Trends in Neuroscience and Education 5 (2016) 1–11

Contents lists available at ScienceDirect

Trends in Neuroscience and Education

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

Research paper

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

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ARTICLE INFO

Article history:
Received 27 May 2015
Received in revised form
11 January 2016
Accepted 28 January 2016
Available online 29 January 2016

Keywords:
Mindfulness
Adolescence
ERP
Attention
Metacognition
Mind wandering

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.

1. Introduction

Mindfulness interventions involve guided training of present-moment awareness with a kind and accepting attitude [1]. The benefits of mindfulness-based interventions for cognitive processing are well documented in both clinical [2] and non-clinical [3] 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 [4–7].

Two important factors emphasised in education policy are well-being [8] and metacognition [9]. Well-being in children and adolescents is a growing concern, with one in 10 young people thought to have a diagnosed mental illness, including emotional, attention, and conduct disorders [10]. And beliefs about cognitive ability have been associated with poorer test performance despite an individual's aptitude [11], suggesting an important contribution of metacognition to academic achievement. Initial evidence suggests that school-based mindfulness training may improve well-being [4,5,12]. 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 [13]. Metacognition is also related to mind wandering, referring to an individual's attention shifts away from goal-orientated focus, often without awareness [14]. Mind wandering has been shown to reduce after mindfulness practice in adults [15] and a negative relationship was found between mind wandering and well-being in young people [16].

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 [17]. 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

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http://dx.doi.org/10.1016/j.tine.2016.01.001

(enquiry) 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 [18]. This has also been demonstrated experimentally, where mindful attention moderated the relationship between depressive affect and negative cognitions [19]. 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 [20], particularly the prefrontal cortex (PFC) and anterior cingulate cortex (ACC) that are centrally involved in error processing, attention monitoring, and control [21]. Young peoples' impulsivity, for example, directly relates to the undeveloped nature of these frontal regions [22]. Inappropriate impulsivity is associated with a lack of inhibition, a central part of executive attention through which we monitor and control attentional processes [23]. Importantly, mindfulness training has been shown to increase markers of response inhibition and improve selective attention in adults [24]. 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. [25,26]. 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 [27], 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 [28]. Of particular relevance is the N200 (N2) ERP component, which can be elicited in conflict tasks and is a sensitive marker of response inhibition [29,30]. More negative N2 responses post-mindfulness training indicate better target detection and inhibition of automatic responses, as shown in previous adult research [26]. In terms of target-related information processing, the P300 (specifically the P3b) component is typically assessed, showing modulation as the result of cognitive load [31], 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 [32], and less mind wandering [33]. However, Moore et al. [26] 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 [34]. Another sub-component of the P300 is the P3a, thought to index attention capture to unexpected stimuli [35]. 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 [36]. 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.

2. Methods

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

3. 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 enroled 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 [37,38]. 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