and clinical psychology*, 70(2), 275-287.

Velanova, K., Wheeler, M. E., & Luna, B. (2008). Maturational changes in anterior cingulate and frontoparietal recruitment support the development of error processing and inhibitory control. *Cerebral Cortex*, *18*(11), 2505-2522.

Waxer, M., & Morton, J. B. (2011). The development of future-oriented control: An electrophysiological investigation. *NeuroImage, 56(3)*, 1648-1654.

Williams, M., & Penman, D. (2011). *Mindfulness: a practical guide to finding peace in a frantic world* (Vol. 360). London: Piatkus.

World Health Organisation. (2011). Education: Shared interests in well-being and development. Geneva: World Health Organisation. URI: http://www.who.int/iris/handle/10665/44737#sthash.gtxAgDSv.dpuf

Zenner, C., Herrnleben-Kurz, S., & Walach, H. (2014). Mindfulness-based interventions in schools-A systematic review and meta-analysis. *Frontiers in Psychology*, 5, 603.

Chapter Five – Effects of school-based mindfulness training on emotion processing and well-being in adolescents: Evidence from event-related potentials

Text similar to how it appears in: Sanger, K. L., Thierry, G., & Dorjee, D. (Under Review). Effects of school-based mindfulness training on emotion processing and well-being in adolescents: Evidence from event-related potentials. *Developmental Science*.

Abstract

In a non-randomised study with a wait-list control group, we investigated the efficacy of a school-based mindfulness curriculum delivered by schoolteachers in older secondary school students (16-18 years). We measured changes in emotion processing indexed by P3b event-related potential modulations, in an affective oddball task using static human faces. Event-related responses were recorded to happy and sad face oddballs, presented in a stimulus stream of frequent faces with neutral expression, before and after eight weeks of mindfulness training. Whilst the mean amplitude of the P3b –a peak of event-related brain potentials typically elicited by infrequent oddballs– decreased in mean amplitude between testing sessions in the control group, it remained unchanged in the training group. Significant increases in self-reported well-being and fewer doctor visits for mental health support were also reported in the training group as compared to controls. The observed habituation to emotional stimuli in controls contrasts with maintained sensitivity in mindfulness-trained students. These results suggest that in-school mindfulness training for adolescents has scope for increasing awareness of socially relevant emotional stimuli, whether positive or negative, and thus may decrease vulnerability to depression.

Introduction

Adolescence is a time of stress vulnerability, with high academic demands and social pressures. It is also considered a sensitive point for depression onset, with the reward system of the brain (ventral striatum) maturing before the prefrontal regions (PFC, ACC) that balance decision-making and regulate behaviour (Ernst, Pine, & Hardin, 2006). According to the Rescorla-Wagner learning model, the dopaminergic response to reward means that when a distal goal is not achieved, dopamine expression is suppressed, which can lead to prolonged suppression of the reward system (Schultz, 2010). In adolescents, this reward suppression combined with an immature PFC can result in a weak ability to regulate emotion, triggering depression (Weir, Zakama, & Rao, 2012). Indeed the World Health Organisation lists depression as the top cause of years lost to disability in adolescents (WHO, 2015), and the National Institute for Health and Care Excellence recommends that schools develop procedures to detect early symptoms of depression (NICE, 2005).

In an attempt to promote mental health, some schools are introducing mindfulness-based interventions into their curricula. The practice of secular mindfulness can be described as intentional attending to the present moment experience, with a kind and accepting attitude (Kabat-Zinn, 1994). Improvements in anxiety and recurrent depression after mindfulness training are well documented in adults (e.g. Williams et al., 2014), and psychological benefits of mindfulness training have also been shown in adolescents (Biegel, Brown, Shaprio, & Schubert, 2009; Kuyken et al., 2013). Specifically, initial studies of school-based programmes have found improvements in perceived stress and well-being, as well as reductions in anxiety and depression (Huppert & Johnson, 2010; Kuyken et al., 2013; Metz et al., 2013; Raes, Griffith, Van der Gucht, & Williams, 2014; see Felver, Celis-de Hoyos, Tezanos, & Singh, 2016, or Zenner, Herrnleben-Kurz, & Walach, 2014 for an overview of school-based research).

Mindfulness-based interventions have been shown to improve healthy reflection on distressing memories in adults (Hargus, Crane, Barnhofer, & Williams, 2010), and to attenuate interference from negative stimuli in university students (Eddy, Brunyé, Tower-Richardi, Mahoney, & Taylor, 2015; Ortner, Kilner, & Zelazo, 2007). This is relevant to depression research, where clinical groups have been found to demonstrate a negativity bias in autobiographical memory, and in response to visual and auditory affective stimuli (Gotlib, & Neubauer, 2000). Mindful and depressed participants also seem to differ in how they relate to others. Adults with major depression disorder (MDD) tend to struggle with cognitive empathy, including perspective taking and theory of mind (Schreiter, Pijnenborg, & aan het Rot, 2013), while mindfulness training may increase empathy (Block-Lerner, Adair, Plumb, Rhatigan, & Orsillo, 2007; Music, 2014). Consistent with this view, Hölzel et al. (2011) reported increased grey matter concentration in the temporal-parietal junction (TPJ), a key area for social cognition and perspective taking, after mindfulness-based stress reduction (MBSR). However, there is currently no evidence to support the existence of similar benefits in adolescents.

When considering how mindfulness may impact on neural correlates of depression or depression vulnerability in adolescence, we can assume a divergent pattern of activation between depression and mindfulness-based change (Deng, Li, & Tang, 2014; Desrosiers, Klemanski, & Nolen-Hoeksema, 2013; Way et al., 2010). There are different models of depression, upon which we can hypothesise a potential impact of mindfulness training in adolescents. The Emotion Context Insensitivity (ECI) model for example, proposes that depression is characterised by a lack of response to both positive and negative emotional stimuli, a coping mechanism preventing further reactivity in individuals' experiencing long-term, high-intensity stress (Rottenberg, Gross, & Gotlib, 2005). A meta-analysis supporting this model (Bylsma, Morris, & Rottenberg, 2008), shows that MDD groups exhibit dampened responses to both positive and negative stimuli compared to controls. In the adolescent literature, Blom et al. (2015) reported that depressed adolescents showed significantly reduced anterior / middle insular cortex activation when viewing sad as opposed to happy faces, as compared to controls, an effect considered a developmental signature of depression (see Smith, Steinberg & Chein, 2013).

It has been argued that mindfulness encourages openness to both positive and negative experience whilst minimizing reactivity or rumination. It can promote activation, and neural connectivity in regions associated with social understanding, bodily awareness, and empathy – the insular cortex (Farb, Segal, & Anderson, 2012) and the TPJ (Hölzel et al., 2011). Birnie, Speca, and Carlson (2010) also showed that mindfulness training can increase social connectedness and empathy while decreasing personal distress. Mindfulness training may therefore enhance the processing of emotional expression, a mechanism by which individuals can then connect with others. Indeed this was assessed after MBCT in adults currently in recovery from depression, with De Raedt et al. (2012) finding that mindfulness training encouraged a more equal receptiveness to both positive and negative facial stimuli, in comparison to a clinical control group. Such an effect in adolescents, who may also be thought of as a population vulnerable to depression, could enhance social connectedness and potentially buffer them against mental illness (Donald & Dower, 2002; Music, 2014).

Event-related brain potentials (ERPs) have several advantages for neurodevelopmental research in an education context: their temporal resolution is high, the recording system is portable thus allowing for testing in schools, and the method is cost-effective in comparison to *f*MRI (Sanger & Dorjee, 2015). To our knowledge however, no neuroscientific research has yet investigated changes in emotion processing with mindfulness training in adolescents, using either fMRI or ERPs. One appropriate ERP marker for detecting such changes is the P300 (particularly the P3b), which indexes task-related information processing (Sutton, Braren, Zubin, & John, 1965). The P3b has been associated with several brain regions, but evidence suggests a key link with the anterior cingulate cortex (ACC) and TPJ (Kok, 2001; Polich, 2007). The ACC is involved in top-down regulation of attention and emotion (Bush, Luu, & Posner, 2000), and both brain regions are sensitive to modulation by mindfulness-based training (Cahn & Polich, 2006; Hölzel et al., 2007; Hölzel et al., 2011). Moreover, the P3b has previously been used as an index of choice in cognitive empathy tasks (e.g. Fan & Han, 2008; Ikezawa, Corbera, & Wexler, 2013; Meng et al., 2012). The P3b is also modulated by change in emotive facial processing in adults with depression (Cavanagh & Geisler, 2006). Specifically, P3b amplitudes elicited by happy faces are reduced in MDD participants, indicating a dampened ability to process positive facial cues. Given the negative correlation between mindfulness and depression documented in previous studies (Deng et al., 2014; Desrosiers et al., 2013), it can be hypothesised that mindfulness training would increase P3b amplitudes to happy faces. Consistent with the predictions of the ECI model of depression and results of MBCT effects in adults vulnerable to depression (De Raedt et al., 2012), P3b responses to sad faces may equally be modulated, while self-report measures would show increased well-being. These predictions would corroborate the pattern of enhanced affective processing, without negative mood induction, which has been observed in previous research (Birnie et al., 2010; Dorjee et al., 2015).

The purpose of this study was to investigate longitudinal changes in emotion processing in older secondary school students (16-18 years), after mindfulness training, delivered as a module in Personal, Social, and Health Education (PSHE). The evaluations included self-report questionnaires and P3b modulations recorded in a computerised emotion oddball task using affective facial stimuli (happy and sad face oddballs, presented amongst frequent neutral faces). In line with previous findings (Huppert & Johnson, 2010; Metz et al., 2013), we expected that mindfulness training would improve well-being and mental health in trained adolescents compared to control participants. Critically, we expected that P3b responses elicited by emotional stimuli would be significantly increased in the intervention group. This would suggest that mindfulness-based practice enhances the processing of socially relevant stimuli and healthy emotional exposure, a pattern that contrasts with neurocognitive responses to emotional stimuli in people with depression (Blom et al., 2015; Cavanagh & Geisler, 2006). In order to test whether mindfulness training impacts on positive or negative stimuli differently, given the divergent clinical literature on affective processing and limited evidence of depression effects in adolescents, happy and sad target oddballs will be analysed separately.

Methods

Participants

The study was approved by the Ethics Committee in the School of Psychology at Bangor University, prior to participant recruitment. Participants were recruited from four schools in North Wales (UK), two for the training group and two wait-list controls. The schools were matched on socio-economic status and academic attainment across groups. Sixth form students (16-18 years) from all schools were recruited after presentations describing the study, and sign-up sheets placed in sixth form common rooms. Participants volunteered for questionnaires plus ERP recordings during an experimental task, or only questionnaires. Those participating in the ERP part of the study were allocated a time-slot in January-February (pre-training) and in April-June (post-training). Participation was open to the entire sixth form for control students, and all those enrolled on the mindfulness course for the training group.

The total sample population was N = 48 (21 training group), however class attendance records led to the exclusion of one training group participant who only attended one mindfulness session. In order to compare self-report and ERP measures, analysis was run only on participants who completed all assessments at both time points. This led to a final sample of 40 students (19 training group, mean [M] age 16.8, standard deviation [SD] 0.6), as several participants had opted to only complete self-report measures. Baseline differences were assessed using independent t-tests for age, doctor visits, and sickness absences. A chi-square analysis was additionally run for gender, past training relating to stress relief, cognitive skills, and mindfulness experience. No significant baseline differences were identified (all *ps* > .05). However age and gender were marginally significant (*ps* = .06) due to more Year 13 participants volunteering in the control group (training group M = 16.6, SD = 0.6 / control group M = 17.0, SD = 0.6) and more boys volunteering in the training group. However the difference between 16 and 17 year olds in developmental terms is minimal (Paulluel, Nougier, & Olivier, 2010; Waxer & Morton, 2011). To ensure that mindfulness effects were not impacted by gender, given that previous literature has shown differential gender effects on P3b-indexes of empathy (Han, Fan & Mao, 2008), ERP analysis was also ran as a hierarchical multiple regression, additionally controlling for age and gender. All other baseline differences were strongly non-significant (all *ps* > .1).

Measures

The Five-Facet Mindfulness Questionnaire (FFMQ; Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006) assessed whether mindfulness levels increased after training. It has 39-items and five subscales: Observing, Describing, Acting with Awareness, Non-Judging, and Non-Reacting. The final score can be calculated as FFMQ-Total for each individual, or by subscale, with a higher score indicating more mindful disposition. The internal consistencies (Cronbach α) for these facets are good, reported as 0.83 for FFMQ-O, 0.91 for FFMQ-D, 0.87 for FFMQ-AwA, 0.87 for FFMQ-NJ, and 0.75 for FFMQ-NR (Baer et al., 2006).

The Perceived Stress Scale (PSS; Cohen, Kamarck, & Mermelstein, 1983) evaluated ability to cope with stress, and has good internal consistency (Cronbach α = 0.85: Cohen et al., 1983). The PSS has been used previously in mindfulness research, showing reductions in scores in adults (Baer, Carmody, & Hunsinger, 2012) and adolescents (Biegel et al., 2009) after mindfulness training. It consists of 10 items scored on a 5-point Likert scale, where a higher score indicates more perceived stress during the last month.

The World Health Organisation, Well-Being Index 5-item version (WHO-5; WHO Collaborating Centre in Mental Health, 1998) can provide a valid measure of depression levels in adolescents (Blom, Bech, Högberg, Larsson, & Serlachius, 2012), and asks how participants' have felt over the past two weeks. It uses a 6-point Likert scale, and phrases questions positively e.g. "I have felt active and vigorous". It has good internal reliability in adults, with a Cronbach α of 0.84 (Bech, Olsen, Kjoller, & Rasmussen, 2003).

The Toronto Empathy Questionnaire (TEQ; Spreng, McKinnon, Mar, & Levine, 2009) is a brief self-report measure created on the basis of a factor-analysis of longer empathy questionnaires. The measure has been successfully used with adolescents (Barry, Kauten, & Lui, 2014; Brewer & Kerslake, 2015). The TEQ conceptualizes empathy as primarily an emotional process e.g. “When someone else is feeling excited, I tend to get excited too”. It includes 16 questions, eight of which are reverse coded. Scores are measured on a 5-point Likert scale from 0 (never) to 4 (always). The internal reliability with adoelscents is good, with Spreng et al. (2009) reporting Cronbach’s alpha ranging 0.85 – 0.87 across three studies.

An acceptability measure was designed for the study, asking mindfulness-trained students to rate their satisfaction with the mindfulness course, and report on home practice. Course enjoyment was measured on a 7-point Likert scale from 1 (not at all) to 7 (very much) and home practice was measured on a 4-point Likert scale from 1 (never) to 4 (every day). Class attendance records were accessed via the school. Results of this are already published in Sanger and Dorjee (2016).

Participants also provided data pre- and post-training regarding the number of sickness absences, the frequency of visits to their local doctor (GP), and the reason for GP visits. Students were free to leave any questions they did not wish to answer.

Emotional oddball paradigm

Happy, sad, and neutral faces from the Karolinska database (Goeleven, De Raedt, Leyman, & Verschuere, 2008) were used in the oddball task. Happy (10%) and sad (10%) faces were the target stimuli, including 15 male and 18 female face pairs, which participants were instructed to respond to by pressing the spacebar on a computer keyboard, using their dominant hand. The frequent (80%) non-target faces were two repeated images of one male and one female individual with a neutral expression. Data from the Goeleven et al. (2008) validation paper were used to balance stimuli, with analyses of variance (ANOVA) showing no significant difference in arousal levels between target emotions ($F(1,62) = 3.0$, $p = .09$), between genders ($F(1,62) < 0.1$, $p = .91$), and no significant interaction between emotion and gender ($F(1,62) = 0.97$, $p = .33$). Mean correct emotion identification scores for selected stimuli were >75%.

Face stimuli were presented in the centre of the computer monitor for 900 ms, with an inter-stimulus interval of 750 ms. Participants performed the task in three blocks of 110 trials with the same proportion of the oddball and neutral stimuli in each block, and faces were displayed randomly within each block. Block presentation was counterbalanced across participants. The task took 9-minutes to complete, plus breaks between blocks.

Mindfulness-based Programme

An age appropriate mindfulness-based curriculum called '.b Foundations' (MiSP; http://mindfulnessinschools.org/) was delivered over eight 50-minute sessions plus an initial orientation session. The course was taught by participants' regular schoolteachers within the PSHE curriculum. For a full description of the implementation model please see Sanger and Dorjee (2016).

Procedures

This study followed a non-randomised, pre-post design with wait-list control group. Participants were tested individually during school hours, scheduled within independent study periods, using a portable EEG system. Quiet testing spaces were provided on school premises. At baseline all procedures were explained to participants, and informed consent was obtained before the start of testing. Participants were asked to come to their testing sessions with clean, dry hair and not to use any hair products or conditioner. During the EEG set-up period students filled in self-report measures. If these were not completed during set-up, students took them away in a sealed envelope and were asked to return them on the next school day.

EEG signal was recorded with 36 Ag/AgCl electrodes placed according to the 10-20 standard system, using the right mastoid as the reference site (then combined with A1 the left mastoid site offline) and FPz as the system's ground. EEG data were recorded with Neuroscan NuAmps amplifiers with a sampling rate of 1 kHz. Two electrodes placed above and below the right eye, monitored ocular movements. Additionally, electrodes attached on both forearms recorded heart rate variability, the results of these analyses will be reported elsewhere. Electrode impedance was kept below 7 kΩ. The EEG signal was filtered online with a bandpass filter between 0.01 – 200 Hz, and additional filtering was applied offline using a zero phase shift low-pass filter with a cut-off frequency of 30 Hz, and a 48 dB/Oct slope. ERP data were manually cleaned, rejecting motor and irregular ocular artefacts. An algorithm in Neuroscan Edit software was then employed to regress out eye-blink artefacts, and mathematically remove artefacts using the Gratton, Coles, & Donchin (1983) method. The data was epoched into 1000 ms segments (beginning 100 ms before stimulus onset), and baseline corrected relative to pre-stimulus activity. Averages for each condition and participant, as well as grand averages across participants for each condition and group were then computed, considering only correct trials i.e. trials in which happy or sad target faces had been correctly detected. ERPs elicited by neutral faces (standard stimuli) were computed from the last neutral face that preceded an emotional target stimulus. This method of standard ERP calculation ensures that standard stimuli were maximally habituated (i.e. maximally standard in nature) and by the same token, that trial numbers were comparable between oddball and standard conditions.

Data Analysis

Pre-post questionnaire and oddball task performance measures were analysed using mixed factorial analysis of variance (ANOVA), with a 2 (time: pre, post) x 2 (group: training, control) design. Significant interactions were further investigated using paired samples t-tests. Outliers above and below two standard deviations (SD) of the group mean were removed prior to analysis. ERP analysis was conducted over a cluster of centro-parietal electrodes, showing maximal P3b amplitudes at Pz (CP2, CPz, CP4, P2, Pz, and P4). See *figure 1* for visual illustration. Separate ANOVAs were conducted for each task condition, based on the analysis approaches of previous ERP literature that we grounded our study design and predictions upon (Cavanagh & Geisler, 2006; Ikezawa et al., 2014; and Fan & Han, 2008). Significant interactions were further investigated using paired sample t-tests, using a Greenhouse-Geisser adjustment of degrees of freedom where applicable. There is conflicting evidence in the school-based literature regarding the impact of mindfulness training engagement on outcome (Foret et al, 2012; Huppert & Johnson, 2010), so correlation analyses assessed any moderating effects of course attendance, satisfaction, and home practice in the training group. Additionally, P3b changes were correlated with empathy scores across groups, to check its sensitivity to index social connectedness. For this correlation, P3b mean amplitudes in the standard control condition were subtracted from the target conditions, this ensured that the ERP signal correlated with empathy was directly related to emotional response only. This approach to correlations with self-report measures was also used by Ikezawa et al. (2014) and Fan & Han (2008). A hierarchical multiple regression assessing post-training average P3b mean amplitudes as the dependant variable for all task conditions, controlling for pre-training mean amplitudes and group, then age, then gender, examined whether the marginal group differences in age and gender impacted on the main ERP findings.

Results

Five-Facet Mindfulness Questionnaire

The FFMQ had an acceptable level of internal reliability (Cronbach α) within this sample at baseline, 0.82 for FFMQ-Total, 0.76 for FFMQ-O, 0.86 for FFMQ-D, 0.83 for FFMQ-AwA, 0.87 for FFMQ-NJ, and 0.68 for FFMQ-NR. Mixed factorial ANOVA results for FFMQ-

Total did not reveal any significant effects (all *p*s > .1). Subscales were also analysed, but no significant effects were found (all *p*s > .1).

Perceived-Stress Scale

Baseline reliability for the PSS was good (α = 0.83). Two participants did not provide responses on this measure, reducing the sample to n = 38. There was no main effect of time ($F(1,36) = 3.6$, $p = .07$) or group ($F(1,36) = .2$, $p = .66$) and no interaction ($F(1,36) = 1.5$, $p = .23$). A significant positive correlation was found between PSS change score and self-reported enjoyment of the mindfulness course, suggesting that participants in the training group who reported more enjoyment of the course actually increased in perceived stress ($r = .65$, $p = .004$). Interestingly, post-hoc analysis found that perceived stress change pre-post did not correlate with change in well-being scores in the training group ($r = -.08$, $p = .78$), while a strong relationship between these variables was found in the control group ($r = -.76$, $p < .001$).

WHO-5 Well-Being Index

The WHO-5 was reliable within this sample (α = 0.79). Five participants did not contribute to this measure, reducing the sample to n = 35. The mixed factorial ANOVA revealed a significant main effect of time ($F(1,33) = 12.9$, $p = .001$, $\eta^2 = .26$), with all participants well-being increasing by post-test. There was a non-significant effect of group ($F(1,33) < .1$, $p = .81$), and marginally significant time by group interaction ($F(1,33) = 3.1$, $p = .08$, $\eta^2 = .06$). As the interaction was in the predicted direction, follow-up paired samples t-tests were conducted, showing the trend to be due to an increase in self-reported well-being in the training group ($t(15) = -4.3$, $p = .001$, $d = 1.1$), whilst no significant changes were observed in the control group ($t(18) = -1.2$, $p = .24$).

TEQ Empathy Questionnaire

The reliability of this measure at baseline was good (α = 0.84). Four participants did not provide responses, reducing the sample to n = 36. The ANOVA showed a significant main effect of time ($F(1,34) = 10.1$, $p = .003$, $\eta^2 = .23$), with participants' empathy reducing pre-post, and a significant main effect of group (*F*(1,34) = 8.8, *p* = .006, η^2 = .21) indicating that the training group were less empathetic on average. The interaction effect was non-significant (*F*(1,34) = .3, *p* = .61). However, changes in this measure correlated positively with course attendance (*r* = .66, *p* = .006) and marginally with home practice (*r* = .49, *p* = .06), suggesting that those who attended more of the mindfulness course and practiced more displayed larger increases in empathy.

Health Measures

ANOVAs revealed no change in absenteeism over time (*F*(1,38) = .6, *p* = .45), between group (*F*(1,38) = 1.3, *p* = .25) or an interaction (*F*(1,38) = .9, *p* = .35). GP visits were also not affected by time (*F*(1,38) = .6, *p* = .44) or group differences (*F*(1,38) = 1.2, *p* = .28), the time by group interaction was also non-significant (*F*(1,38) = 3.0, *p* = .09, η^2 = .07). To investigate the possibility of differential effects for visits due to physical and mental health reasons, GP visits were further broken down accordingly (e.g. asthma and stress respectively). For mental health related visits only, the ANOVA showed no change over time (*F*(1,38) = .3, *p* = .58) or group (*F*(1,38) = .7, *p* = .42), but there was a significant time by group interaction (*F*(1,38) = 5.0, *p* = .03, η^2 = .12). However, follow-up paired samples t-test revealed only trends towards significance, with reduced visits in the training group (*t*(18) = 1.7, *p* = .11, *d* = .39) and a non-significant increase in GP visits over time in the control group (*t*(20) = -1.5, *p* = .16, *d* = .32). Nevertheless the effect sizes indicate a moderately important finding. On visual inspection there appeared to be baseline group differences on GP visits, *see table 1*, however independent t-tests confirmed that these were not significant at baseline for general or specifically mental health visits (*p*s > .05).

	Questionnaire means (SD)			
	Pre-Training Group	**Post-Training Group**	**Pre-Control Group**	**Post-Control Group**
FFMQ-Total	119.9 (15.9)	120.4 (12.7)	121.1 (17.1)	122.3 (20.6)
FFMQ-O	24.4 (6.3)	24.1 (5.3)	24.6 (5.2)	23.6 (5.3)
FFMQ-D	26.1 (5.8)	24.6 (4.3)	26.0 (6.3)	26.4 (5.7)
FFMQ-AwA	24.1 (5.4)	23.3 (4.2)	24.2 (6.9)	23.8 (6.5)
FFMQ-NJ	25.8 (6.4)	27.5 (5.9)	26.0 (6.6)	27.7 (6.5)

FFMQ-NR	19.6 (3.4)	20.7 (3.5)	20.4 (4.4)	20.9 (4.5)
PSS	20.1 (6.7)	19.8 (4.9)	22.5 (6.7)	19.7 (6.0)
WHO-5	**48.0 (16.7)****	**64.8 (20.4)****	55.6 (19.6)	61.1 (16.9)
TEQ	43.1 (10.8)	39.8 (8.7)	50.5 (7.1)	48.1 (7.0)
Health-Absenteeism	3.5 (3.7)	3.4 (3.8)	4.9 (5.5)	5.9 (7.5)
Health-GP Visits	**1.1 (2.4)~**	**0.5 (0.7)~**	0.3 (0.8)	0.5 (0.7)
Health-Psychological GP Visits	**0.4 (1.0)~**	**0.1 (0.2)~**	0 (0)	0.2 (0.6)

Table 1: Pre to post self-report measure changes in training and control groups (< .05; ** < .01; ~ = trend towards significance in follow-up t-test analysis)*

Task Performance

Mixed factorial ANOVAs assessed oddball task performance. There was a significant main effect of time on accuracy to happy target faces ($F(1,38) = 4.8$, $p = .04$, $\eta^2 = .11$), but no significant main effect of group ($F(1,38) < .1$, $p = .88$), and no significant interaction ($F(1,38) = .5$, $p = .48$), suggesting that all participants became more accurate by post-test. A marginally significant positive correlation was found between mindfulness course enjoyment and improved target accuracy to happy faces ($r = .40$, $p = .07$). No significant effects of accuracy were found for sad target faces (all *p*s > .1). No significant changes in response time (RT) were reported in either emotion target conditions (all *p*s > .05).

P3b ERP Analysis

A 2 (time: pre, post) x 3 (condition: happy, sad, standard) x 2 (group: training, control) mixed ANOVA assessed any variation in trial numbers included in ERP analysis across conditions and groups. There were no significant main effects of time or group (*p*s > .1) and the significant main effect of condition ($F(2,76) = 2503.7$, $p < .001$) was clarified with simple contrasts to show that this difference was only between standard and oddball conditions ($p < .001$), while there was no significant difference between emotional targets ($p > .05$). There were no significant interactions (all *p*s > .1). Table 2 shows the average number of trials included per condition.

	Mean (SD) trials per condition for ERP analysis					
	Pre-Happy	**Pre-Sad**	**Pre-Standard Neutral**	**Post-Happy**	**Post-Sad**	**Post-Standard Neutral**
Training Group	32.1 (.8)	31.6 (1.6)	52.5 (3.5)	31.2 (1.9)	31.1 (1.9)	50.5 (4.0)
Control Group	32.0 (1.5)	31.4 (2.0)	51.4 (4.4)	31.6 (1.3)	31.2 (1.9)	51.8 (3.3)

Table 2: Means and standard deviations (SD) for average number of trials included in ERP analysis across groups and conditions.

Planned comparisons of P3b mean amplitudes showed a significant variance across all three task conditions (all *p*s < .05). The sad target condition elicited the most positive P3b amplitudes, followed by happy targets, and then standard neutral stimuli. This significant variation in mean amplitudes between conditions supported the use of separate ANOVAs in order to study longitudinal change effects between groups. The hierarchical multiple regression analysis, run separately for each condition, used post-training P3b mean amplitudes as the dependant variable. Potential age and gender effects showed no additional contributions over and above when controlling for pre-training mean amplitudes and group, for any stimulus type (all *F* changes > .1).

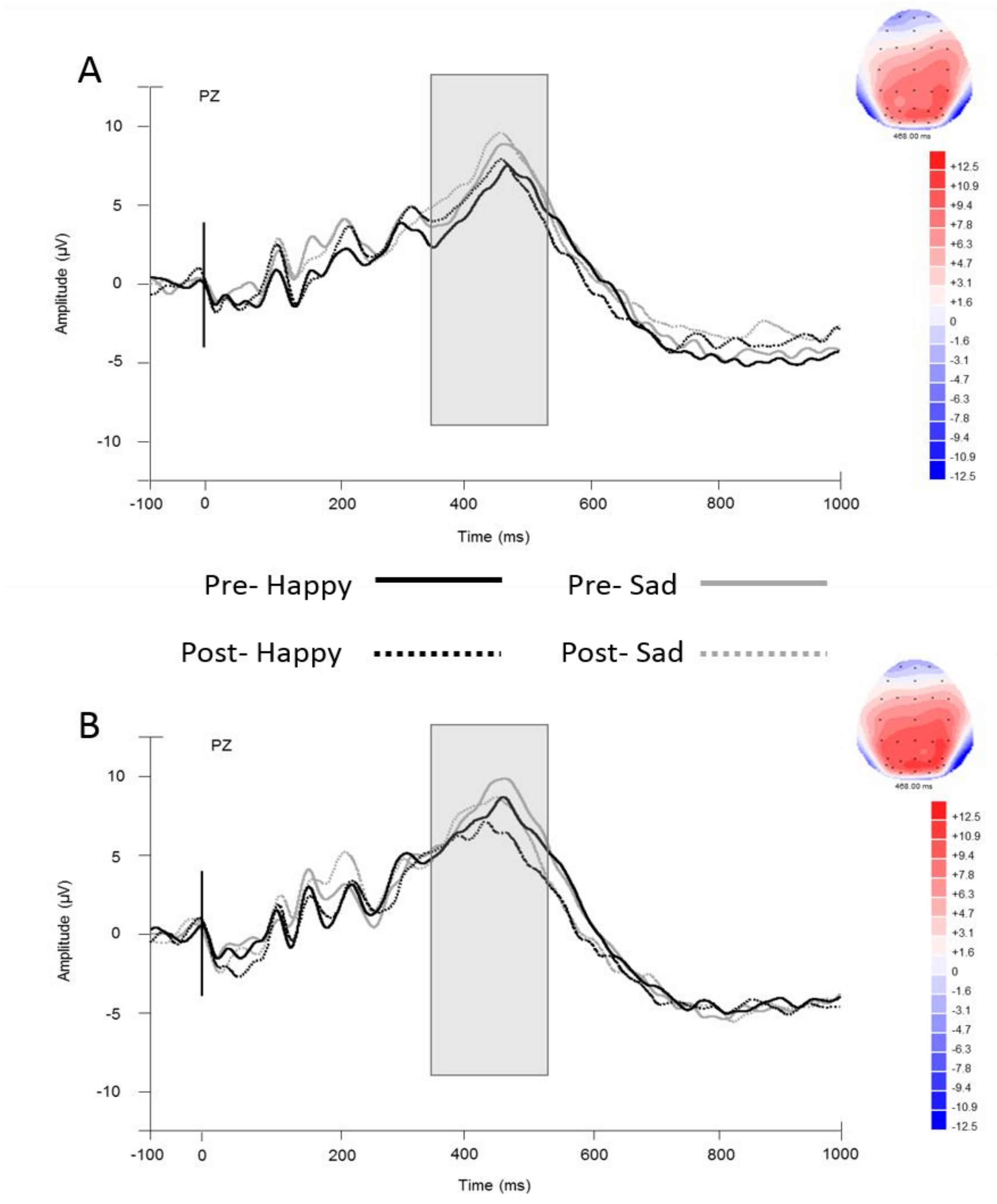

Figure 1: P3b mean amplitude pre-post target responses and topography for the training group (A) and controls (B).

Neutral Condition

Figure 2 illustrates the ERP effects in training and control groups. Standard neutral faces elicited significantly less positive P3b mean amplitudes over time ($F(1,38) = 6.50$, $p = .02$, $\eta^2 = .080$), no main effect of group was shown ($F(1,38) = .23$, $p = .63$), and there was a significant main effect of electrode ($F(5,190) = 9.12$, $p < .001$, $\eta^2 = .074$). No significant interactions were found (all *p*s > .1). In terms of latency effects, two significant outliers were identified (2 SDs above the group mean), leaving a sample of N = 38 participants. P3b latency was found to not differ over time ($F(1,36) = 1.59$, $p = .22$), there was a significant main effect of group ($F(1,36) = 4.88$, $p = .03$, $\eta 2 = .119$) suggesting that the training group had an earlier peak latency overall, and no significant interaction was found ($F(1,36) = 2.73$, $p = .11$).

Happy Target Condition

There were two outliers in the control group identified and removed from mean amplitude analysis. The subsequent mixed ANOVA only revealed a significant time by group interaction effect ($F(1,36) = 4.09$, $p = .05$, $\eta^2 = .047$), no other main effects or interactions were significant (all *p*s > .05). The follow-up paired samples t-tests were run on the average mean amplitude across electrodes of interest, showing a reduction in P3b mean amplitude by post-test in the control group ($t(18) = 2.34$, $p = .03$, $d = .54$), no change was found in the training group ($t(18) = -.31$, $p = .76$). A positive correlation was also noted between average mean amplitude change across groups, as subtracted from neutral standard responses, and TEQ score change ($r = .37$, $p = .03$), *see figure 3*, indicating that for all participants an increase in P3b mean amplitude related to an increase in empathy. The ANOVA for latency revealed no significant effects (all *p*s > .1).

Sad Target Condition

The mixed ANOVA showed a non-significant main effect of time ($F(1,38) = .45$, $p = .51$), and group ($F(1,38) = .04$, $p = .84$), and a significant effect of electrode ($F(5,190) = 7.76$, $p < .001$, $\eta^2 = .070$). There was a marginally significant time by group interaction effect ($F(1,38) = 2.87$, $p = .09$, $\eta^2 = .033$), and all other interactions were non-significant (all *p*s > .1). A follow-up was conducted on this marginal effect, as mean amplitudes were in the predicted direction (only control participants showed reduced responses to emotional target stimuli by post-test). T-tests revealed that mean P3b positivity reduced over time in the control group ($t(20) = 2.10$, $p = .05$, $d = .46$), with no change in the training group ($t(18) = -.60$, $p = .56$). A positive correlation was also noted between average mean amplitude change, as subtracted from neutral standard responses, and TEQ score change ($r = .33$, $p = .05$). Similar to the results for happy targets, this suggests that more positive P3b over time was associated with an increase in empathy. The mean latency ANOVA revealed no significant effects (all *p*s > .1).

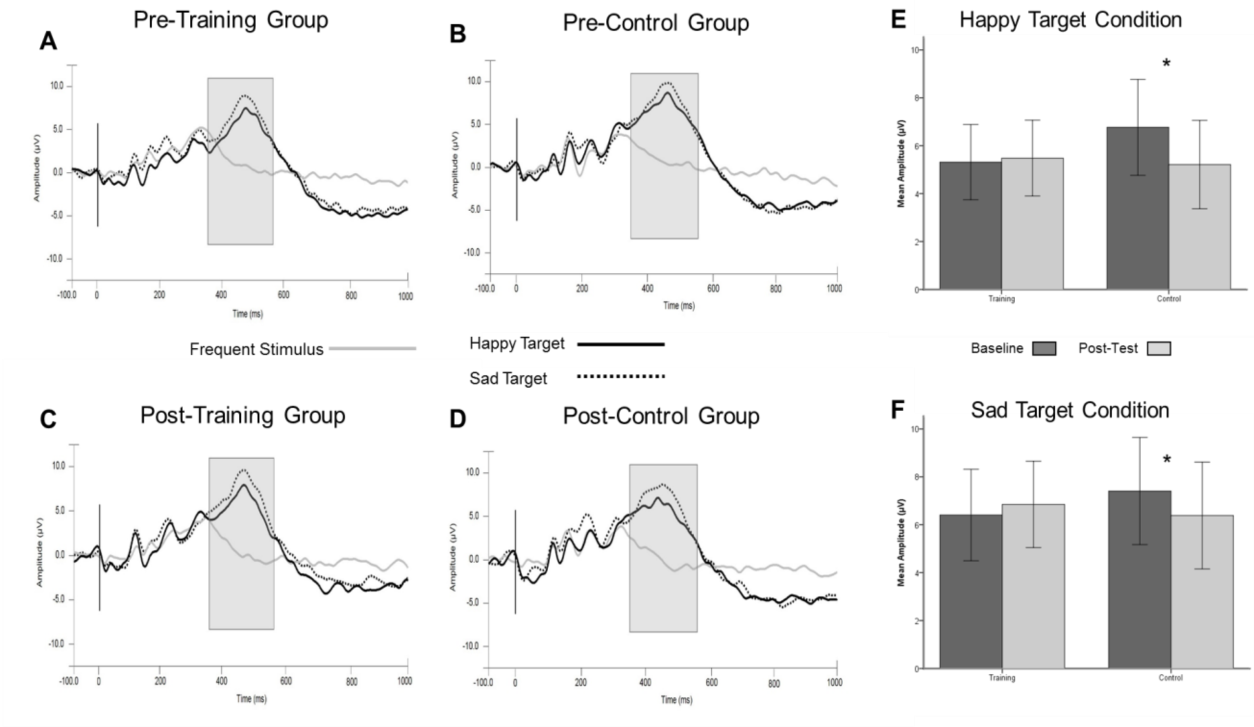

Figure 2: Graphs A-D show general waveform highlighting the P3b time window. Graphs E and F show P3b mean amplitude change in control group pre-post to happy (t-test p = .03) and sad (t-test p = .05) facial targets.

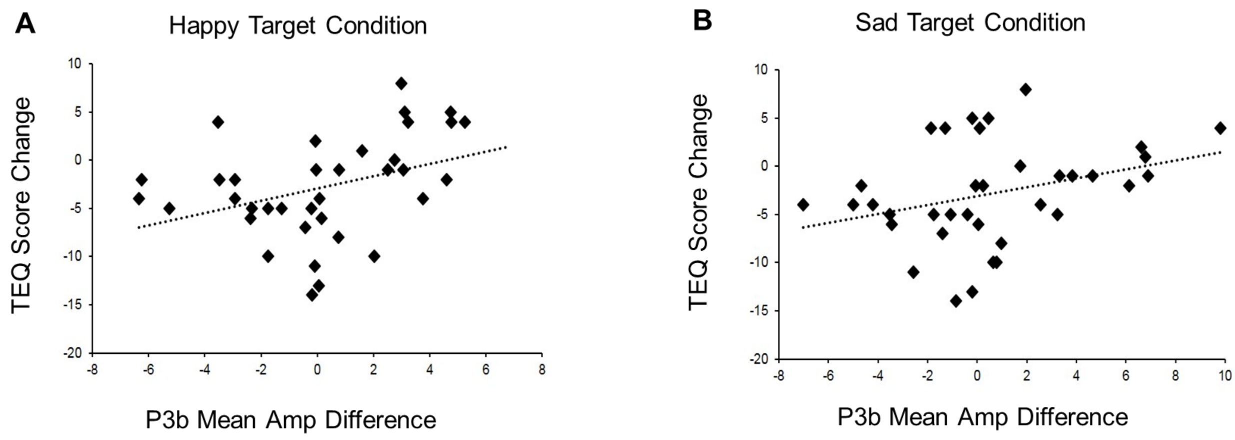

Figure 3: Correlation plots represent significant association between TEQ empathy score change and P3b modulation to happy (A: r = .37, p = .03) and sad (B: r = .33, p = .05) facial targets.

Discussion

We studied emotion processing before and after a school-based mindfulness programme in adolescents. Mindfulness training was associated with maintained P3b mean amplitudes to correctly identified happy and sad target faces in an oddball task, whereas target-related P3b amplitude was reduced over time in wait-list controls. There were no between-group effects on response time or accuracy, but mindfulness course satisfaction positively correlated with improved accuracy for happy faces. Training-based improvements were also noted in self-reported well-being and health measures, with significant increases on the WHO-5 well-being index and trends towards less mental health-related GP visits. Although mindfulness training did not impact TEQ scores overall, course attendance and home practice both positively correlated with empathy change. Overall, this study demonstrated that a mindfulness-based PSHE module delivered by internal schoolteachers can positively impact students' emotion processing and well-being.

Modulation in P3b responses to happy and sad faces also correlated with changes in empathy. This suggests that mindfulness practice may help sustain attentional focus on socially-relevant affective stimuli, overriding typical stimulus habituation (Geisler & Polich, 1994; Ravden & Polich, 1998), and potentially indexing heightened empathy. The finding of stable P3b amplitudes elicited by affective targets, along with self-reported well-being increases, also aligns with our initial predictions and is consistent with previous research, showing that adolescents with MDD tend to show reduced levels of neural activity when processing sad faces (Blom et al., 2015). In addition, research supporting the ECI model of depression demonstrated that many adults with MDD show a general impairment in processing of affective stimuli manifesting through dampened responses (Bylsma, Morris, & Rottenberg, 2008). In contrast, mindfulness training has been shown to enhance brain activity and mood in adults (Bostanov et al., 2012; Williams et al., 2014). This study was the first to demonstrate the modulation of depression-related ERP markers of emotion processing in adolescents. Tentatively, we can interpret these findings as suggesting that mindfulness practice, which encourages curiosity and exposure to emotion without judgement or reactivity, can help maintain attention on socially-relevant affective stimuli, in comparison to controls who reduced attentional efforts as they habituated to affective targets.

The self-report findings support previous research on school-based mindfulness training, showing a significant increase in well-being (Huppert & Johnson, 2010; Metz et al., 2013). The inclusion of health-related data adds to our knowledge of school-based intervention effects, suggesting that mindfulness training may reduce adolescents' needs to seek mental health advice. Marginal decreases in GP visits for psychological reasons (e.g. stress, trouble sleeping) were found in the training group, and similarly control participants reported marginal increases. This divergent pattern of GP visits was supported by moderate effect sizes, which is important to examine given the limited sample size. The timing of data collection may be relevant here, as students were preparing for summer exams and the potential for stress and anxiety would have been high. The health-related data might therefore suggest that mindfulness practice had a buffering effect on psychological well-being, manifesting in less need to seek help during this challenging period.

Interestingly, there were no changes between groups in terms of perceived stress. Reductions in perceived stress have previously been found after mindfulness training in school-based and adult intervention studies (Baer et al., 2012; Biegel et al., 2009; Metz et al., 2013; Shapiro, Brown, & Biegel, 2007), but the current data showed a positive correlation between perceived stress change scores and mindfulness course satisfaction. Post-hoc, we explored the relationship between PSS and WHO-5 fluctuations to investigate the impact of participants' increased stress reporting. Whilst self-reported change on these measures was strongly correlated in controls, there was no such relationship in training participants. Mindfulness is the practice of attending to the present moment with curiosity and acceptance, allowing people to become aware of their experience without reactivity (Kumar, Feldman, & Hayes, 2008; Goldin & Gross, 2010). This data would suggest that mindfulness practice enhanced students' affective awareness without impairing wellbeing, an emotion regulation strategy previously found in adults with anxiety problems learning mindfulness (Goldin & Gross, 2010). Moreover, no pre-post change was seen in empathy scores, but within the training group both course attendance and home practice positively correlated with increased empathy. We speculate that greater engagement with mindfulness practice could be required for self-reported empathy change. Interestingly, P3b mean amplitude to targets, which were significantly modulated by mindfulness training, also correlated with empathy scores. It may be that ERP measures operate as a more sensitive measure of initial changes in social cognition.

Limitations and Future Directions

The positive correlation between mindfulness course satisfaction and improved target accuracy to happy faces could have resulted from increased performance motivation. However, three other results go against a motivation bias significantly impacting on our results. Firstly, there was no difference in RT and target accuracy between the groups at pre- or post-test. Secondly, the significant correlation between course satisfaction and perceived stress is contradictory to motivation bias effects. Thirdly, the marginal decrease over time in GP visits was a naturalistic behavioural effect, not a performance-based outcome, and is unlikely to have been impacted by motivation bias. Nevertheless, future studies should take motivational bias into consideration and include manipulations that can reduce its effects, such as an active control group.

The limited sample size for self-report measures must be considered. Although using the same sample for self-report and ERP measures ensures a more accurate comparison between assessments, it does constrain the likelihood of finding significant differences between groups. However, effect sizes were used to gather a truer reflection of the impact of mindfulness training on adolescents, as these are not so constrained by sample size (Cumming, 2012). Another limitation was the lack of follow-up results in this study, which is a common problem in the vast majority of neuroscientific intervention studies for logistical and cost-related reasons. We hope that future work will build on these initial findings and explore the long-term effects of mindfulness training in adolescents. Of particular interest could be improvements in self-reported well-being and empathy after continued practice, as well as sustained changes in ERP indices of emotional processing predictive of anxiety and depression. These should provide more conclusive evidence of possible long-term well-being protective effects of mindfulness training delivered in the school context.

Conclusions

To our knowledge, this non-randomised controlled study was the first neurocognitive investigation of longitudinal modulations in emotional processing in adolescents, resulting from mindfulness training delivered by schoolteachers as part of a regular school curriculum. The results show that mindfulness training can maintain participants' attention and associated exposure to socially relevant affective stimuli, while improving their self-reported well-being. Mindfulness practice may also have a buffering effect on stress-related symptoms, as suggested by the marginal reduction in training group GP visits, and trend towards increased visits within the control group. Overall, these results suggest that mindfulness training delivered as part of the school curricula might be effective in improving the well-being of older school-aged students during a period of heightened stress and depression vulnerability. The study also highlights the potential of neuroscientific methods in contributing to our understanding of mindfulness effects in education.

References

Baer, R. A. (2003). Mindfulness training as a clinical intervention: A conceptual and empirical review. *Clinical psychology: Science and practice, 10(2)*, 125-143.

Baer, R. A., Carmody, J., & Hunsinger, M. (2012). Weekly Change in Mindfulness and Perceived Stress in a Mindfulness-Based Stress Reduction Program. *Journal of Clinical Psychology, 68(7)*, 755-765.

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.

Barry, C. T., Kauten, R. L., & Lui, J. H. (2014). Self-Perceptions of Empathy and Social Support as Potential Moderators in the Relation between Adolescent Narcissism and Aggression. *Individual Differences Research*, *12(4-A)*, 170-179.

Bech, P., Olsen, L. R., Kjoller, M., & Rasmussen, N. K. (2003). Measuring well-being rather than the absence of distress symptoms: a comparison of the SF-36 Mental Health subscale and the WHO-Five well-being scale. *International Journal of Methods in Psychiatric Research, 12(2)*, 85-91.

Biegel, G. M., Brown, K. W., Shapiro, S. L., & Schubert, C. M. (2009). Mindfulness-based stress reduction for the treatment of adolescent psychiatric outpatients: A randomized clinical trial. *Journal of consulting and clinical psychology, 77(5)*, 855-866.

Birnie, K., Speca, M., & Carlson, L. E. (2010). Exploring self-compassion and empathy in the context of mindfulness-based stress reduction (MBSR). *Stress and Health*, *26*(5), 359-371.

Block-Lerner, J., Adair, C., Plumb, J. C., Rhatigan, D. L., & Orsillo, S. M. (2007). The case for mindfulness-based approaches in the cultivation of empathy: Does nonjudgmental, present-moment awareness increase capacity for perspective-taking and empathic concern?. *Journal of marital and family therapy*, *33(4)*, 501-516.

Blom, E. H., Bech, P., Högberg, G., Larsson, J. O., & Serlachius, E. (2012). Screening for depressed mood in an adolescent psychiatric context by brief self-assessment scales: testing psychometric validity of WHO-5 and BDI-6 indices by latent trait analyses. *Health and quality of life outcomes*, *10*(1), 149.

Blom, E. H., Connolly, C. G., Ho, T. C., LeWinn, K. Z., Mobayed, N., Han, L., Paulus, M. P., Wu, J., Simmons, A. N., & Yang, T. T. (2015). Altered insular activation and increased insular functional connectivity during sad and happy face processing in adolescent major depressive disorder. *Journal of Affective Disorders, 178*, 215-223.

Bostanov, V., Keune, P. M., Kotchoubey, B., & Hautzinger, M. (2012). Event-related brain potentials reflect increased concentration ability after mindfulness-based cognitive therapy for depression: a randomized clinical trial. *Psychiatry Research*, 199(3), 174-180.

Brewer, G., & Kerslake, J. (2015). Cyberbullying, self-esteem, empathy and loneliness. *Computers in Human Behavior*, *48*, 255-260.

Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in cognitive sciences*, *4*(6), 215-222.

Bylsma, L. M., Morris, B. H., & Rottenberg, J. (2008). A meta-analysis of emotional reactivity in major depressive disorder. *Clinical Psychology Review, 28(4)*, 676-691.

Cahn, B. R., & Polich, J. (2006). Meditation states and traits: EEG, ERP, and neuroimaging studies. *Psychological Bulletin*, *132(2)*, 180.

Carlson, L. E., Speca, M., Patel, K. D., & Goodey, E. (2003). Mindfulness-based stress reduction in relation to quality of life, mood, symptoms of stress, and immune parameters in breast and prostate cancer outpatients. *Psychosomatic Medicine, 65(4)*, 571-581.

Cavanagh, J., & Geisler, M. W. (2006). Mood effects on the ERP processing of emotional intensity in faces: a P3 investigation with depressed students. *International Journal of Psychophysiology, 60(1)*, 27-33.

Cohen, S., Kamarck, T., and Mermelstein, R. (1983). A global measure of perceived stress. *Journal of Health and Social Behavior, 24*, 386-396.

Cumming, G. (2012). Understanding the new statistics: effect sizes, confidence intervals, and meta analysis. New York: Routledge.

Davey, C. G., Yücel, M., & Allen, N. B. (2008). The emergence of depression in adolescence:

development of the prefrontal cortex and the representation of reward. *Neuroscience and Biobehavioral Reviews, 32(1)*, 1-19.

Davidson, R. J., Kabat-Zinn, J., Schumacher, J., Rosenkranz, M., Muller, D., Santorelli, S. F., Urbanowski, F., Harrington, A., Bonus, K., & Sheridan, J. F. (2003). Alterations in brain and immune function produced by mindfulness meditation. *Psychosomatic Medicine, 65(4)*, 564-570.

De Raedt, R., Baert, S., Demeyer, I., Goeleven, E., Raes, A., Visser, A., ... & Speckens, A. (2012). Changes in attentional processing of emotional information following mindfulness-based cognitive therapy in people with a history of depression: Towards an open attention for all emotional experiences. *Cognitive therapy and research*, *36(6)*, 612-620.

Deng, Y. Q., Li, S., & Tang, Y. Y. (2014). The relationship between wandering mind, depression and mindfulness. *Mindfulness, 5(2),* 124-128.

Desrosiers, A., Klemanski, D. H., & Nolen-Hoeksema, S. (2013). Mapping mindfulness facets onto dimensions of anxiety and depression. *Behavior Therapy, 44(3)*, 373-384.

Donald, M., & Dower, J. (2002). Risk and protective factors for depressive symptomatology among a community sample of adolescents and young adults. *Australian and New Zealand journal of public health*, *26(6)*, 555-562.

Dorjee, D., Lally, N., Darrall-Rew, J., & Thierry, G. (2015). Dispositional mindfulness and semantic integration of emotional words: Evidence from event-related brain potentials. *Neuroscience Research.* DOI: 10.1016/j.neures.2015.03.002.

Eddy, M. D., Brunyé, T. T., Tower-Richardi, S., Mahoney, C. R., & Taylor, H. A. (2015). The effect of a brief mindfulness induction on processing of emotional images: an ERP study. *Frontiers in psychology*, *6*.

Ernst, M., Pine, D. S., & Hardin, M. (2006). Triadic model of the neurobiology of motivated behavior in adolescence. *Psychological Medicine, 36(03),* 299-312.

Fan, Y., & Han, S. (2008). Temporal dynamic of neural mechanisms involved in empathy for pain: an event-related brain potential study. *Neuropsychologia*, *46*(1), 160-173.

Felver, J. C., Celis-de Hoyos, C. E., Tezanos, K., & Singh, N. N. (2016). A systematic review of mindfulness-based interventions for youth in school settings. *Mindfulness, 7(1)*, 34-45.

Foret, M. M., Scult, M., Wilcher, M., Chudnofsky, R., Malloy, L., Hasheminejad, N., & Park, E. R.

(2012). Integrating a relaxation response-based curriculum into a public high school in Massachusetts. *Journal of adolescence*, *35*(2), 325-332.

Geisler, M. W., & Polich, J. (1994). P300 habituation from visual stimuli? *Physiology & behaviour, 56(3)*, 511-516.

Goeleven, E., De Raedt, R., Leyman, L., & Verschuere, B. (2008). The Karolinska directed emotional faces: a validation study. *Cognition and Emotion, 22(6)*, 1094-1118.

Goldin, P. R., & Gross, J. J. (2010). Effects of mindfulness-based stress reduction (MBSR) on emotion regulation in social anxiety disorder. *Emotion*, *10(1),* 83-91.

Gotlib, I. H., & Neubauer, D. L. (2000). Information-processing approaches to the study of cognitive biases in depression. Stress, coping, and depression, Chapter 7, 117-143. Eds. S. L. Johnson., A. M. Haynes., T. M. Field., N. Schneiderman., & P. McCabe. Lawrence Erlbaum Associates Inc, New Jersey.

Gratton, G., Coles, M. G. H., & Donchin, E. (1983). A new method for off-line removal of ocular artefact. *Electroencephalography and Clinical Neurophysiology, 55(4)*, 468-484.

Grossman, P., Niemann, L., Schmidt, S., & Walach, H. (2004). Mindfulness-based stress reduction and health benefits: A meta-analysis. *Journal of Psychosomatic Research, 57(1)*, 35-43.

Han, S., Fan, Y., & Mao, L. (2008). Gender difference in empathy for pain: an electrophysiological investigation. *Brain Research*, *1196*, 85-93.

Hargus, E., Crane, C., Barnhofer, T., & Williams, J. M. G. (2010). Effects of mindfulness on meta awareness and specificity of describing prodromal symptoms in suicidal depression. *Emotion, 10(1)*, 34.

Hölzel, B. K., Ott, U., Hempel, H., Hackl, A., Wolf, K., Stark, R., & Vaitl, D. (2007). Differential engagement of anterior cingulate and adjacent medial frontal cortex in adept meditators and non-meditators. *Neuroscience Letters*, *421(1)*, 16-21.

Hölzel, B. K., Carmody, J., Vangel, M., Congleton, C., Yerramsetti, S. M., Gard, T., & Lazar, S. W. (2011). Mindfulness practice leads to increases in regional brain gray matter density. *Psychiatry Research: Neuroimaging*, *191(1)*, 36-43.

Huppert, F. A., & Johnson, D. M. (2010). A controlled trial of mindfulness training in schools: The importance of practice for an impact on well-being. *The Journal of Positive Psychology, 5(4)*, 264-274.

Ikezawa, S., Corbera, S., & Wexler, B. E. (2013). Emotion self-regulation and empathy depend upon longer stimulus exposure. *Social cognitive and affective neuroscience*, doi:10.1093/scan/nst148.

J. Kabat-Zinn. Wherever You Go, There You Are: Mindfulness Meditation in Everyday Life, Hyperion, NewYork, 1994.

Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology*, *38(3)*, 557-577.

Kumar, S., Feldman, G., & Hayes, A. (2008). Changes in mindfulness and emotion regulation in an exposure-based cognitive therapy for depression. *Cognitive Therapy and Research, 32(6)*, 734-744.

Kuyken, W., Weare, K., Ukoumunne, O. C., Vicary, R., Motton, N., Burnett, R., Cullen, C., Hennelly, S., & Huppert, F. (2013). Effectiveness of the Mindfulness in Schools Programme: non-randomised controlled feasibility study. *The British Journal of Psychiatry, 203(2)*, 126-131.

Lang, P.J., Bradley, M.M., Cuthbert, B.N. (2008). International Affective Picture System (IAPS): Affective Ratings of Pictures and Instruction Manual. Technical Report A-8. Gainesville, FL: University of Florida.

Meng, J., Hu, L., Shen, L., Yang, Z., Chen, H., Huang, X., & Jackson, T. (2012). Emotional primes modulate the responses to others’ pain: an ERP study. *Experimental brain research*, *220*(3-4), 277-286.

Metz, S. M., Frank, J. L., Reibel, D., Cantrell, T., Sanders, R., & Broderick, P. C. (2013). The effectiveness of the learning to BREATHE program on adolescent emotion regulation. *Research in Human Development, 10(3)*, 252-272.

Mindfulness in Schools Project website, retrieved 14/05/2015: http://mindfulnessinschools.org/courses/b-foundations/

Music, G. (2014). The buzz trap: Speeded-up lives, distractedness, impulsiveness and decreasing empathy. *Psychodynamic Practice*, *20(3)*, 228-249.

National Institute for Health and Care Excellence, (2015), Depression in children and young people: Identification and management in primary, community and secondary care, NICE Clinical Guideline 28, ISBN 978-1-4731-1041-0.

Ortner, C. N., Kilner, S. J., & Zelazo, P. D. (2007). Mindfulness meditation and reduced emotional interference on a cognitive task. *Motivation and Emotion, 31(4)*, 271-283.

Polich, J. (2007). Updating P300: an integrative theory of P3a and P3b. *Clinical Neurophysiology*, *118(10)*, 2128-2148.

Raes, F., Griffith, J. W., Van der Gucht, K., & Williams, J. M. G. (2014). School-based prevention and reduction of depression in adolescents: A cluster-randomized controlled trial of a mindfulness group program. *Mindfulness, 5(5)*, 477-486.

Ravden, D., & Polich, J. (1998). Habituation of P300 from visual stimuli. *International Journal of Psychophysiology, 30(3)*, 359-365.

Rottenberg, J., Gross, J. J., & Gotlib, I. H. (2005). Emotion context insensitivity in major depressive disorder. *Journal of Abnormal Psychology, 114(4)*, 627-639.

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.

Sanger, K. L., & Dorjee, D. (2016). Mindfulness training with adolescents enhances metacognition and the inhibition of irrelevant stimuli: Evidence from event-related brain potentials. *Trends in Neuroscience and Education.* doi:10.1016/j.tine.2016.01.001.

Schreiter, S., Pijnenborg, G. H. M., & aan het Rot, M. (2013). Empathy in adults with clinical or subclinical depressive symptoms. *Journal of Affective Disorders, 150(1)*, 1-16.

Schultz, W. (2010). Review Dopamine signals for reward value and risk: basic and recent data. *Behavioural and Brain Functions, 6(24)*.

Sedlmeier, P., Eberth, J., Schwarz, M., Zimmermann, D., Haarig, F., Jaeger, S., & Kunze, S. (2012). The psychological effects of meditation: a meta-analysis. *Psychological Bulletin, 138(6)*, 1139.

Shapiro, S. L., Brown, K. W., & Biegel, G. M. (2007). Teaching self-care to caregivers: effects of mindfulness-based stress reduction on the mental health of therapists in training. *Training and Education in Professional Psychology, 1(2)*, 105-115.

Shapiro, S. L., Carlson, L. E., Astin, J. A., & Freedman, B. (2006). Mechanisms of mindfulness. *Journal of Clinical Psychology, 62(3)*, 373-386.

Slagter, H. A., Lutz, A., Greischar, L. L., Francis, A. D., Nieuwenhuis, S., Davis, J. M., & Davidson, R.

J. (2007). Mental training affects distribution of limited brain resources. *PLoS biology, 5(6)*, e138, 1228-1235.

Sliz, D., & Hayley, S. (2012). Major depressive disorder and alterations in insular cortical activity: a review of current functional magnetic imaging research. *Frontiers in Human Neuroscience, 6*.

Smith, A. R., Steinberg, L., & Chein, J. (2013). The role of the anterior insula in adolescent decision making. *Developmental Neuroscience, 36(3-4)*, 196-209.

Spreng, R. N., McKinnon, M. C., Mar, R. A., & Levine, B. (2009). The Toronto Empathy Questionnaire: scale development and initial validation of a factor-analytic solution to multiple empathy measures. *Journal of personality assessment*, *91*(1), 62-71.

Sutton, S., Braren, M., Zubin, J., & John, E. R. (1965). Evoked-potential correlates of stimulus uncertainty. *Science, 150*, 1187–1188.

Way, B. M., Creswell, J. D., Eisenberger, N. I., & Lieberman, M. D. (2010). Dispositional mindfulness and depressive symptomatology: correlations with limbic and self-referential neural activity during rest. *Emotion, 10(1)*, 12.

Weir, J. M., Zakama, A., & Rao, U. (2012). Developmental risk I: depression and the developing brain. *Child and adolescent psychiatric clinics of North America, 21(2)*, 237-259.

Williams, J. M. G., Crane, C., Barnhofer, T., Brennan, K., Duggan, D. S., Fennell, M. J., … & Russell, I. T. (2014). Mindfulness-based cognitive therapy for preventing relapse in recurrent depression: a randomized dismantling trial. *Journal of consulting and clinical psychology*, *82*(2), 275-286.

Williams, M., & Penman, D. (2011). Mindfulness: a practical guide to finding peace in a frantic world (Vol. 360). London: Piatkus.

World Health Organisation data and statistics. Retrieved 21/04/2015 from http://www.who.int/maternal_child_adolescent/epidemiology/adolescence/en/

World Health Organization (WHO) Collaborating Centre for Mental Health, Frederiksborg General Hospital, 1998.

Zenner, C., Herrnleben-Kurz, S., & Walach, H. (2014). Mindfulness-based interventions in schools – a systematic review and meta-analysis. *Frontiers in Psychology, 5*.

Chapter Six – Chapter Analysis and General Discussion

This thesis examined whether a mindfulness-based school programme could support the development of older adolescents. In Chapters One and Two it introduced the growing international concerns around young persons' mental health and well-being, how mindfulness-based approaches have already been used to lessen psychological burden in adults, university students, and school-aged children, and neurodevelopmental research that has demonstrated mindfulness' potential to maximise attention and emotion regulation skills. Together with Chapter Three, where the available neuroscientific evidence was critically evaluated, we made the case for using EEG methodology and predicted that mindfulness training might facilitate neural and behavioural development in adolescents, particularly targeting markers of neural plasticity in the still developing frontal lobes. In Chapters Four and Five this was tested experimentally. The main outcomes investigated were event-related potential (ERP) markers of attention and emotion processing, supported by secondary self-report findings on trait mindfulness, mind wandering, metacognition, well-being, and perceived stress. The study also looked at self-reported empathy, absences from school, GP visits, and mindfulness course satisfaction, engagement, and attendance records.

This chapter will summate the project outcomes before considering these findings together, relating them to the wider context of neurodevelopmental research, adolescent mental health, and education policy.

Chapter Three

This chapter analytically reviewed the available literature concerning mindfulness intervention studies with older school-aged students relevant to neuroscientific research, and related these findings to the more advanced adult neuroscientific literature on mindfulness. This formed the necessary theoretical foundations for the empirical research presented in

Chapters Four and Five, and particularly informed the predictions regarding modulations in neural plasticity resulting from mindfulness training in adolescents. The review was divided into two main topics; attention and emotion-based changes, with a key overarching theme of what possible impacts the developing prefrontal cortex (PFC) may have on expected neurocognitive changes with mindfulness training in adolescents. Essentially, neurodevelopmental researchers agree that although adolescents can perform at adult levels on cognitive tasks by mid-adolescence (Cepeda, Kramer, & Gonzalez de Sather, 2001), the executive control and emotion regulation systems predominately supported by frontal brain structures do not fully mature until early-mid 20s (Sowell, Thompson, Holmes, Jernigan, & Toga, 1999). This means that adolescents are much more prone to 'hot cognitions', and to respond reflexively rather than reflectively when under stress (Albert & Steinberg, 2011; Spear, 2013). Mindfulness practice, known to stimulate the PFC in adults and long-term meditators (Hölzel et al., 2007), could facilitate the development of these control systems and enhance adolescents' ability to regulate their attention and emotional responses. Hence, this chapter aimed to suggest that mindfulness practice could help adolescents self-regulate in order to enhance mental processing and take more deliberate, self-aware actions.

Another key aim of this chapter was to stimulate intervention and clinical research to use neuroscientific methods when evaluating mindfulness in schools, highlighting the advantages of such an approach. Specifically, we make the case for using ERPs, given the portability of the EEG recording system, cost-effectiveness, and the temporal accuracy of ERPs in measuring task-related processing. Based on past research in adults, and taking into account the developmental trajectory, the chapter also presented tentative predictions of what brain activity changes might be expected after adolescents are trained in mindfulness practices, such as more negative N2 and less positive P3b mean amplitudes to non-target stimuli, indicating an increase in attention efficiency. These particular predictions were investigated in Chapter Four. And although the evidence-base for ERP markers of emotion regulation is limited, modulation of the P3b was suggested to potentially indicate a change in how affective stimuli are processed by adolescents in emotion-based tasks, such as affective picture viewing. This was empirically examined in Chapter Five. The ERN / Pe complex was discussed as another pair of ERP markers for assessing emotion regulation, as these components represent the automatic response to conflict between desired and actual responding (error), and the consequent appraisal of that error. Teper and Inzlicht (2013) previously found that mindfulness can enhance markers of awareness and attention to an error in order to correct it (ERN), without increasing a person's self-judgement related to that error (Pe).

The review concludes that a neurodevelopmental perspective to the examination of mindfulness-based effects in adolescents would enhance our understanding of the underlying mechanisms of change, as well as provide new avenues for hypotheses. The study of mindfulness-based change through its neurocognitive impact, and taking the neurodevelopmental trajectory into consideration, should also facilitate appropriate curriculum delivery and therefore maximize the approaches benefit to adolescents. It was with these thoughts in mind that the following attention and emotion-based studies were designed and discussed.

Chapter Four

This chapter presented the first experimental paper of the thesis, and tested the predictions made in Chapter Three regarding attention enhancement resulting from mindfulness training in adolescents, as marked by ERPs. Specifically, the chapter investigated whether a mindfulness-based training programme for 16-18 year olds delivered within the school curriculum could enhance attention efficiency and metacognition. Four schools in north Wales were recruited for the study, with trial arm allocation being decided pragmatically based on which schools could implement the mindfulness curriculum within the next year, and our ability to match socio-economic status between trial arms. Two trainers, one from the Centre for Mindfulness Research and Practice (CMRP) and one external Mindfulness in Schools Project (MiSP) trainer, then delivered an introductory mindfulness course to schoolteachers in the training group. After four months of individual practice, schoolteachers with sufficiently developed mindfulness practice received 14-hours of training focusing on how to deliver the .b Foundations curriculum to their students. The introductory mindfulness course was delivered to 12 secondary school teachers, six from each intervention-arm school. After a four-month gap, the CMRP trainer contacted the schoolteachers and discussed their engagement with mindfulness and whether they felt ready to deliver the curriculum in school. This left five teachers approved as skillful enough, to advance to the next level of training. Supervision was also offered throughout the school-based module, via telephone, group meetings (so teachers could discuss progress and trouble-shoot any issues), and classroom observations. Programme fidelity was discussed in chapter three, highlighting the importance of researching high quality mindfulness interventions in order to avoid Type I and II errors. The current trial aimed to hold to this principle, while also demonstrating that internal schoolteachers can take on the long-term responsibility of delivering mindfulness-based curricula.

The results of the adolescent mindfulness course with 47 participants (40 ERP participants) showed a significant enhancement of metacognition in the training group, as well as an increase in N2 negativity in response to non-target stimuli (colour-deviant and frequent conditions) in the computerized oddball task. By contrast, the control group included in the ERP analysis showed an increase in self-reported mind wandering over time, while no change was reported in the mindfulness group. Regression analysis found that enjoyment of the mindfulness course explained 16% of the adjusted variance in improved target accuracy in the attention task, with students who enjoyed the mindfulness course improving significantly more. These results supported the predictions made in Chapter Three. Specifically, the ERP analysis did indeed find that mindfulness training enhanced N2 responses, a marker of automatic attention capture and response inhibition. And while mind wandering did not decrease in the training group, as has been reported in past adult literature (Mrazek, Smallwood, & Schooler, 2012), they did appear to retain task focus while control participants mind wandered more the second time they completed the oddball task. It is possible that the summer post-testing schedule impacted on this result, as all students were preparing for end of term exams and their cognitive abilities would have already been strained. However, the stability of focus over time seen in intervention participants might suggest that mindfulness practice can help maintain attention stamina and prevent the increase in mind wandering that was seen in control students.

We did not find an increase in P3b mean amplitudes across the task after mindfulness training, which would have indicated more consistent attention and information processing to task stimuli, and replicated adult findings of reduced mind-wandering post-training (Mrazek, Smallwood, & Schooler, 2012; Smallwood, Beach, Schooler, & Handy, 2008). Neither did we find decreased P3b to target stimuli, which Chapter Three discussed as an indication of less elaborative processing, and has been reported in adult mindfulness training studies of executive attention (Moore, Gruber, Derose, & Malinowski, 2012). Perhaps the modulation of automatic attention-based responding (N200) occurs first when training adolescents in mindfulness approaches, and it will only be with increased practice that later ERP components of stimulus categorisation processing are affected. Potentially the lack of change over time could be an effect of effort, with the mindfulness group being better able to orient towards and categorise stimuli, but as a result of increased focus compared to controls by the second time-point (indicated by less mind-wandering in the ERP training group compared to controls), they continued to process to all stimuli. This would have been reflected in maintained P3b mean amplitudes (Barron, Riby, Greer, & Smallwood, 2011).

Chapter Five

In the second experimental paper, predictions relating to emotion processing and well-being were investigated, using emotionally salient facial target stimuli in an oddball paradigm eliciting emotion-related P3b modulation. This task was preferred to an investigation focusing on markers of error processing as the latter would have required a much longer task to gain a sufficient number of trials per condition for analysis. This is one of the current limitations of school-based testing, since participant sessions are restricted to the 50-minute lesson time. Participant testing sessions included both ERP tasks (attention and emotion processing) as well as the battery of self-report measures, however the questionnaires could be taken away if not completed during EEG set-up.

A significant difference between training and control groups was found in P3b-marked responses to socially relevant emotional stimuli (happy and sad target faces). The control students appeared to have habituated to the stimuli by the second time point, responding with significantly less positive mean P3b amplitudes. The intervention group however, maintained P3b mean amplitudes for both happy and sad target faces over time, although between group differences were stronger for happy targets. This result would seem to suggest that mindfulness training encouraged sustained interest in these emotional target faces. Interestingly, changes in empathy scores positively correlated with target-related P3b modulations, providing converging evidence that this measure of brain activity did represent social and affective relevance. These between group differences in P3b response over time supports the predictions made in Chapter Three, which suggested that the P3b ERP component could index changes to emotion processing and regulation after mindfulness training. This pattern of activity also supports the specific connections outlined in Chapter Two between P3b responses, its neural substrates in the temporal-parietal junction, and social connectedness.

The results reported in Chapter Five suggested that mindfulness practice did enhance student well-being, as the training group significantly increased in this self-report measure over time. Unlike the previous adolescent research discussed in Chapter Three, this study found no change in perceived stress, indeed within the training group the students who most enjoyed the course actually showed an increase in perceived stress. However, post-hoc correlation analysis found that while changes in well-being and perceived stress were highly related in control students, they were not correlated in mindfulness-trained students. Potentially mindfulness training encouraged students to become more aware of their stress, but enabled them to observe it without internalization and therefore it did not relate to changes in well-being. Such a finding would resonate with the aims of secular mindfulness i.e. the mechanism of re-perceiving; where a practitioner learns to change the relationship they have with internal and external experiences (Shapiro, Carlson, Astin, & Freedman, 2006). The development of this skill in adolescents after mindfulness training would be worth further investigation.

General Discussion

This thesis developed and tested neuroscientific predictions regarding modulations in attention and emotion processing resulting from mindfulness training with adolescents. This work was based on relevant adolescent neurodevelopmental research, as well as previous mindfulness intervention studies in adults, university students, and adolescents. The predictions were assessed using two experimental paradigms and self-report measures in a longitudinal, non-randomised study with a wait-list control group. The results have shown that ERP markers of attention and emotion processing are sensitive to modulation resulting from mindfulness training, and these changes are detectable after an eight-week programme. Specifically, the main findings included improvements in N2-marked automatic stimulus detection and response inhibition, and P3b-marked affective information processing. These ERP modulations were supported by self-reported changes across groups, as changes to N2 amplitudes in the attention oddball significantly correlated with the ‘uncontrollability’ subscale of the metacognition questionnaire (r = .35, p = .04), and P3b mean amplitude changes during the emotion processing task positively correlated with empathy scores (r = .37, p = .03). Aside from the ERP-indexed changes, self-reports indicated improvements in metacognition, well-being, and general health (indexed by GP visits).

Interestingly, significant positive correlations between mindfulness course enjoyment, and improved target accuracy were found in both experimental tasks. In the attention task, course satisfaction correlated with better accuracy to target (r = .45, p = .05) and in the emotion processing task a similar positive correlation related to target accuracy for happy faces (r = .40, p = .07). The fact that only positive target responses correlated with course enjoyment in the emotion oddball, while the task required participants to quickly and accurately respond to happy and sad targets, suggests that this data is not simply the result of demand characteristics. This selective result offers further evidence that mindfulness training may negate negativity bias, such as that observed in clinically depressed samples (Deng, Li, & Tang, 2014; Desrosiers, Klemanski, & Nolen-Hoeksema, 2013; Gotlib & Neubauer, 2000). This finding is also important when considering future research and the implementation of mindfulness curricula in schools, as it highlights that course attendance and practice frequency are not the only factors that need to be monitored and encouraged in order to maximise students' potential. The current data suggests that the course needs to be enjoyable and feel worthwhile for the students enrolled, which is likely to facilitate higher quality of engagement with mindfulness practice. Enjoyment may also alleviate the burden of engaging so often in a new skill, which can be difficult to find time for, and become frustrating to the student when practice is difficult. It would be interesting for future investigations to test the long-term effects of course satisfaction, whether these participants continue to practice more often, or experience more long-term benefits. Chapters Three and Four also discussed some of the benefits of having internal schoolteachers deliver the curriculum, one element of this being that they could more easily tailor courses to the specific needs of their classes.

Significant ERP findings were reported in both the attention and emotion processing tasks. The N200 modulation in Chapter Four is in line with past adult literature of mindfulness-based enhancements to conflict monitoring as indexed by ERP modifications (Teper & Inzlicht, 2013). The lack of habituation found in mindfulness-trained participants, compared to controls in Chapter Five, (indexed by maintained P3b mean amplitudes to affective targets) suggests that they continued to process these faces with a ‘beginners mind’, allocating the same amount of attention resources to their processing as during pre-testing.

The predictions for ERP effects were made based on past adult and university student literature reporting effects of mindfulness, as well as developmental psychology findings outside of mindfulness research. This interdisciplinary approach was necessary given the absence of directly relevant adolescent neurocognitive research on mindfulness effects. The research reported in Chapters Three – Five demonstrates that older adolescent participants may benefit from mindfulness training, in terms of neural plasticity, as shown by specific ERP component modulation. The changes in markers of response inhibition and non-target related conflict monitoring (N2) and affective information processing (P3b) support our earlier predictions regarding possible neurocognitive changes in adolescents training in mindfulness (Sanger & Dorjee, 2015). The results are also in line with theoretical accounts and empirical findings from adult research, which suggests that mindfulness induces more efficient attention allocation through the development of top-down executive control in frontal brain regions (Allen et al., 2012; Hölzel et al., 2007; Moore et al., 2012; Teper & Inzlicht, 2013), and facilitates greater social-connectedness and cognitive empathy (Birnie, Speca, & Carlson, 2010).

Developmental neuropsychologists have suggested that older adolescence is a late catchment point for cognitive interventions focussed on developing the prefrontal cortex (Spear, 2013), and the research reported in this thesis aimed to test whether mindfulness training could be such an intervention. Other higher order brain regions such as the temporal-parietal junction are also known to be still developing during older adolescence (van den Bos, van Dijk, Westenberg, Rombouts, & Crone, 2011), and developmental research has shown its under-development can index later anti-social and criminal behaviour (van den Bos et al., 2014). As the current results would suggest, mindfulness training in schools may bolster the development of brain regions involved in attention, emotion-processing, and cognitive empathy, without the need for explicit didactic instruction on these issues. Encouraging these capacities while also increasing self-reported well-being and metacognition would appear to be an efficient use of school time, encouraging a more focussed, positive, and psychologically healthy learning environment.

As was discussed in Chapter One, the mental health of young people is becoming a salient national and international issue, with around 13.5% of UK 10-15 year olds living with high levels of distress (ONS, 2016) for example. Accordingly, much of positive psychology and developmental neuroscience research is dedicated to investigating ways in which we can enhance the well-being of young people, with evidence suggesting the importance of prevention and early intervention through skills training and mental health awareness (Ollendick, King, & Chorpita, 2006). An interesting aspect of the current project, a school-based mindfulness curriculum for older adolescents, is that it offers the improvements evidenced in this thesis without specifically targeting mental health or explicitly teaching any skills apart from attending to the present moment and relating to the mind in a non-judgmental, accepting, and kind way (Kabat-Zinn, 1994). Secular mindfulness can be used as a method of enhancing attention, cognitive or behavioural performance, stress-relief, creativity, self-awareness, empathy, etc (Chambers, Lo, & Allen, 2008; Coholic, 2011; Greenberg, Reiner, & Meiran, 2012; Kuyken et al., 2013; Malinowski, 2013; Moore & Malinowski, 2009; Sanger & Dorjee, 2016; Teper & Inzlicht, 2013; Winning & Boag, 2015). Indeed, several studies have found that it's those poorest on a given factor that would report the most improvement. For example, Dorjee, Perry, & Silverton (2014) found that young children with high baseline negative affect reported the most improvement in mindfulness and reductions in negative affect, and it is adults with three or more episodes of recurrent depression that have been found to experience the most clinical improvements after mindfulness training (Williams et al., 2014). Delivering courses to the entire year group would mean that the intervention could help the most vulnerable students without singling them out, and those without psychological problems could still experience enhancements to attention control, or social connectedness.

References

Albert, D., & Steinberg, L. (2011). Judgment and decision making in adolescence. *Journal of Research on Adolescence, 21(1)*, 211-224.

Allen, M., Dietz, M., Blair, K. S., van Beek, M., Rees, G., Vestergaard-Poulsen, P., ... & Roepstorff, A. (2012). Cognitive-affective neural plasticity following active-controlled mindfulness intervention. *The Journal of Neuroscience, 32(44)*, 15601-15610.

Barron, E., Riby, L. M., Greer, J., & Smallwood, J. (2011). Absorbed in thought the effect of mind wandering on the processing of relevant and irrelevant events. *Psychological Science, 22(5)*, 596-601.

Birnie, K., Speca, M., & Carlson, L. E. (2010). Exploring self‐compassion and empathy in the context of mindfulness‐based stress reduction (MBSR). *Stress and Health, 26(5)*, 359-371.

Cepeda, N. J., Kramer, A. F., & Gonzalez de Sather, J. (2001). Changes in executive control across the life span: examination of task-switching performance. *Developmental Psychology, 37(5)*, 715-730.

Chambers, R., Lo, B. C. Y., & Allen, N. B. (2008). The impact of intensive mindfulness training on attentional control, cognitive style, and affect. *Cognitive Therapy and Research, 32(3)*, 303-322.

Coholic, D. A. (2011). Exploring the feasibility and benefits of arts-based mindfulness-based practices with young people in need: Aiming to improve aspects of self-awareness and resilience. In *Child & Youth Care Forum* (Vol. 40, No. 4, pp. 303-317). Springer US.

Deng, Y. Q., Li, S., & Tang, Y. Y. (2014). The relationship between wandering mind, depression and mindfulness. *Mindfulness, 5(2)*, 124-128.

Desrosiers, A., Vine, V., Klemanski, D. H., & Nolen‐Hoeksema, S. (2013). Mindfulness and emotion regulation in depression and anxiety: common and distinct mechanisms of action. *Depression and Anxiety, 30(7)*, 654-661.

Dorjee, D., Perry, L., & Silverton, S. (2014, October). *Dispositional mindfulness, mind wandering, and emotional awareness in primary school children.* Poster presented at the International Symposia in Contemplative Studies. Boston, MA.

Greenberg, J., Reiner, K., & Meiran, N. (2012). “Mind the trap”: mindfulness practice reduces cognitive rigidity. *PloS One, 7(5)*, e36206.

Gotlib, I. H., & Neubauer, D. L. (2000). Information-processing approaches to the study of cognitive biases in depression. In S. L. Johnson, A. M. Hayes, T. M. Field, N. Schneiderman, & P. McCable (Eds.) *Stress, Coping, and Depression*, (pp. 117-143). Psychology Press.

Hölzel, B. K., Ott, U., Hempel, H., Hackl, A., Wolf, K., Stark, R., & Vaitl, D. (2007). Differential engagement of anterior cingulate and adjacent medial frontal cortex in adept meditators and non-meditators. *Neuroscience Letters, 421(1)*, 16-21.

Kabat-Zinn, J. (1994). Wherever you go, there you are: Mindfulness meditation in everyday life. New York, NY: Hyperion.

Kuyken, W., Weare, K., Ukoumune, O. C., Vicary, R., Motton, N., Burnett, R., … Huppert, F. (2013). Effectiveness of the Mindfulness in Schools programme: Non-randomised controlled feasibility study. *British Journal of Psychiatry, 203*, 126-131.

Malinowski, P. (2013). Neural mechanisms of attentional control in mindfulness meditation. *Frontiers in Neuroscience, 7(8)*, 10-3389.

Moore, A. W., Gruber, T., Derose, J., & Malinowski, P. (2012). Regular, brief mindfulness meditation practice improves electrophysiological markers of attentional control. *Frontiers in Human Neuroscience, 6, 18*.

Moore, A., & Malinowski, P. (2009). Meditation, mindfulness and cognitive flexibility. *Consciousness and cognition, 18(1)*, 176-186.

Mrazek, M. D., Smallwood, J., & Schooler, J. W. (2012). Mindfulness and mind-wandering: finding convergence through opposing constructs. *Emotion, 12(3)*, 442-448.

Office of National Statistics. (2016). *Measuring national well-being: Life in the UK: 2016*. Retrieved from: http://www.ons.gov.uk/peoplepopulationandcommunity/wellbeing/articles/measuringnationalwellbeing/2016#childrens-well-being

Ollendick, T. H., King, N. J., & Chorpita, B. F. (2006). Empirically supported treatments for children and adolescents. Child and adolescent therapy: *Cognitive-Behavioral Procedures, 3*, 492-520.

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.

Sanger, K. L., & Dorjee, D. (2016). Mindfulness training with adolescents enhances metacognition and the inhibition of irrelevant stimuli: Evidence from event-related brain potentials. *Trends in Neuroscience and Education, 5(1)*, 1-11.

Sanger, K. L., Thierry, G., & Dorjee, D. (Under review). Effects of school-based mindfulness training on emotion processing and well-being in adolescents: Evidence from event-related potentials. *Developmental Science*.

Shapiro, S. L., Carlson, L. E., Astin, J. A., & Freedman, B. (2006). Mechanisms of mindfulness. *Journal of Clinical Psychology, 62(3)*, 373-386.

Smallwood, J., Beach, E., Schooler, J. W., & Handy, T. C. (2008). Going AWOL in the brain: Mind wandering reduces cortical analysis of external events. *Journal of cognitive neuroscience, 20(3)*, 458-469.

Sowell, E. R., Thompson, P. M., Holmes, C. J., Jernigan, T. L., & Toga, A. W. (1999). In vivo evidence for post-adolescent brain maturation in frontal and striatal regions. *Nature Neuroscience, 2(10)*, 859-861.

Spear, L. P. (2013). Adolescent neurodevelopment. *Journal of Adolescent Health, 52(2)*, 7-13.

Teper, R., & Inzlicht, M. (2013). Meditation, mindfulness and executive control: the importance of emotional acceptance and brain-based performance monitoring. *Social, Cognitive, and Affective Neuroscience, 8(1)*, 85-92.

Van den Bos, W., van Dijk, E., Westenberg, M., Rombouts, S. A., & Crone, E. A. (2011). Changing brains, changing perspectives the neurocognitive development of reciprocity. *Psychological Science, 22(1)*, 60-70.

Van den Bos, W., Vahl, P., Güroğlu, B., van Nunspeet, F., Colins, O., Markus, M., ... & Crone, E. A. (2014). Neural correlates of social decision-making in severely antisocial adolescents. *Social, Cognitive, and Affective Neuroscience, 9(12)*, 2059-2-66.

Williams, J. M. G., Crane, C., Barnhofer, T., Brennan, K., Duggan, D. S., Fennell, M. J., ... &

Shah, D. (2014). Mindfulness-based cognitive therapy for preventing relapse in recurrent depression: A randomized dismantling trial. *Journal of Consulting and Clinical Psychology, 82(2)*, 275-286.

Winning, A. P., & Boag, S. (2015). Does brief mindfulness training increase empathy? The role of personality. *Personality and Individual Differences, 86*, 492-498.

Chapter Seven – Conclusions

The last decade has seen a strong influx in interest for bringing mindfulness into school curricula, yet the enthusiasm precedes an evidence base that could guide focussed considerations regarding the potential impacts of mindfulness in education. This thesis set out to contribute to the relatively limited evidence, particularly to the scarce literature on neurocognitive modifications induced by mindfulness training in adolescents. The research presented here suggests that training in mindfulness can modulate brain activity as well as improve adolescents' well-being and metacognition. Specifically, this project showed that mindfulness-based training can modulate ERP markers of attention inhibition and emotion processing, with implications for reduced risk-taking and depression vulnerability respectively. It seems that mindfulness-based programmes are worth further examination, and as the current study shows, neurocognitive evaluations could provide new insights to inform research design, mechanisms of mindfulness-based change, and programme implementation within schools.

Aside from the actual new findings regarding modulations in neurocognitive markers and high acceptability of training, some results also highlight the importance of quality in course delivery, with implications for further tailoring of mindfulness-based programmes to adolescents. This study demonstrated in both attention and emotion processing paradigms that course satisfaction significantly correlated with task improvement, indicating that enjoyment may be more influential than simply frequency of mindfulness practice. This subtle distinction in measurement, looking at engagement rather than exposure would suggest that more service user involvement from adolescents might maximise training outcomes, as well as enhance course design and delivery. Further research, including qualitative studies to provide a richness of understanding, could lead mindfulness programmes to help future generations of adolescents through what is known to be a challenging developmental period.

The format of course delivery used in this project, a mandatory class for all those enrolled in PSHE widely introduces mindfulness training into schools. Such an approach provides all students with basic training from which they can immediately benefit, and whether they decided to continue practicing mindfulness or not, it would be another device in their ‘toolbox’ of coping and learning strategies. The attention-based benefits of practicing mindfulness are at the core of its diverse applications, and it remains to be seen how long the immediate gains documented in this thesis last, and how predictive they are of later mental health. In terms of coping and adaptive emotion regulation, mindfulness could be one method of enhancing well-being related to neurocognitive processing and hence prevent negative reactivity from escalating into a clinical condition. This is particularly relevant since adolescence is known to be a critical period in the development of life-long mental illness. Developing skills in mindfulness from school-age may enable greater self-awareness to notice when an individual’s attention abilities or well-being needs support, and potentially enhance the skills needed to address the difficulty early on, or at least seek outside support in a timely manner. This would likely support the individual’s self-efficacy, and potentially have broader implications for health service use and community well-being.