Examining the Effects of a Mindfulness-Based Intervention Using a Neurofeedback Device on Adolescent Introspection: A Quasi-Experimental Time-Series Design

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Abstract

This study explored whether adolescent's introspection increased while engaged in a mindfulness-based intervention (MBI). Using a quasi-experimental design, the researchers identified high school students (n=13) with elevated levels of anxiety to participate in an 11-week, multiphase MBI. Participants' introspection ability was assessed by comparing self-reported levels and observed percentage of time calm as recorded by a neurofeedback (NFB) device three times a week during the program. Using general linear modeling, results indicated a significant interaction effect with moderate effect sizes between self-reported scores by phase on NFB scores, $F(2, 407)=4.12$, $p=0.017$ and a significant interaction between sex and self-reported scores on NFB scores overall, $F(1, 407)=5.05$, $p=0.025$. Female participants appeared to have increased introspection compared to males. Results support the use of MBIs to foster introspection in adolescents. The MBI with an NFB device appeared to improve introspection, a key factor in accurate self-report.

Keywords: introspection, neurofeedback, adolescents, mindfulness-based intervention, quantitative methodology

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Mindfulness includes a variety of practices, concepts, and skills meant to increase the awareness, acceptance, and understanding of the present (Kabat-Zinn, 2003). Developing mindfulness skills may increase the ability for introspection which could enable individuals to provide more accurate self-report information (Kiken et al., 2015). Introspection is the ability to examine one's emotional and cognitive state, therefore increasing their awareness and understanding of the present (Schwitzgebel, 2010, Weger et al., 2018). However, introspection is considered a higher order cognitive skill that some individuals might not possess (Fleming et al., 2010). The purpose of this study is to explore the effects of a mindfulness-based intervention (MBI) on adolescent introspection by comparing self-report (SR) percentage of time calm to observational data in the form of neurofeedback (NFB) scores (electroencephalogram [EEG] output) collected during a multiphase MBI. Understanding this relationship will provide insight into adolescent introspection. In response to the call for research to better understand how mindfulness intersects with factors such as age, race, sex, and socio-economic status (SES), we examined these factors impact on introspection (Bodenlos et al., 2017; Waldron, et al., 2018).

Mindfulness

Mindfulness is a term used to describe a set of skills, practices, and beliefs defined as "the awareness that emerges through paying attention on purpose, in the present moment, and nonjudgmentally to the unfolding of experience moment by moment" (Kabat-Zinn, 2003, p. 145). Influenced by Buddhist and Eastern philosophical roots, mindfulness is taught through meditation practices with the goal of increasing self-awareness through repeated practice (Kiken et al., 2015). Many researchers are interested in developing mindfulness programs for children and adolescents to increase calm and support mental health functioning and academic achievement (Franco et al., 2016; Zenner et al., 2014). MBI have been shown to effectively

address a variety of goals in clinical and non-clinical populations, especially for anxiety (de Abreu Costa et al., 2019; Renshaw & Cook, 2017). As most mindfulness research has been conducted with middle-aged adults, there have been calls to increase the body of research on the effects of MBI on children and adolescents (Chin et al., 2019; Tan, 2016).

Factors such as age, sex, ethnicity, and SES may influence MBI outcomes but have not been thoroughly researched. The efficacy of MBI on adolescents' social-emotional wellbeing has been established but researchers have not fully explored how age impacts factors such as introspection (Tan & Martin, 2015). Researchers have found MBI outcomes do differ according to sex, with females tending to be more responsive to mindfulness interventions (Kang et al., 2018; Rojiani et al., 2017). Developmental differences of the adolescent brain indicate that the prefrontal cortex of females develops earlier and faster than adolescent males (Fleming et al., 2010; Shaw et al., 2019). It appears that females are more likely to respond to mindfulness interventions and increase their introspection when considering adolescent brain development. While there is scant research addressing ethnicity and SES differences on MBI outcomes (Pina et al., 2019), researchers have shown the efficacy of MBI with diverse populations is comparable with results from non-minority samples (Bluth et al., 2016; Fung et al., 2019).

Mindfulness Based Interventions and Self-Report

While there is not a unanimous measure of 'mindfulness', many mindfulness measures rely on self-report (Baer, 2019; Goodman et al., 2017; Pallozzi et al., 2017). Self-report measures rely on self-perception and introspection for honest and accurate reporting, skills an adolescent may or may not possess (Fleming et al., 2010; Shaw et al., 2019). Despite concerns about self-report accuracy, researchers and counselors continue to use self-report to assess mindfulness in participants and clients. Scholars have called for the development of objective measures of mindfulness in place of self-report measures (Baer, 2019; Goldberg et al., 2018; Pallozzi et al., 2017). EEG output is a potential objective measure to study the effects of MBI. A correlation between recorded brainwave activity and a self-report measure of the same variable (i.e., calm),

provides evidence of EEG output as an objective measure of mindfulness and supports the continued use of self-report for assessing MBI.

Mindfulness Based Interventions Using Neurofeedback

Consumer grade NFB devices are not only a popular method to facilitate the mind-body connection and promote mindfulness, but also provide EEG output useful for assessing MBI. Martinez and Zhao (2018) explored the effect of MBI with a consumer grade NFB headband with adolescents and found evidence supporting the use of an NFB headband to teach mindfulness, increase concentration, and reduce the amount of time out-of-class. NFB provides feedback on brain waves associated with states of consciousness and neurological activity to allow users to learn from their feedback (Shaefer, 2018) by measuring the activity of neurons across the cortex of the brain via EEG (Desai et al., 2015). After clients learn to use this feedback, they can implement mindfulness outside of a session to achieve the same physiological effects without the use of technology (Crockett et al., 2017).

While there are numerous classifications to EEG wavelengths, Demos (2005) identifies five common types of brain waves measured by NFB devices: gamma (32 – 100 Hz), beta (12 – 32 Hz), alpha (8 – 13 Hz), theta (4 – 8 Hz), and delta (0.5 – 4 Hz). Gamma waves are associated with heightened states of perception and awareness and relate to the feeling of strong capability or peak performance for problem-solving (Desai et al., 2015). Beta waves occur during normal states of consciousness when people are alert and concentrating on tasks (Demos, 2005; Schaefer, 2018). Beta activities correlate with academic performance and emotions (Desai et al., 2015). Alpha waves are prominently active when a person is awake, but they are only moderately active when a person is in a calm state (Desai et al., 2015). Theta waves occur in sleep or calm states and can also relate to the inability to focus (Berman & Stevens, 2014). Delta waves are generated in a state of extremely deep meditation and dreamless sleep (Berman & Stevens, 2014). The headband used in the current study analyzes these brain waves, dividing them into three states: calm, neutral, and active. While the exact combination of these

brain waves used by the NFB headband to measure a calm state is proprietary, based on previous research, it is likely a combination of increased gamma, alpha, and theta waves and decreased delta waves (Schaefer, 2018; Shapiro et al., 2011).

Purpose

This study purports to explore adolescents' ability for introspection using a NFB device to measure MBI effectiveness by comparing SR percentage of time calm to observational data in the form of EEG output collected during a multiphase MBI and provide insight into adolescent introspection (i.e., congruence between self-reported and observed data), a key element in the ability to be mindful and provide an accurate self-report. Additionally, in response to the call for research to develop a better understanding of the influence of how mindfulness intersects with factors such as age, race, sex, and socio-economic status (Bodenlos et al., 2017; Waldron, et al., 2018), we attempted to identify factors leading to increased introspection.

RQ_1: How does participating in a MBI effect high school students' level of introspection?

H_1: As participants engage in the MBI their ability for introspection will increase as evidenced by an increase in positive correlation between their self-reported percentage of time calm and observed NFB scores.

RQ_2: Are there demographic factors (sex, ethnicity, and SES) that influence how a MBI effects high school students' level of introspection?

H_2: As participants engage in the MBI females will have higher levels of introspection compared to males, but there will be no differences in introspection for minoritized compared to non-minoritized participants or based on SES.

Method

Design

A time-series quasi-experimental design was employed due to the selection of participants to participate in the mindfulness program. The Beck's Anxiety Inventory for Youth (BAI-Y) was used to identify eligible participants with subclinical levels of anxiety based upon a

specified cut-off score of moderate to severe. The researchers used observed scores via the NFB headband and self-reported survey measurements collected at 33 times, with points for each of the 13 participants during the study: 9 during the pre-intervention phase, 15 during the intervention phase, and 9 during the post-intervention phase. Data was collected simultaneously at each session over the course of the 11-week mindfulness program.

Participants

An initial sample of 21 potential participants elected to participate and completed the BAI-Y to assess levels of anxiety. The BAI-Y assesses severity of symptomology by conversion of raw scores into norm referenced T-scores. Based on the BAI-Y manual (Beck et al., 2005), a score of 55 to 59 is mildly elevated, 60 to 69 is moderately elevated, and >70 is extremely elevated. Participants with an initial T-score of 55 or higher on the BAI-Y were invited to participate in the study. The BAI-Y has strong psychometric qualities with reported Cronbach's α of 0.92 and test-retest reliability coefficient of .87 for 15–18-year-old males and females (Beck at al., 2005).

Of the initial sample, 8 did not meet the BAI-Y cutoff criteria to participate in the experimental group but continued to receive the experience of using the NFB headband. The remaining sample consisted of 13 participants identified as high-achieving high school students at a public high school in the southern part of the United States. The aim of the MBI was to help participants develop mindfulness skills to gain insight into physiological, emotional, and cognitive states. The average age of participants was 17.1 years (SD = .61) with 8 (62%) in 11th grade and 5 (38%) in 12th grade; 5 (38%) were male and 8 (62%) were female. Six (46%) identified as White (Hispanic/Latinx), 5 (38%) as White (Non-Hispanic), 1 (8%) as Pacific Islander, 1 (8%) as Asian. Eight (62%) of the participants were identified as low-SES based on receiving free or reduced lunch.

Measures

The type of NFB device used in this study is a consumer grade wearable headband with

technology that senses brain wave activity. The manufacturer has a preset sampling rate of 256 Hz with dry silver electrode sensors located at Fpz (reference), AF7/8, and two conductive silicon temporal sensors (TP9/10) using the International 10-20 system for electrode placement. This device (i.e., MUSE™) has been previously used and supported in clinical research studies (Hunkin et al., 2021; Krigolson et al., 2017; Martinez & Zhao, 2018; Ratti et al., 2017; Segawa, 2019). While wearing the headband, users participated in a guided meditation session where they received continuous feedback on brain activity in the form of auditory stimulation and responded by focusing on their respiration and engaging in learned mindfulness practices (Martinez & Zhao, 2018). To answer the research question, we used observed data recorded by the headband's EEG reading and self-report. We decided to use percentage of time recorded as calm to inform participants' time spent in a calm state. Each state described above is measured by a unique combination of EEG brainwaves. While this information is proprietary and protected by the manufacturer, previous research indicates it is likely a combination of increased gamma, alpha, and theta waves and decreased delta waves (Schaefer, 2018; Shapiro et al., 2011). In addition to percentage of time calm recorded by the NFB headband, we asked participants to self-report percentage of time spent in a calm state.

Mindfulness-Based Intervention

The MBI program, developed by the manufacturer of the NFB device, was administered to all 21 participants and was monitored by the authors, one of which is a clinician with Board Certification in Neurofeedback. Participants received auditory feedback indicating calm, active, or neutral states which increased or decreased according to the intensity of these states during the sessions. The purpose of the audio was to provide feedback to the participants and act as a system of reinforcement. During active states, participants were provided with unpleasant audio simulating a rainstorm and strong waves. During neutral and calms states, participants were rewarded with audio simulating gentle waves. Birds chirping indicated and rewarded considerable time spent in a calm state. The MBI consisted of 15 sessions that pertained to the

essential skills of meditation (e.g., breathwork, focus and attention, body awareness, visualization, redirecting, nonjudgment, etc.) that participants engaged in during the intervention phase.

Procedure

Following a pre-determined intervention protocol, participants completed three 5-minute mindfulness sessions per week for 11 weeks using the NFB headband unless the school or student's schedule required alteration. Participants completed each session on campus, in a private room that offered low-level lights, window blinds, and various chairs for comfort. Sessions were facilitated by a school counselor, a school counseling intern, or a research team member. During the pre-intervention phase, three sessions per week for three weeks, participants were instructed to keep their eyes closed and attempt to keep their minds calm while they experienced unguided sessions while only receiving auditory feedback from the device. In the intervention phase, comprised of three sessions per week for five weeks, participants learned calming techniques through an MBI program as described above. During the post-intervention phase, comprised of three sessions per week for three weeks, participants experienced unguided sessions where they attempted to use the new mindfulness skills to remain in a calm state only receiving the device's auditory feedback. At the end of each session, a research team member documented the NFB recorded data and participants completed a self-report survey in which they estimated the percentage of time they were in a calm state. Participants were not provided any information regarding their NFB recorded data.

Analysis

Because the collected data included categorical and continuous predictors, we used a general linear model (GLM) with repeated and between-subject predictors to assess how introspection changes over time. For this study, we used phase, self-reported calm scores (SR), sex, ethnicity, and SES as predictor variables. We used NFB scores recorded by the headband as a dependent variable. The data was assumed to be distributed normally with no outliers after

examining Mahalanobis' distance, histograms, skewness, and kurtosis test.

Prior to running the analysis, it was necessary to estimate the model fit characteristics. Given the reduced sample (n=13), a compound symmetry covariance structure was selected based on model fit characteristics to estimate two parameters to model the residuals (Liu et al., 2012). The parameters estimated were a variance parameter for residuals at each time point and a covariance parameter for each pair of residuals. Residual variances were assumed to be constant across time points and each pair of residuals has the same covariance ($\hat{p}_{1,2} = \hat{p}_{1,33}$). The restricted models are:

M_1: NFB scores$_{it}$ = π_{0i}
M_2: NFB scores$_{it}$ = π_{0i} + π_{1i}Phase$_{it}$ + π_{2i}SR$_{it}$ + π_{3i}Sex$_i$
M_3: NFB scores$_{it}$ = π_{0i} + π_{1i}Phase$_{it}$ + π_{2i}SR$_{it}$ + π_{3i}Sex$_i$ + π_{4i}Phase+SR$_{it}$
M_4: NFB scores$_{it}$ = π_{0i} + π_{1i}Phase$_{it}$ + π_{2i}SR$_{it}$ + π_{3i}Sex$_i$ + π_{4i}Phase+SR$_{it}$ + π_{5i}Phase+Sex$_i$

The full model is:

M_F: NFB scores$_{it}$ = π_{0i} + π_{1i}Phase$_{it}$ + π_{2i}SR$_{it}$ + π_{3i}Sex$_i$ + π_{4i}Phase+SR$_{it}$ + π_{5i}Phase+Sex$_i$ + π_{6i}Phase+Sex+SR$_{it}$

The initial model contains solely the parameter estimate (π) of the NFB scores intercept followed by the building of additional individual parameters and interactions to account for variance explained. Model 2 contains the parameters for simple or main effects. Model 3 adds the two-way interaction for Phase and SR (π_{4i}Phase+SR$_{it}$) and Model 4 adds the additional parameter for the two way-interaction for Phase and Sex (π_{5i}Phase+Sex$_i$). Ethnicity and SES were not included as they were non-significant parameters and did not account for additional variance explained. The initial model found 41% of explained variance for between participant effects on NFB scores, with the addition of interactions between SR scores and phase as well as SR scores and sex contributing 16% more variance explained. The full model contains all the previous model information and includes the parameter estimation for the three-way interaction effect for Phase, Sex, and SR on NFB scores (π_{6i}Phase+Sex+SR$_{it}$). Model information results indicated the final full model explaining 57% of the variance.

After the model building procedure, we conducted the GLM procedure to compare mean

scores and test for differences in model effects using the final model. Pearson's r correlation coefficient was used to determine the strength and direction of the linear relationship between the two variables of interest (SR scores, NFB scores) to conceptualize participant introspection. Next, we looked at the interaction effects to determine if there were statistically significant differences between variables. To explore the differences in the model, we calculated the parameter estimates (or model coefficients) to assess the associated change and each predictor's contribution using least-squares estimation. The coefficient describes the contributing magnitude of that predictor and direction of the relationship. A t-test is used to test the null hypothesis and determine if the parameter does contribute to the model.

Results

To answer the first research question, how does participating in a MBI effect high school students' level of introspection, we assessed the relationship between participant's SR percentage of time calm on NFB scores by phase using Pearson's *r* correlation. Table 1 provides the descriptive statistics for overall NFB recorded and SR scores across and by each phase. Higher scores indicate higher percentages of the conscious state being measured, "calm." Notably, average NFB recorded scores decreased between phases, where average SR scores saw a peak during the intervention phase. Pearson's correlation indicated there is a significant correlation across phases between SR scores and NFB recorded scores (r=0.18, p<0.001). There was no significant correlation between SR scores and NFB recorded scores in the pre-intervention (r=-0.02, p=0.85), but a significant correlation in the intervention (r= 0.26, p<0.001) and post-intervention (r= 0.33, p<0.001). According to Cohen (1998, 1992) these correlations varied around .3 yielding medium effect sizes. The results found a significant interaction effect between SR scores by phase on NFB scores, $F(2, 407)=4.12$, p=0.017. Parameter estimates indicated significant effects between the intervention phase (β=0.18, t=2.36, p=0.02) and post-intervention phase (β=0.22, t=2.67, p=0.01) when compared to pre-intervention. Table 3 provides parameter estimates. The main effects are not discussed since

there are significant interactions (see Table 3). The differences in phases indicate that as participants engaged in the MBI, they developed introspection into their conscious state. Further, participants' level of introspection continued in post-intervention phase (see *Figure 1*).

To answer the second research question, are there demographic factors (sex, ethnicity, and SES) that influence how a MBI effects high school students level of introspection, we assessed the relationship between self-reported percentage of time calm and NFB scores by phase, controlling for demographic predictors. Table 2 provides the descriptive statistics for overall NFB and SR scores by sex and for each phase. Interestingly, both male and female average NFB scores decreased across phases, while SR scores saw a peak in average score during the intervention phase. Average male SR scores without the intervention were the lowest averages, however shared similar averages to the NFB score during the intervention phase. Pearson's correlation indicated there is a significant correlation for females between SR scores and NFB scores in intervention (r=0.36, p<0.001) and in post-intervention (r=0.46, p<0.001). According to Cohen (1988, 1992) these significant correlations varied between .3 and .5 indicating a medium to medium-large effect sizes. There are no significant correlations for Males between SR and NFB scores overall, for the pre-intervention, intervention, or post-intervention phases. The results found a significant interaction effect between sex and SR scores on NFB scores overall, $F(1, 407)=5.05$, p=0.025, but there was not a significant three-way interaction between sex, phase, and SR scores on NFB scores. Parameter estimates indicated significant effects between female SR scores and male SR scores on NFB scores (β=0.17, t=2.25, p=0.03). Looking at the overall study without phase differences, females had increased introspection compared to males (see Figure 1).

Discussion

Regarding the first research question, results indicated participating in the MBI did increase adolescents' level of introspection. Initially, participants showed a lack of introspection as evidenced by low correlation between SR percentage of time calm and NFB scores. However,

statistically significant correlations and medium effect sizes between SR percentage of time calm and NFB scores during the intervention phase and post-intervention phase indicated increased levels of introspection for the entire sample during and after participation in the MBI. Our findings suggest that the MBI implemented in this study, using integration of a mindfulness program facilitated by guided meditations and neurofeedback, does support the development of introspection, a key element in the ability to be mindful and provide accurate self-report.

These results align with previous research identifying the development of awareness of affective states through introspection as a core skill taught and practiced through mindfulness (Kabat-Zinn, 2003; Kiken et al., 2015). Current results are also consistent with prior research that used self-reported and observed data to suggest MBIs improve introspection. For example, Baird et al. (2014) found that participants in a two-week meditation program experienced enhanced introspection accuracy as measured by metacognitive judgments of cognition for memory, compared to a control group. Additionally, Fox et al. (2012) found that participants in a body-scan meditation program increased introspection accuracy when comparing subjective reports of tactile sensory sensitivity to objective measures of sensitivity using psychophysical and cortical measures. Based on the current findings and previous research, it appears that MBIs do increase high school students' introspection.

Regarding the second research question, results indicated an overall difference between males and females, with female participants showing higher levels of introspection than males. Female participants showed a statistically significant increase in introspection after the MBI was introduced and post-intervention. Further, female participants had statistically significant correlations with medium to medium-large effect sizes between SR percentage of time calm and NFB scores overall, during the intervention phase, and post-intervention, indicating increased introspection. There were no statistically significant differences between phases and no statistically significant correlations between SR percentage of time calm and NFB scores for males. Overall, female participants showed greater introspection than males. There were no

statistically significant differences in introspection based on ethnicity or SES.

These findings are consistent with prior research demonstrating sex differences related to school based MBIs (Kang et al.; 2018; Rojiani et al. 2017). When examining the effects of a 12-week university-based meditation training course on college students' affect, mindfulness, and self-compassion, Rojiani et al.(2017) found that females were more responsive to the school-based MBI as evidenced by greater decreases in negative affect, and greater increases in mindfulness measures, and self-compassion scales. Kang et al. (2018) also found that a school based MBI had greater positive effects for female participants.

A potential explanation for the apparent discrepancy in female versus male introspection ability is the difference in prefrontal cortex development. Specifically, Fleming et al. (2010) found a correlation between introspective ability and prefrontal cortex development. Other neuroscience research has demonstrated sex differences in prefrontal cortex development (Shaw et al., 2019), putting females at an advantage for intrapersonal tasks such as introspection.

The lack of significant differences in introspection based on ethnicity or SES is consistent with previous research that has found MBI to be helpful regardless of ethnicity or SES. For example, Bluth et al. (2016) found ethnically diverse at-risk students who engaged in a weekly school-based mindfulness program during one semester was effective on improving participant outcomes regardless of ethnic background. In addition Fung et al. (2019) found that students who participated in a 12-week school-based mindfulness intervention was beneficial for low-income ethnic minority adolescents.

Limitations

A major limitation of this study is the lack of consensus of a reliable or objective measure of mindfulness. As a result, researchers have been encouraged to creatively explore ways to objectively measure mindfulness concepts (i.e., NFB devices). However, the use of a consumer grade NFB device is novel and requires further exploration as a tool to measure mindfulness (Hunkin et al., 2021; Krigolson et al., 2017; Ratti et al., 2017; Segawa, 2019). The use of a

consumer grade NFB device has its own limitations of inability to control or monitor raw EEG, filtered brainwave activity, and the thresholds due to manufacturer proprietary rights. Another potential limitation of this study relates to common factors known to disrupt NFB device readings (i.e., connectivity issues, problems with contact between skin and EEG reference sensors, and hardware/software failure). However, the research team took steps to ensure the accuracy of NFB data by following manufacturer directives and requiring the documentation of major disruptions (none were recorded). Finally, despite having many observations, the small sample size of participants potentially limited the analysis, results, and generalizability of the study.

Implications for Practice

Overall, the results of this study support the use of MBIs to promote introspection in adolescents, especially females. More specifically, the MBI using an NFB device supports the development of introspection and mindfulness. Thus, practitioners should consider using MBIs with NFB devices when working with adolescents to promote mindfulness and potentially foster prefrontal cortex development. Because results indicated that females experienced higher levels of introspection using the MBI and NFB device, practitioners should consider using this intervention particularly with this population. Further, results indicate that this intervention could help female students develop introspection, though more research is needed. While the results did not show a statistically significant increase, data did suggest that the MBI was minimally effective for promoting introspection in males. Thus, practitioners might consider using MBI and NFB devices when working with adolescent males. This study also lends support to the use of NFB devices with adolescents to promote mindfulness in a time efficient manner based upon the positive relationship between NFB and SR scores. The NFB device and MBI used in this study took 5 minutes, three times a week to implement; 45 minutes less than a typical 60-minute counseling session.

The results support the use of MBI's using a consumer grade NFB device within a school

setting. Although the focus of the present study was to further understand adolescents' introspection ability, it is important to note that participants reported an increased sense of calm and self-regulation during heightened arousal states while participating in and after the MBI. Thus, MBIs using an NFB device appear to be promising efficient and effective tools for school counselors to address the mental health needs of their students. The potential to increase mindfulness skills such as introspection in as little as 5 minutes, three times per week, causing minimal academic interruption, and requiring little oversite from school counselors is a promising intervention which may have broad application and utility for students.

Finally, results suggest practitioners could use the NFB headband from this study to address anxiety and monitor therapeutic progress. For example, increased introspection should allow clients to more accurately appraise their conscious states and aid them in interrupting the anxiety feedback loop. As they learn to interrupt that feedback loop, using mindfulness skills and NFB, their ability to self-regulate should increase, decreasing maladaptive elevated emotional states. Increasing introspection should lead to more accurate self-report of intrapersonal emotional states, allowing practitioners to understand the efficacy (or lack of) of the counseling process. Finally, based on the high correlations between self-report and NFB scores, practitioners might be able to use NFB output, in association with client self-report, to track therapeutic progress. As promising as using an NFB headband in practice may be, practitioners interested in utilizing NFB devices are strongly encouraged to follow the Biofeedback Certification International Alliance (BCIA) Professional Standards and Ethical Principles and become BCIA certified or collaborate with a clinician certified in neurofeedback.

Implications for Research

Future research should compare different consumer grade and non-consumer grade NFB devices to enhance the validity and application of devices in practice and research. Additional research could also explore the effects of specific MBI guided practices (i.e. breathwork, body awareness, cognitive awareness, visualization). Further considerations of sex

differences such as males engaging increased time during the intervention is also warranted. While the current study considered variables such as race, ethnicity, and SES, results and previous literature (Felver et al., 2016; Pina et al., 2019) suggest the need for further exploration. Finally, self-report measures have been identified as a limitation in the study of consciousness, specifically for mindfulness (Baer, 2019; Baird et al., 2014; Fox et al., 2012). Social science research relies on self-report measures to gather data from individuals (Baer, 2019; Young, 2013) and it is often the most convenient means to study consciousness, despite self-report measures potentially being problematic for several reasons such as participants providing socially desirable answers (Krumpal, 2013) and intentional and/or unintentional inaccuracies due to lack of introspection (Baer, 2019). Statistically significant correlations between self-report and NFB scores in the current study provide evidence of the accuracy of self-reported data, specifically related to mindfulness, thus supporting its potential utility for future research. However, additional research is needed to support the use of NFB devices for augmenting, improving, and expanding upon self-report data in mindfulness research.

Conclusion

The purpose of this study was to explore the effects of a MBI on adolescent introspection by comparing SR percentage of time calm to observational data in the form of NFB scores collected during a multiphase MBI. Understanding this relationship provides insight into adolescent introspection, a key element in mindfulness and the ability to increase one's awareness towards conscious states. Additionally, we attempted to identify factors leading to increased introspection. Results support the research hypotheses that participation in an MBI using an NFB device increases introspection, a key factor in accurate self-report. Participants appeared to improve their introspection ability as indicated by statistically significant correlations between SR percentage of time calm and NFB scores during and after engaging in the MBI. Only female participants demonstrated increased levels of introspection as evidenced by statistically significant increases in introspection during and after participating in the MBI.

Statistically significant correlations between overall SR percentage of time calm and NFB scores were observed during and after the MBI. Consistent with previous research, results of this study support the use of MBIs to foster introspection. Lastly, it appears the MBI and NFB device are useful for working with adolescents, particularly females, to increase mindfulness and monitor progress.

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Field Code Changed

Table 1

Descriptive Statistics for NFB and SR scores

	NFB		SR			
	M	SD	M	SD	*r*	*p*
Overall	41.28	26.17	46.19	28.54	0.18	<0.001
Pre-	48.27	25.39	41.37	29.24	-0.02	0.85
Intervention	41.08	26.87	49.60	27.82	0.26	<0.001
Post-	34.64	24.07	45.27	28.51	0.33	<0.001

Note: r represents the correlation between SR and NFB scores for each phase.

Table 2

Descriptive Statistics for NFB and SR scores based on Sex

	Male				Female				Male		Female	
	NFB		SR		NFB		SR					
	M	SD	M	SD	M	SD	M	SD	*r*	*p*	*r*	*p*
Overall	44.39	25.01	40.60	26.76	39.33	26.73	49.72	29.11	0.01	0.94	0.31	<0.001
Pre-	55.00	24.49	37.44	27.45	44.07	25.2	43.86	30.24	-0.22	0.15	0.13	0.28
Intervention	43.75	25.55	44.39	26.73	39.39	27.65	52.92	28.11	0.12	0.32	0.36	<0.001
Post-	34.85	20.59	37.27	25.83	34.51	26.14	50.23	29.13	0.06	0.68	0.46	<0.001

Note: r represents the correlation between SR and NFB scores for each phase by sex.

Table 3

Parameter Estimates for Effects

Effect	Phase	β	Standard Error	DF	*t*	*p*
Intercept		38.84	7.85	11	4.95	<0.01
SR score		0.16	0.06	407	2.50	0.01
Phase	Int	-17.40	3.91	24	-4.45	<0.01
Phase	Post	-23.99	4.27	24	-5.61	<0.01
SR * Phase	Int	0.17	0.07	407	2.36	0.02
SR * Phase	Post	0.22	0.08	407	2.67	<0.01
SR * Sex		0.17	0.08	407	2.25	0.03

Note: Estimates are in comparison to Pre-Intervention and Female scores

Figure 1

Differences in participants self-reported scores on NFB scores by sex and by phase