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ORIGINAL ARTICLE

Online-based Mindfulness Training Reduces Behavioral Markers of Mind Wandering

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Abstract It is estimated that people spend almost half their waking hours lost in stimulus-independent thought, or mind wandering, which in turn has been shown to negatively impact well-being. This has sparked a rise in the number of cognitive training platforms that aim to boost executive functioning, yet it is unclear whether mind wandering can be reduced through online training. The current study aimed to investigate whether behavioral markers of mind wandering can be reduced through two short-term online-based interventions: mindfulness meditation and brain training. Using a randomized controlled design, we assigned one group of participants to 30 days of mindfulness training ($n = 54$) and another to 30 days of brain training ($n = 41$). Mind wandering and dispositional mindfulness were assessed pre- and post-intervention via the Sustained Attention to Response Task (SART) and the Mindful Attention to Awareness Scale (MAAS), respectively. We found significant reductions in mind wandering and significant increases in dispositional mindfulness in the mindfulness training group but not the brain training group. A lack of any significant change in the brain training group may be driven by methodological limitations such as self-report bias. These results indicate that short online mindfulness-based interventions may be effective in reducing mind wandering.

Keywords Mindfulness · Mind wandering · Cognitive training

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Introduction

Mind wandering involves thinking about events or experiences unrelated to the task at hand. It has been estimated that mind wandering occupies up to 46% of our waking lives and been shown to negatively impact subjective well-being (Killingsworth and Gilbert 2010). Some studies suggest that mindfulness-based interventions (MBIs) may be effective at reducing mind wandering (e.g. Levinson et al. 2014). In addition, there has been a recent surge in the number of mindfulness-based smartphone apps, as well as the number of online platforms that aim to increase cognitive performance and enhance well-being through cognitive training. Thus, the main aim of this study was to investigate whether a laboratory-based behavioral marker of mind wandering would decrease following two types of online-based cognitive training interventions: anMBI and cognitive training.

Behavioral markers of mind wandering are frequently measured in the laboratory via the Sustained Attention to Response Task or SART (Robertson et al. 1997). The performance markers of the SART are among the most carefully validated and commonly used indirect measures of mind wandering (Mrazek et al. 2012). The SART requires subjects to respond to sequentially presented targets and to withhold responding when infrequent targets are presented centrally on an otherwise black screen. According to Robertson et al. (1997), 'sustained attention' can be defined as task-relevant processing during monotonous tasks that encourage automatic, mindless responding, and susceptibility to distractors (both endogenous and exogenous in origin) that can induce off-task behavior. This type of off-task behavior can be captured by the SART. Specifically, the SART is designed such that the automatic response is the 'default', thereby encouraging a habitual response pattern that must be periodically overwritten by a conscious executive decision to refrain from responding.

Thus, the critical measure of sustained attention is the ability to successfully withhold a response when presented with infrequent targets. The SART has shown internal consistency when tested for reliability by Robertson et al. (1997), and the authors found a significant correlation between performance on the SART and self-report of cognitive failures during everyday life. This suggests that the SART has real-life applicability.

There is increasing evidence to suggest that mindfulness training can improve measures of cognitive performance and reduce mind wandering (Jha et al. 2015; Levinson et al. 2014; Morrison et al. 2014; Mrazek et al. 2013). Mindfulness has been operationalized in a variety of ways, with different definitions drawing attention to different central components of the practice (Grossman et al. 2011). While some accounts consider mindfulness as a state of sustained non-distraction (Brown and Ryan 2003), other accounts focus on mindfulness as a multifactorial construct, emphasizing aspects other than awareness, such as orientation to experience (Bishop et al. 2004). Mrazek et al. (2012) argue that there is, nevertheless, a consensus that sustained attentiveness is a fundamental property of mindfulness. MBIs typically offer instructions on how to stabilize and focus attention on ones' present moment experiences, as opposed to ruminating about the past or worrying about the future. In contrast to mind wandering, mindfulness entails a capacity to avoid distraction (Smallwood and Schooler 2006) and can thus be a kind of oppositional construct to mind wandering.

A second type of intervention that could potentially decrease mind wandering is cognitive training (Hardy et al. 2015). Comparing an MBI to an intervention with similar cognitive demands creates an opportunity to directly contrast the efficacy of two types of interventions with purported cognitive benefits. A study by Gopher et al. (1994) found that cognitive training helped air cadets to develop better attentional control. In addition, a study by Hardy et al. (2015) analysed data from 2667 participants on a range of cognitive abilities, following 10 weeks of online training with a programme that uses a variety of tasks within cognitive training. Having a pool of varied tasks is thought to be important in reducing reliance on task-specific strategies, thereby increasing the probability of developing transferable enhancements. The results revealed a small, but significant improvement on aggregate cognitive performance in the training group compared to an active control. Furthermore, the authors found the cognitive training programme to significantly improve performance on a Go/No Go task compared to the active control group. The Go/No Go task was considered a measure of response inhibition and processing speed, much like the SART. Furthermore, Hardy et al. (2015) found that 10 weeks of cognitive training (Lumosity) showed improvements on self-reported measures of concentration in participants. However, the majority of studies that have reported benefits following cognitive training have utilized cohorts consisting of older adults or preschool children (Owen et al. 2010). Thus, it remains unknown whether short-term online-based cognitive training programmes can increase measures of attentional control in healthy adults, and whether any such benefits are comparable to those that might arise from an MBI. To this end, we used cognitive training (via the Lumosity platform) as an active control to the MBI.

Jon Kabat-Zinn has stated that mindfulness meditation is 'the work of a lifetime' (Kabat-zinn 2003), p. 149), and emphasizes that understanding the complexity of mindfulness can only be understood through sustained personal practice through days, weeks and years. This statement helps to provide the necessary context for why most mindfulness-based studies utilize either cross-sectional designs that draw on meditation experts with thousands of hours of experience (e.g. Slagter et al. 2007), or employ mindfulness programs involving 7–8 weeks of training, including weekly group sessions (e.g. Kirk et al. 2014; Morrison et al. 2014). However, a number of recent studies have investigated the efficacy of short-duration programmes, such as those involving only 2 weeks of mindfulness training and their ability to reduce mind wandering (e.g. Mrazek et al. 2013). In a study investigating the impact of dose (number of hours practiced) on mindfulness-based intervention outcomes, Carmody and Baer (2008) found no correlation between mean effect size of an MBI and number of in-class hours. Furthermore, Wahbeh et al. (2014) found in a survey of 500 English-speaking adults that the majority of participants (43%) preferred an Internet format of mindfulness intervention to a group format. These results suggest that adaptations of MBIs could be valuable for populations that might otherwise refrain from engaging in mindfulness practice because of time constraints and physical distance from mindfulness meditation centres. Thus, the present study is an attempt to investigate whether more convenient methods of supplying MBIs could provide results comparable to those reported by traditional MBIs. In order to investigate the hypothesis that online-based mindfulness training reduces mind wandering, we designed a longitudinal randomized controlled study using the SART. We compared one subject cohort that was given 4 weeks of online-based mindfulness training (via the Headspace app) with another cohort that was given 4 weeks of an online-based brain training intervention (via the Lumosity platform). Both interventions were purely online-based, but differed in content (see 'Methods' section for further details on the two interventions). The current study builds on previous work by investigating the extent to which mindfulness training improves mind wandering capacity (Jha et al. 2015; Morrison et al. 2014).

Methods

Subjects

A total of 137 healthy volunteers participated in the study. Subjects were randomized into two groups. One group received Headspace training for a duration of 4 weeks, while the other group received Lumosity training for 4 weeks. Twenty-one subjects from both groups either dropped out of the study (that is, did not show up for testing at T2), or did not comply with the exclusion criteria of prior experience (i.e. regular practice) with mindfulness meditation. Thus, the total number of subjects from which data could be collected in the Headspace group amounted to 54. In the Lumosity group, the final number of subjects included in the analysis amounted to 41 subjects. The mean age for the Headspace group was 41.4 years (std = 9.5) and in the Lumosity group it was 43.4 years (std = 10.0). There were no significant age differences between the two groups (two-sample $t = 0.95$; df = 93; $p < 0.3$).

Recruitment involved advertising among staff at University of Southern Denmark. The study was framed as a program lasting 4 weeks that would provide insights into the cognitive benefits of two types of online-based interventions—mindfulness and brain training. This recruitment strategy was employed in order to reduce self-selection bias and to recruit volunteers from a broad demographic. Subjects were recruited with the understanding that the study consisted of comparing two equally valid online-based programs. In addition, subjects were notified that they would be assigned to one of the two interventions 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 - Project ID: 42932).

Experimental Procedures

Subjects completed two testing sessions: one before and another following the 4-week training interventions. 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 2 s each with 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 1–2 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, successful omissions of response to rare targets (%NoGo Success) are the most commonly used indirect marker of mind wandering. Secondly, SART omissions occur when participants fail to make a response to non-targets. Non-target errors on the SART suggest disengagement from the task as they reflect a failure to button press in response to a stimulus (Cheyne et al. 2009), 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. These three performance measures correlate with one another and with self-reported dispositional mind wandering (Cheyne et al. 2009).

Psychometric Data

All subjects completed the Mindfulness Attention Awareness Scale (MAAS) (Brown and Ryan 2003). The MAAS is a 15-item scale designed to assess a core characteristic of dispositional mindfulness.

Training Procedure

Procedure for Headspace Training

The mindfulness training intervention consisted of a 4-week app-based program provided by Headspace (https://www.headspace.com/). The content of the training was modelled after the core practices and concepts of mindfulness (Kabat-Zinn et al. 1992). Subjects did not receive an introductory session to mindfulness, but were simply provided with access codes to the Headspace app, and followed the program for 4 weeks. The program included daily guided meditations that increase in duration. For the first 10 days, the daily home practice requirement was 10 min, with the following 10 days increasing to 15 min daily, and the final 10 days increasing to 20 min daily. Subjects were instructed to follow the program in full. Headspace provided a report detailing how much time each participant had spent meditating via the app. In the Lumosity group, data on adherence was obtained through self-report.

Procedure for Lumosity Training

A brain training program was chosen as an active comparison condition for the mindfulness (Headspace) training. To allow for a balanced comparison between the two interventions, an app-based program was chosen (http://www.lumosity.com/). Lumosity training consists of brain training and the purported effects of the games are improvements in memory, attention, flexibility, speed of processing and problem solving, which is extrapolated based on scientific results using lab-based brain training (e.g. Jaeggi et al. 2008). Subjects did not receive an introductory session to brain training, but were simply provided with instructions on how to use the Lumosity app. Subjects were instructed to use the app for an identical duration as the Headspace group, and follow the program in full. Unlike the Headspace intervention, there was no planned 30-day program that they followed, but rather a range of tests based on a preliminary test of cognitive abilities taken at the beginning of the program. The Headspace group follow the same programme regardless of individual differences at baseline.

Results

We assessed adherence to training in the two programs in order to confirm that there were no differences in training dose between groups (Fig. 1). Our key analysis focused on performance on the SART and correlations between home practice, MAAS and SART scores.

We first assessed the impact of and adherence to the two training programs (Headspace and Lumosity training). Training dose for the Headspace group across the 54 subjects (35 females) amounted to a mean of 302.7 min (std = 96.2). For the 41 subjects (29 females) in the Lumosity group, the total amount of home practice amounted to 293.6 min (std = 72.2). There was no significant difference in terms of practice/dose response across the two groups (two-sample $t = 0.5$; df = 93; $p < 0.61$). This result suggests that there were no differences in motivation between the two training groups and indeed, that the two groups adhered to the required training dose completing 67.1% of the required home practice for the Headspace group and 65.1% for the Lumosity group.

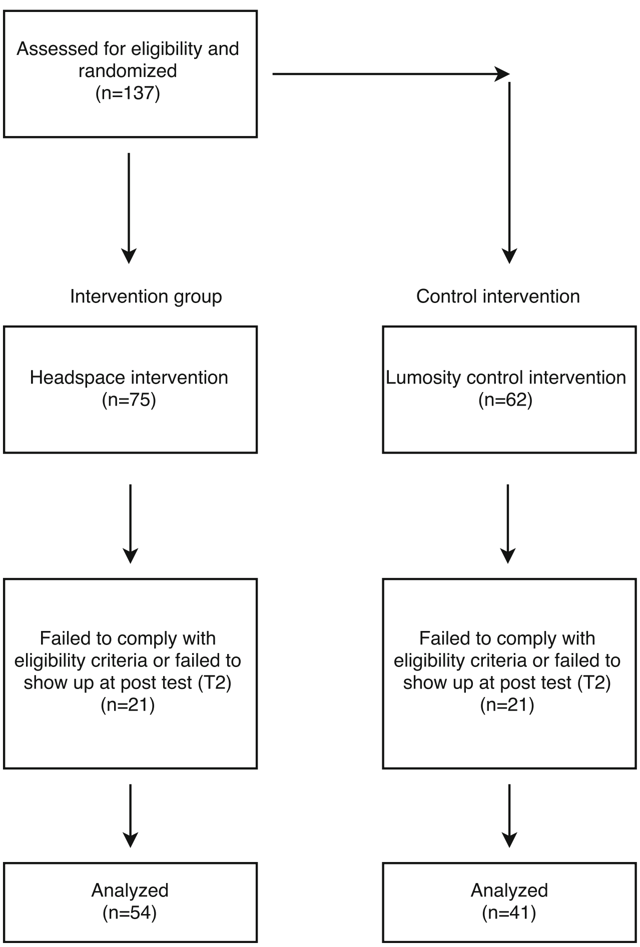


Fig. 1 Flowchart of participants initially assessed and final amount of participants analyzed in the study

SART Performance

We next assessed the impact of the two training interventions (Headspace and Lumosity) on three indirect measures of mind wandering. That is, we employed a series of ANOVAs to inspect time (T1, T2) by intervention type (Headspace, Lumosity), for the three SART-related outcome variables; NoGo success rate, reaction time coefficient of variability and SART omissions. Significant interaction effects were followed post hoc by paired sample and independent *t* tests.

Firstly, we first computed the mean response in terms of % NoGo success. The average response in the Headspace group at baseline was 53.6% (std = 23.6) and 49.7% for the Lumosity group (std = 23.3). At T2, the Headspace group mean was 68.3% (std = 22.9), whereas the Lumosity group mean was 55.8% (std = 26.7). Thus, the %NoGo success outcome variable significantly increased over time ($F(1,93) = 6.43$; $p < 0.01$), with a main effect of intervention type ($F(1,93) = 6.05$; $p < 0.01$) and an interaction of time and intervention type ($F(1,93) = 7.52$; $p < 0.01$). Post hoc *t* tests showed that the time by intervention type interaction was driven by a performance increase over time within the Headspace group (paired $t = 4.9$; df = 53; $p < 0.00001$). Such an increase was however not evident in the Lumosity group (paired $t = 1.7$; df = 40; $p < 0.08$) (Fig. 2). In addition, we did not observe a significant group difference in performance as measured using the %NoGo success variable at T1 (two-sample $t = 0.7$; df = 93; $p < 0.4$). Albeit, the Headspace group did show a performance increase compared to the Lumosity group at T2 (two-sample $t = 2.4$; df = 93; $p < 0.01$) (Fig. 2). These results suggest that Headspace training, but not Lumosity training, significantly improved performance on the SART.

We next computed the reaction time coefficient of variability (RT CV). For the RT CV SART output variable, there was no significant main effect of time ($F(1,93) = 1.73$; $p < 0.7$),

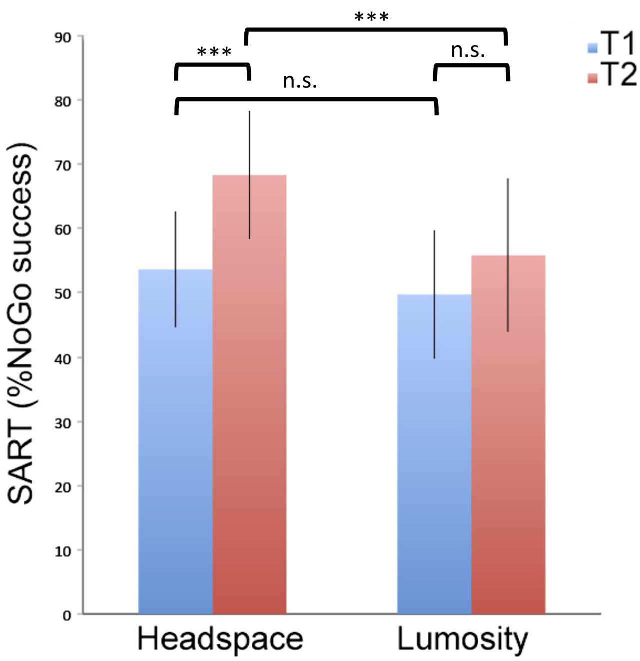


Fig. 2 SART performance measured as %NoGo success over time (T1 and T2) and between the two training interventions (Headspace and Lumosity). *Asterisks* denotes significant result (see main text for specific alpha level); *n.s.* denoted non-significant result. *Error bars* are SEM

intervention type ($F(1,93) = 1.21$; $p < 0.08$) or interaction of time and intervention type ($F(1,93) = 1.63$; $p < 0.7$).

Finally, we extracted the third SART-related outcome variable, namely SART omissions. For SART omissions, we did not observe significant differences in terms of main effect of time ($F(1,93) = 1.69$; $p < 0.7$), intervention type ($F(1,93) = 2.22$; $p < 0.6$) or interaction of time and intervention type($F(1,93) = 1.72 < 0.7$).

We also inspected the correlation coefficients in the Headspace group between the three SART measures employed, as there is evidence that they tend to correlate (e.g. Morrison et al. 2014; Mrazek et al. 2012). For each of the three measures, we computed the difference score between T2 and T1, and observed negative correlations between %NoGo success and SART omissions ($R = -0.5$; $p < 0.01$); %NoNo success and RT CV ($R = -0.32$; $p < 0.01$) and a positive correlation between SART omissions and RT CV ($R = 0.55$; $p < 0.01$).

Correlation between SART and Home Practice

We next sought to investigate the relationship between task performance and dose response in order to probe for a correlation between home practice and increased task performance. For this correlation analysis, we used the T2 score (%NoGo success) for each group separately and plotted it against a variable computing the subject-by-subject home practice/dose response. The Pearson correlation coefficient (R) for the Headspace group was significant at $R = 0.6$; $p < 0.001$; two-tailed (Fig. 3a). The Pearson correlation coefficient (R) for the Lumosity group was $R = -0.15$; $p < 0.32$; two-tailed (Fig. 3b). This result suggests that quantity of home practice had a significant impact on the change in SART performance at T2 for the Headspace group, but not the Lumosity group.

MAAS Performance

We also looked for a difference in MAAS scores at T1 and T2 in the two intervention groups. In the Headspace group, the mean MAAS score at baseline was 57.1 (std = 12.6) and post-intervention it was 60.1 (std = 10.6). The MAAS score significantly increased over time ($F(1,93) = 5.65$; $p < 0.01$), with a main effect of intervention type ($F(1,93) = 5.12$; $p < 0.01$) and an interaction of time and intervention type ($F(1,93) = 5.41$; $p < 0.01$). Post hoc t tests showed that the time by intervention type interaction was driven by a significant increase in MAAS score from T1 to T2 in the Headspace group (paired $t = 2.4$; df = 53; $p < 0.01$). By contrast the Lumosity group did not display significant differences in MAAS at T1 (average 59.5 (std = 12.0)) compared to T2 (average 59.8 (std = 14.6)) (paired $t = 0.27$; df = 40; $p < 0.78$).

Correlation between MAAS and Home Practice

In addition, we sought to find a correlation between MAAS and home practice. As we did not find a significant change in the Lumosity group in terms of MAAS scores, we only computed a correlation for the Headspace group, using the T2 MAAS variable against a measure of home practice. The Pearson correlation coefficient for the Headspace group was significant at $R = 0.32$; $p < 0.01$; two-tailed (Fig. 4).

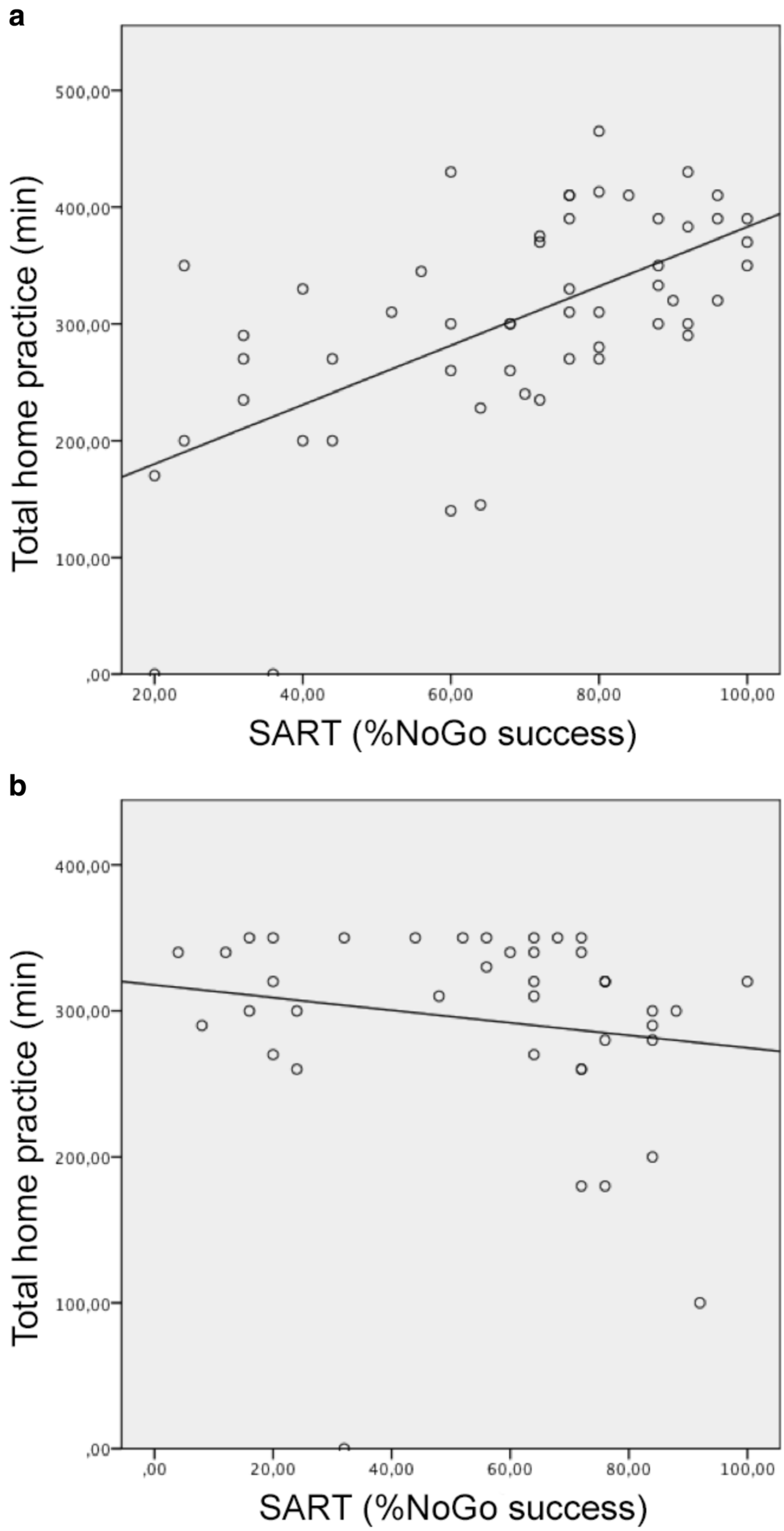
Correlation between SART and MAAS

Based on the significant increase in %NoGo Success and MAAS score for the Headspace group, we performed a correlation between these two variables at T2. We found a significant correlation between SART performance (%NoGo success) and the MAAS. Specifically, the correlation coefficient for the Headspace group was $R = 0.39$; $p < 0.003$; two-tailed (Fig. 5a). There was no significant relationship between the SART and the MAAS in the Lumosity group ($R = 0.02$; $p < 0.84$; two-tailed) (Fig. 5b).

Discussion

In this study, we confirm a hypothesis that a short-term online-based mindfulness intervention (Headspace) decreased mind wandering, as measured by the ability to withhold a prepotent response during a monotonous task. In comparison, a short-

Fig. 3 Correlation between total minutes of home practice and SART performance. Plots of correlations are displayed separately across the two groups **a** Headspace and **b** Lumosity. Only the Headspace group display a significant correlation ($R = 0.6$). Each data point represents a subject



term online-based cognitive training program (Lumosity) did not significantly reduce mind wandering on this measure. Furthermore, our results indicate that mindfulness levels as measured by MAAS increased in the Headspace group and

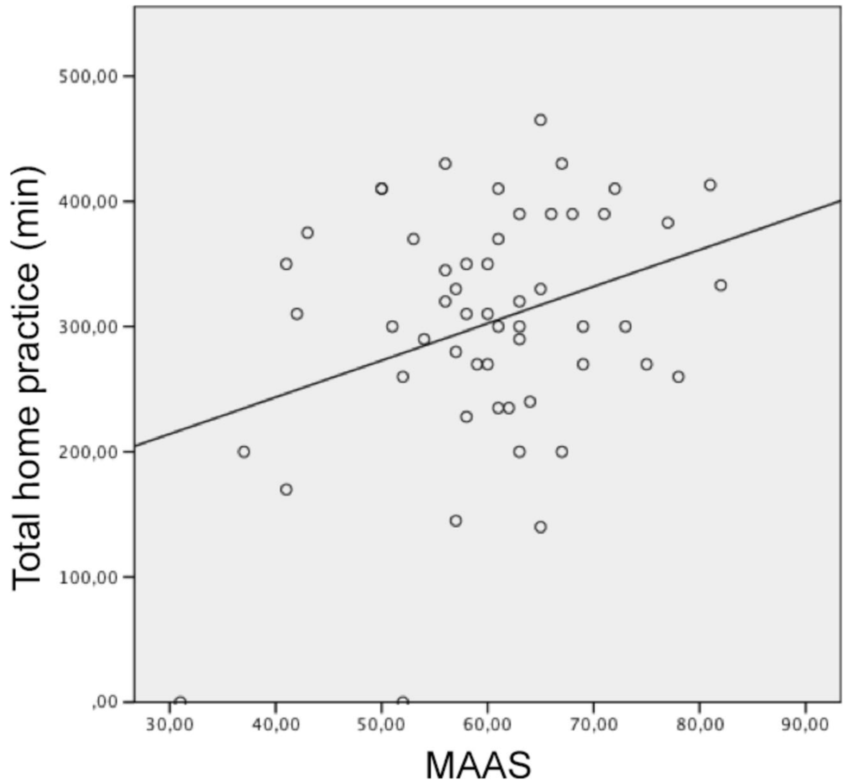


Fig. 4 Correlation between total minutes of home practice and MAAS score at T2 for the Headspace group. Each data point represents a subject

that this increase is related to better performance on the SART. Mindfulness did not increase following Lumosity training, and levels of mindfulness were not associated with performance on the SART in this group. Taken together, these results point towards mindfulness as being a useful tool in alleviating mind wandering and thus increasing performance in tasks that are otherwise susceptible to distraction. Based on the results from the Lumosity group, it does not appear that a short-term online-based cognitive training intervention has the same effect on this particular measure of mind wandering.

The results in the Headspace group are consistent with several previous results. Mrazek et al. (2012) found that just 8 min of mindful breathing improved performance on the SART compared to two control groups—reading and passive relaxation. Both the previous and the present studies find that mindfulness training is effective in reducing mind wandering. The present study is the first to our knowledge to document this effect with a purely online-based intervention. However, 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. Mrazek et al. (2012) 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.

Our results are not consistent with Gopher et al. (1994) and Hardy et al. (2015), who showed that cognitive training has a positive impact on attentional control and concentration and that magnitude of gains in performance was correlated with amount of home practice. One reason for this could be that the cognitive intervention used in this study has different properties to the one used by Gopher et al. (1994), for example, by not targeting attentional control as directly. There are other studies that have failed to find effects following computerized cognitive training. Owen et al. (2010) reported improvements in a number of cognitive tasks that were trained via a 6-week online training platform, but failed to find any improvements in cognitive functioning. Borness et al. (2013) also failed to find any significant improvements following a 16-week online cognitive training intervention on cognition or well-being in a sample of healthy white-collar workers from an Australian company. The authors of the latter study suggested that the intervention was spread out across too much time, and hence was 'diluted'. Our study required participants to train intensely within the course of 30 days. However, since we did not have access to adherence data in the Lumosity control group, participants had to self-report the amount of time they had spent engaging in Lumosity training. These reports are susceptible to recall or social desirability bias, and thus might not have accurately reflected the amount of time participants had spent practicing.

An important consideration when interpreting our results is that the SART is only an indirect measure of mind wandering. In theory, the SART encourages mind wandering by requiring

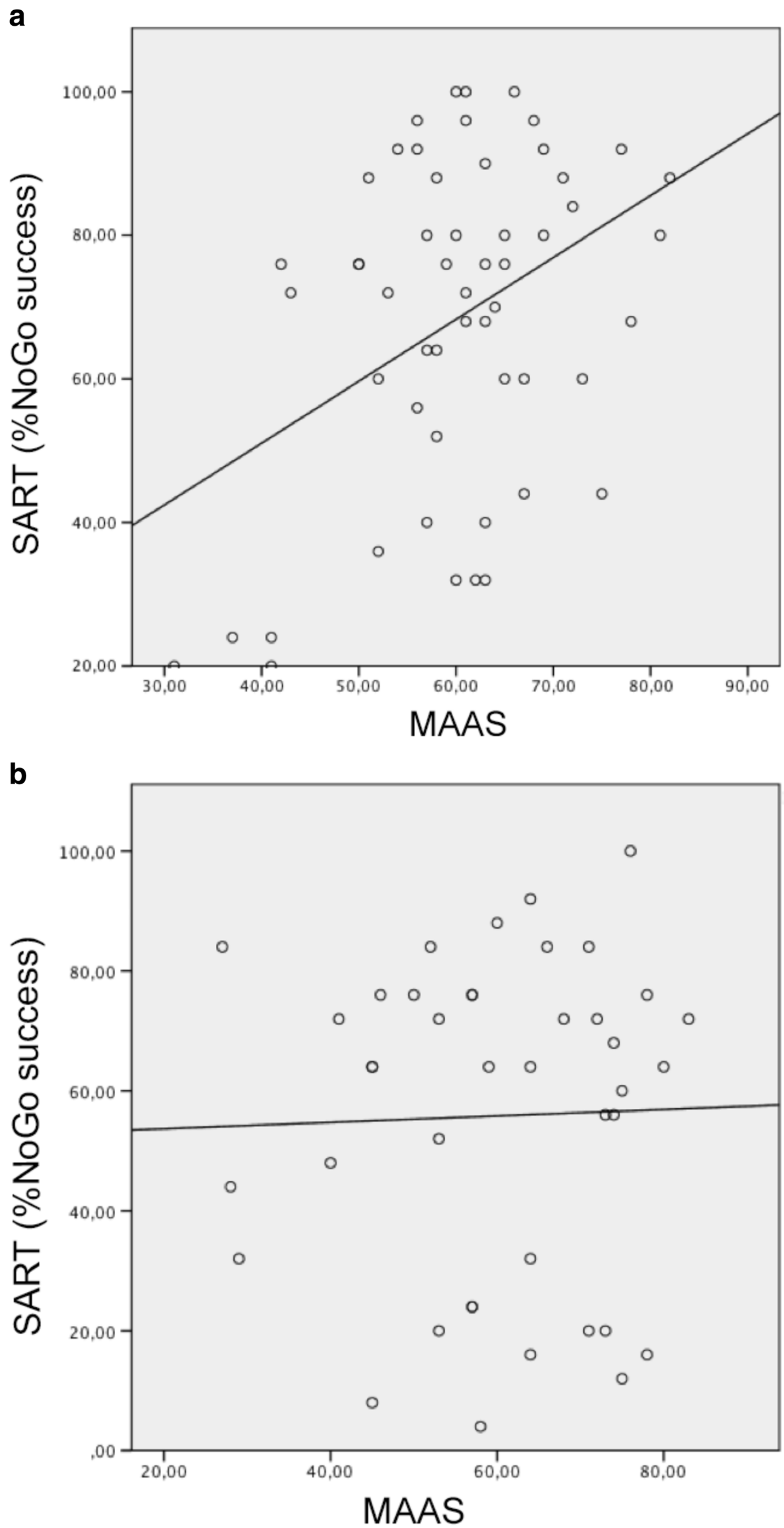


Fig. 5 Correlation between SART performance and MAAS scores at T2. Plots of correlations are displayed separately across the two groups **a** Headspace and **b** Lumosity. Only the Headspace group displays a significant correlation ($R = 0.39$). Each data point represents a subject

participants to engage in a routine and low maintenance task that only requires them to make a conscious decision when an infrequent target is presented. However, the extent to which the SART as a valid measure of sustained attention (and thus mind wandering), as opposed to impulsive control has recently been questioned (Helton et al. 2009). This is based on reported correlations between errors of omission and reaction time to neutral targets, that indicate the SART might induce impulsive responding in participants, rather than measure the extent to which participants can sustain their attention over a short period of time.

Overall accuracy (i.e. %NoGo success) provides a composite of the SART measures that we report (RT CV and SART omissions). Albeit, we only found the former variable but not the two latter variables to be significant between the two groups. This finding is in conflict with existing studies using the SART in the context of mindfulness interventions where typically other SART measures such as RT CV tend to also reflect group differences (e.g. Morrison et al. 2014; Mrazek et al. 2012). One explanation for this might be that in the current study, we employed significantly fewer trials with a total of 240 trials, whereas in previous studies, e.g. Morrison et al. (2014), employed 546 trials.

Klingberg (2010) argues that the end goal of training specific cognitive abilities should be that the training can be transformed onto other domains beyond the trained one. In this manner, it is possible to rule out that the effect reported here can be attributed to newly acquired task-specific strategies. The strongest evidence for improved cognitive abilities thus comes from studies that utilize training which has little relation to the measured outcomes (Mrazek et al. 2013; see also Shipstead et al. (2012) for review of transfer of cognitive abilities in the domain of working memory). From this perspective, the mindfulness intervention in the present study gives support to the claim that the decrease in mind wandering does not stem from specific newly learned strategies or overlap between the training intervention and the tests used. Further evidence in support of this notion is that we found a relationship between SART performance and amount of home practice in the Headspace group, but not the Lumosity group.

Although only marginally significant, we did find that mindfulness levels increased with the amount of home practice in the mindfulness group. This is interesting given our prediction that only a small dose of mindfulness training could raise mindfulness levels and decrease mind wandering, which it did. It also conflicts with Carmody and Baer's 2008 study where they did not find a relationship between mean effect size of an MBI and number of in-class hours. Despite this, it appears that levels of mindfulness do seem to accumulate with experience. We suggest that future research look into dose effect levels to try and estimate if 'more is more'.

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