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ORIGINAL RESEARCH

On-the-Spot Binaural Beats and Mindfulness Reduces Behavioral Markers of Mind Wandering

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Abstract
The experience of a wandering mind is common for most people, and it has been estimated that mind wandering occupies up to 46% of our thoughts during the day. There are recent studies showing entrainment effects leading to a decrease in mind wandering. However, it is not clear if there are state-dependent interventions that may provide a reduction of mind wandering. The main aim of the current study was to investigate in a university student population whether laboratory evidence of mind wandering can be reduced through two on-the-spot interventions; mindfulness meditation for 15 min ($n = 25$) and binaural auditory beats for a duration of 15 min ($n = 27$) relative to a no-intervention control group ($n = 25$). We measured levels of mind wandering at baseline across the three groups and after the 15-min interventions using the Sustained Attention to Response Task (SART). The results indicate that a short-term or on-the-spot mindfulness session for 15 min is successful in significantly reducing laboratory evidence of mind wandering. However, more surprisingly, we found that 15 min of auditory binaural beats also lead to a significant reduction of mind wandering, whereas the control group did not result in differences. We did not observe differences in mind wandering across the three groups at baseline or differences in stress levels across groups. The present outcomes are discussed in terms of the potential of using auditory binaural beats relative to mindfulness as a way to enhance cognitive control.

Keywords Mindfulness · Binaural beats · Mind wandering

Introduction

One of the key predictors of in-attention among students is absentmindedness (Szpunar et al. 2013; Farley et al. 2013; Lindquist and McLean 2011), and in-attention over time results in reduced memory retention of lecture material (Szpunar et al. 2013; Farley et al. 2013). The present paper investigates if there are brief on-the-spot interventions that can harness students' attentional resources to enhance learning.

Studies have demonstrated a strong link between the effects of distraction on cognitive performance and memory (Craik 2014) as well as a negative association with psychological distress among student populations (Deasy et al. 2014). There is a relationship between level of distraction and increased levels of self-perceived stress (Jett and George 2003; Lin et al. 2013). Smartphone usage seem to be a main culprit of declining attention and soaring distraction levels (Ward et al. 2017; Jiang and Zhao 2016; Zheng et al. 2014). Indeed, data suggest a negative relationship between screen time and academic performance (Aguilar et al. 2015; Peiró-Velert et al. 2014). As such, it appears that limited attentional resources have become a growing concern in society (Gazzaley and Rosen 2016). A concern that is captured in the term Continuous Partial Attention (Friedman 2006), which is supported by data showing that neuropsychological measurements of in-attention is souring at 46% (Killingsworth and Gilbert 2010). Thus, there is impetus to investigate if there are on-the-spot interventions that may enhance attention and as a consequence learning in a student population.

Previous research from our group has demonstrated effects of a short online-based mindfulness training regimen on dampening mind wandering (Bennike et al. 2017). The

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training dose consisted of daily training for 4 weeks, but there are mindfulness interventions that has demonstrated similar effects using only 2 weeks of daily training (Mrazek et al. 2013). Similarly, there are studies promoting state-dependent measures of mindfulness, so-called on-the-spot interventions (Hafenbrack 2017; Erisman and Roemer 2010; Mrazek et al. 2012).

The present study is a follow-up on our previous research (Bennike et al. 2017) by asking the question if a 15-min on-the-spot intervention such as mindfulness can exert state-dependent enhancement on mind wandering (Fig. 1) in a student cohort.

Mindfulness is a behavioral therapy that provides systematic training in self-regulation, and emotion management (Kabat-Zinn 1990, 2003). Such skills developed in mindfulness meditation have in a recent study been shown to decrease mind-wandering (Bennike et al. 2017). In one study, mindfulness training was associated with increased academic performance as measured on performance on an MCQ exam (Mrazek et al. 2013). The explanation for these results given by the authors is that mindfulness increases working memory capacity (WMC), and thereby enhancing the propensity to retain more lecture material. This finding is supported by research showing that mindfulness training prevents the deterioration of working memory capacity (WMC) during periods of high stress (Jha et al. 2010), enhances attention (Brefczynski-Lewis et al. 2007), and increases backward digit memory span (Chambers et al. 2008). Taken together, these results suggest that mindfulness training positively impacts cognitive processing including WMC and mind-wandering. Another explanation could be that mindfulness enhances the ability to adaptively regulate emotional responses (Erisman and Roemer 2010). This could give more emotional space to act more focused at the task at hand. For instance, emotion regulation can be thought of as including the awareness and acceptance of emotions, the ability to move toward desired goals in spite of difficult emotions, and the ability to flexibly and adaptively use different regulation strategies, depending on the situation (Gratz and Roemer 2004).

In the current study, as an active control intervention, we included another on-the-spot intervention, namely listening to binaural beats with a similar duration as the mindfulness intervention (15 min). Binaural beats is an intervention with effects pertaining to enhancement of cognitive focus (Colzato et al. 2017) and, in some cases, working memory capacity (Lane et al. 1998). Therefore, we expected this intervention to also impact students' attention levels. Finally, we included a non-intervention control group.

We measured subjects' level of mind wandering using the Sustained Attention to Response Task (SART) (Robertson et al. 1997) that we have previously deployed to detect minute neurocognitive behavioral changes as a function of a 30-day mindfulness training intervention (Bennike et al. 2017). Based on these data, we expected to find a reduced mind wandering effect in the on-the-spot mindfulness intervention employed in the current study. We also expected that an on-the-spot binaural auditory beat intervention would produce a comparable effect, but that the non-intervention control group would not display improvements.

To test these hypotheses, we randomized subjects into the three experimental groups. We tested subjects at baseline on the SART on separate days from deployment of our on-the-spot interventions.

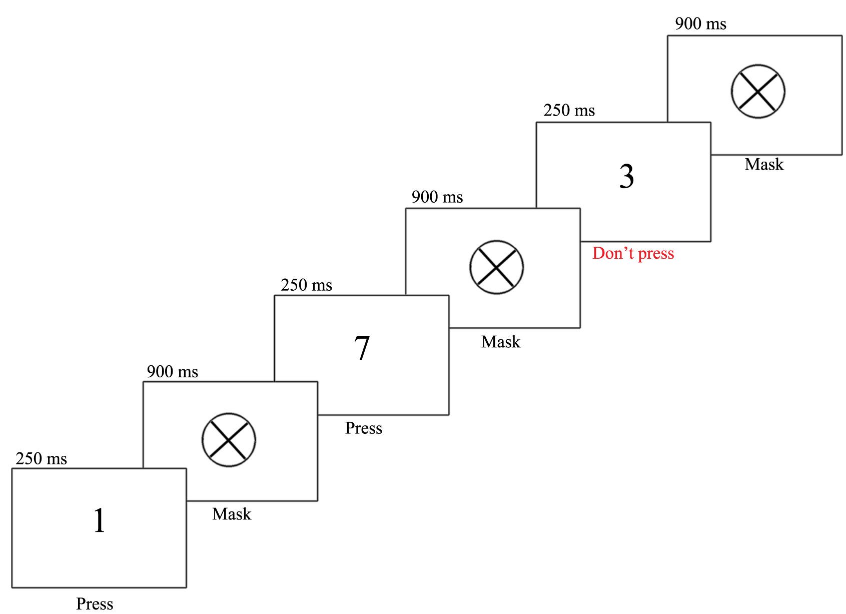

Fig. 1 Outline of the SART task. See "Methods" for further explanation of the timing of the task

Methods

Subjects

A total of 81 healthy volunteers participated in the study. Subjects were randomized into three groups. Four subjects dropped out of the study (that is, did not show up for testing for the on-the-spot interventions). Exclusion criteria were previous experience with mindfulness meditation. The mean age in the mindfulness group ($n = 25$; 13 females) was 23.2 years (± 5.5); for the binaural beats group ($n = 27$; 13 females), it was 22.8 (± 5.8); and finally for the non-intervention control group ($n = 25$; 12 females), it was 22.5 (± 5.9).

Recruitment involved advertising among students at University of Southern Denmark. The study was framed as a program studying the cognitive benefits of two types of on-the-spot interventions (mindfulness and auditory binaural beats) and a non-intervention control group. In addition, subjects were notified that they would be assigned to one of the three groups in a random manner, which eliminated any self-selection effects between the two interventions.

Subjects did not receive monetary compensation for their participation in the study. All procedures were conducted in accordance with the local ethical committee (Videnskabsetisk Komite for Region Syddanmark).

Experimental Procedures

Subjects completed two testing sessions: the first testing session constituted a baseline measure. This measure was collected 2–3 days before deployment of the two on-the-spot interventions. The second testing session took place immediately following the 15-min on-the-spot interventions. For both testing sessions, subjects came to the lab at approximately the same time of day for both testing days. The procedure was similar for the non-intervention control group who came to the lab at approximately the same time of day for both testing days, but did not receive an on-the-intervention, but were only asked to complete the SART.

Subjects were tested on mind wandering using the Sustained Attention to Response Task (SART) (Robertson et al. 1997). The SART is a Go/NoGo task often used as an indirect measure of mind wandering (Cheyne et al. 2009). Stimuli were presented for 250 ms, and a backward mask was presented with a duration of 900 ms and an inter-stimulus interval of 500 ms. Participants viewed a continuous array of digits ranging from 0 to 9. Subjects were asked to respond as quickly as possible to frequent non-targets (digits ranging from 1 to 2 and 4–9) by pressing the space bar and to refrain from responding to rare targets (digit 3). A total of 240 stimuli were presented, including 216 non-targets and 24 targets presented pseudo-randomly such that target stimuli were always separated by at least one non-target stimuli. Several indicators of mind wandering can be derived from SART performance. Firstly, commision errors refers to when a key is pressed in no-go trials (i.e., on trials when "3" is presented). This was referred as % NoGo Success and its calculated as % of successfully withholding target responses (of the "3" stimuli). Secondly, omission errors which occur when participants fail to make a response to non-targets (i.e., after any other number except 3). This measure was referred as % omission and it was calculated as percentage of incorrect responses (to the non-targets) compared to the total amount of non-target responses (Cheyne et al. 2009). Non-target errors on the SART suggest disengagement from the task as they reflect a failure to button press in response to a stimulus, while target errors reflect that the task is being performed in an automated rather than controlled fashion leading to a failure to withhold response to an infrequent target (Robertson et al. 1997).

Thirdly, reaction time variability is a measure of periodic speeding and slowing of response times as attention fluctuates slightly during task performance and is operationalized using the response time coefficient of variability (RT CV). The reaction time variability captures greater speeding and slowing of reaction times throughout the task and reflects disengagement of attention. This measure was referred in this study as RT CV and is measured as coefficient of variation of the reaction time for all non-target corrected responses (Cheyne et al. 2009).

Psychometric Data

All subjects completed the Perceived Stress Scale (PSS) (Cohen et al. 1983). The PSS is a 10-item scale designed to measure the perception of stress. We collected data on the PSS at baseline (T1) before administration of the SART and at T2 the PSS questionnaire was completed before the on-the-spot intervention.

Intervention Procedure

The mindfulness intervention consisted of a 15-min guided audio file that subjects listened to with headphones (Bose QuietComfort 35). The content of the guided audio file was downloaded from Headspace (https://www.headspace.com/). The content of the audio was modeled after the core practices and concepts of mindfulness (Kabat-Zinn et al. 1992).

The binaural beats intervention consisted of a 15-min audio track that subjects listened to with headphones (Bose QuietComfort 35). The track used was composed by Christian Møller Nielsen & Krzysztof Jan Jasik and produced by Christian Møller Nielsen. The specific track had a duration of 4 min, which was repeated four times. The track used 165 Hz in the left and 179 Hz in the right ear, making a binaural beat in the beta range of 14 Hz.

Subjects did not receive an introductory session to mindfulness or binaural beats, but were simply asked to follow the guided mindfulness exercise for 15 min or listen to the music presented to them for 15 min.

At the completion of the 15-min on-the-spot interventions, subjects were placed in front of a laptop (15-in. Apple Macbook Pro) and were asked to read the task instructions for the SART and completed the task.

Statistical Analysis

All data are presented as mean ± SD unless otherwise stated. Assumptions of normal distribution and sphericity of data were checked accordingly. Greenhouse-Geisser correction to the degrees of freedom was applied when violations to sphericity were present. Mixed 2 × 3 ANOVAs were used to assess if there were differences on the perceived stress scale, the SART % NoGo success rate (commission errors), % omission (omission errors), and RT CV, at baseline (T1) relative to immediately after the on-the-the spot interventions (T2) among the three groups (mindfulness vs. binaural beat vs. control). Significant interactions were followed up with simple main effects with Bonferroni corrections as appropriate. If significant interactions were not found, most relevant main effects are reported. Significance was set at 0.05 (two-tailed) for all analyses. The effect sizes for the repeated measures ANOVAs were calculated as partial eta squared (η^2p), using the small = 0.02, medium = 0.13, and large = 0.26 interpretation for effect size (Bakeman 2005). All data analysis was conducted using the statistical packages for social science (SPSS version 21).

Results

To assess if there were performance differences on the SART at baseline (T1) relative to immediately after the on-the-the spot interventions (T2), we employed a mixed ANOVA to inspect time (T1,T2) and group/intervention type (mindfulness, binaural beat, control) (Fig. 2).

First, we computed the average response in terms of % NoGo success. The mindfulness group at baseline was 52% ± 16.1, for the binaural beat group it was 52.1% ± 15.9, and finally the non-intervention it was 52.7% ± 16.5.

A significant group × time interaction for SART % NoGo success rate was found ($p = 0.001$, η^2p = 0.179). Follow-up tests revealed a significant increase in performance from baseline to T2 in the mindfulness group, which was immediately following the on-the-spot intervention. Specifically, this group displayed a significant increase in their performance score to 74.3% ± 11.1% NoGo success rate ($p < 0.001$, η^2p = 0.312). Moreover, we observed a significant increase in performance from baseline in the binaural beat group, who scored 73.7% ±

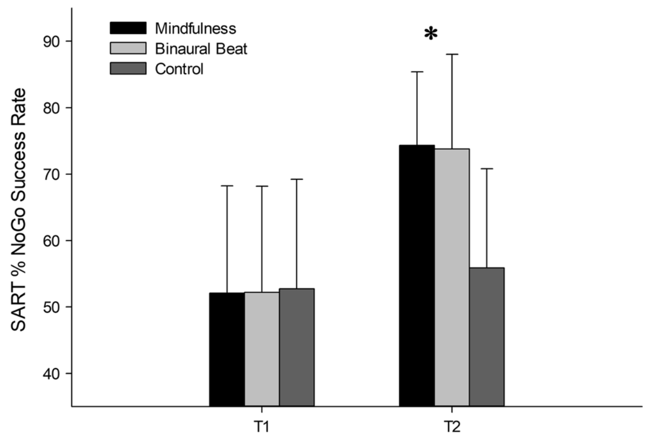

Fig. 2 The effect of mindfulness and binaural beats on-the-spot interventions; and control condition on SART % NoGo success rate from T1 to T2. * Significant group × time interaction ($p = 0.001$)

14.2 ($p < 0.001$, η^2p = 0.316). However, the non-intervention group appeared to maintain performance at T2 with no significant difference in that the average score was 55.8% ± 14.9 ($p = 0.413$, η^2p = 0.009).

No significant interactions were found for % omission and RT CV. However, a main effect of time for % omission ($p = 0.004$, η^2p = 0.157) and for RT CV ($p < 0.001$, η^2p = 0.156) was detected. Reduced % omission errors and reaction time variability are probabaly due to a learning effect of all participants as familiarization to the whole SART test was not provided.

Finally, no significant differences were found for the perceived stress scale (PSS), which showed similar level of stress prior the cognitive task across groups.

Discussion

In the current study, we demonstrated an effect of an on-the-spot mindfulness interventions on mind wandering. Specifically, a 15-min state-dependent mindfulness induction resulted in a 22% improvement in mind wandering. Perhaps surprisingly, the current study showed that our active comparison on-the-spot intervention, namely auditory binaural beats also exhibited a significant improvement on mind wandering effects. Specifically, we found that listening to 15 min of binaural auditory beats resulted in a 21% increase on a subsequent mind wandering task. The non-intervention control group did not result in differences, but rather, as expected, maintained performance on the mind wandering task (SART) across the two test sessions.

Thus, two interesting results emerged from this study: 1) state dependent effect of binaural auditory beats on level of focus, and 2) effects of on-the-spot mindfulness on mind wandering. We will discuss these two results in turn in the following.

Cognitive Effects of State-Dependent Mindfulness Induction

In this study, we confirm our hypothesis that an on the spot 15-min mindfulness intervention decreased mind wandering, as measured by the ability to withhold a prepotent response during a monotonous task. The results are consistent with several previous ones (Hafenbrack 2017; Erisman and Roemer 2010; Mrazek et al. 2012). Both the previous and the present studies find that mindfulness training is effective in reducing mind wandering.

It seems that whether the intervention is an 8-week MBSR course, a 4-week mindfulness app or a 15-min "on the spot" exercise it has a reducing effect on mind wandering. When it comes to reducing mind wandering, it seems that one can get some benefits from a short exercise. It should be interesting to further investigate if the effect of the short on the spot exercise is the same for all levels of dispositional mindfulness or if the effect is more pronounced in those low in dispositional mindfulness.

As Mrazek et al. (2012) point out in their study, we do not yet fully understand which mechanisms are responsible for the observed reductions in mind wandering and propose two possibilities: the first being that mindfulness exercises directly reduce the occurrence of task-unrelated thoughts and the second being that mindfulness exercises improve metacognitive regulation, which in turn might increase awareness of when one's mind has wandered. Once one realizes that their thoughts have drifted, this awareness may allow them to return their thoughts to the task at hand. These arguments are in line with Erisman and Roemer (2010) and their argument that mindfulness provides emotional space to focus on the task at hand. All arguments explain why mindfulness seems to enhance focus by diminishing mind wandering.

Cognitive Effects of Binaural Auditory Beats

Binaural beats is an auditory illusion which has been framed as a class of cognitive and neural entrainment (Reedijk et al. 2013). Binaural auditory beats arises when two tones of a different frequency are presented to each ear. In our study, we applied a tone with a frequency of 165 Hz in the left and 179 Hz in the right ear. This result in a subjectively perceived binaural beat in the beta range of 14 Hz in this case. Supposedly, instead of hearing two different tones, subjects will hear one tone which is the amalgamated difference between the two tones. Previous studies has indeed shown effects of binaural beats on cognitive functioning and mood. It is however unclear how binaural beats exert effects in the brain (Vernon et al. 2012).

Our aim of applying binaural on-the-spot intervention was to investigate whether binaural beats affects subject's ability to focus at a given task at hand, in our case a Go-NoGo task that capture levels of mind wandering in subjects. As presented in the "Results" section, we observed a significant effect of binaural bests, an observation that finds support from related research using brief auditory beats in the alpha range of 2 min duration, and found significant improvement in attention levels and working memory (Carter and Russell 1993). Other studies have shown an effect of 30 min of listening to binaural beats in the beta-range on mood and vigilance (Lane et al. 1998).

The influence of binaural beats on level of focus as measured on the SART was surprinsingly strong. We speculate that the reason for this effect is that suppressing mind wandering and sharpening of attentional focus required in carrying out the Go-NoGo task employed in the current study requires the cognitive resources that seem to be differentially recruited by the binaural bests employed in this study. Specifically, binaural bests had a positive effect on mind wandering; when subjects listened to the auditory binaural beats they were less likely to be "lost in thoughts" and more likely to be more focused on exogenous cues in the task.

Limitations

As we did not have an active control or sham on-the-spot intervention, we are not able to determine if indeed it was the content of the two interventions that drove the performance increase, or simply because subjects received an intervention by the experimenters. Future studies should aim to include an active/sham comparison group. The procedures provided respectively the mindfulness and the binaural groups with 15 min of listning to either the mindfulness meditation or the binaural beats. This also gave the two groups 15 min away from the stress of everyday life before the SART test at T2 whereas the control group did not have this break. Mrazek et al. (2012) had, in their 8-min intervention, both reading and relaxation as control groups and did not find improved SART score in neither control group. Therefore, it is unlikely that the effect comes from the break from everyday life, but that the significant effects are specific to the two interventions we deployed in the current study.

Future Applications of Binaural Beats vs Mindfulness

Based on our results, it would, in future research, be interesting to investigate a potential entrainment effect of binaural auditory beats, similar to our and others work on entrainment effects of mindfulness (e.g., Bennike et al. 2017; Jha et al. 2015; Morrison et al. 2014; Mrazek et al. 2013). There have been some research on entrainment effects using binaural beats with mixed results (Kennel et al. 2010, but see Chaieb et al. 2015).

In our study, subjects were instructed during the binaural beats 15-min interventions to listen to the tones using headphones, and sit in a upright position and relax. Future studies might also explore whether the effect remain if subjects, e.g., perform other cognitive tasks during an on-the-spot intervention, and indeed whether that might yield improvements, similar to the present study, on subsequent tasks. In other words, there might be potential of applying binaural beats while subjects are performing other demanding tasks, and whether this improves the performance.

Compliance with Ethical Standards

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

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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