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ORIGINAL ARTICLE

Older and Wiser? Age-related Change in State and Trait Boredom During Adolescence and Associations with Neural Correlates of Self-regulation

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Abstract

Purpose The purpose of the current study was to examine age-related change in state and trait boredom in 12- to 17-year-old adolescents and test whether neurophysiological correlates of self-regulation relate to boredom during adolescence in the same way that has been found in adults.

Methods Eighty-nine 12- to 17-year-old adolescents participated. Three types of trait boredom were measured: boredom proneness, leisure boredom, and boredom susceptibility. State boredom was also measured after completing a boredom induction task while EEG was recorded. Slopes in frontal alpha asymmetry (FAA) were extracted from the EEG as a measure of approach (leftward shifts) or avoidance (rightward shifts).

Results A curvilinear relationship between age and boredom proneness and age and boredom susceptibility was observed, indicating trait boredom rises and falls across adolescence. State boredom, by contrast, increased linearly with age. Slopes in FAA inversely related only to boredom proneness, indicating higher levels of this type of trait boredom related to an avoidant response as a state of boredom ensues.

Conclusion We suggest the rise and fall of trait boredom across adolescence may be due to changes in person-environment fit during middle adolescence, whereas state boredom may increase with age due to improvements in attentional processes that mundane lab tasks do not satisfactorily engage. The link between FAA and only one type of trait boredom indicates self-regulatory processes and boredom are not yet strongly coupled in adolescence. Implications for prevention of negative behavioral health outcomes associated with high levels of trait boredom are discussed.

Keywords Trait Boredom · State Boredom · Adolescence · Frontal Alpha Asymmetry · EEG

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Boredom is common in daily life and is often situationally induced, such as when completing tasks that are under-stimulating or perceived as meaningless (e.g., Chin et al., 2017). Boredom can increase financial risk taking (Miao et al., 2019), consumption of unhealthy foods (Moynihan et al., 2015), or substance use (Weybright et al., 2015). Adolescents may be at especially high risk for engaging in such unhealthy behaviors when bored due to developmental changes resulting in greater frequency of experiencing and difficulty navigating feelings of boredom (Biolcati et al., 2018; Caldwell et al., 1999). Unfortunately, these challenges may be getting worse. Recent evidence indicates adolescents are increasingly experiencing boredom more often (Weybright et al., 2020). Given this historical trend and potential for negative outcomes, it is important to understand how boredom operates during this developmental stage. In the current study, we examined age-related change in two main types of boredom – state and trait – in 12- to 17-year-old adolescents and asked whether neurophysiological correlates of self-regulation relate to boredom during adolescence in the same way that has been found in adults.

State Boredom

State boredom has been defined as wanting but being unable to engage in a satisfactory activity (Eastwood et al., 2012) and is associated with feelings of constraint, displeasure, frustration, disinterest, and dissatisfaction (Vogel-Walcutt et al., 2012). Even momentary experiences of boredom can increase feelings of meaninglessness and reduce motivation (van Tilburg & Igou, 2011; Vogel-Walcutt et al., 2012). Most theories of boredom posit it arises from a mismatch between the need for engagement and the stimulation present in the environment. For example, Westgate and Wilson (2018) proposed the Meaning and Attention Components model which posits boredom emerges when completing tasks that are perceived as meaningless or are attentionally understimulating or overstimulating. The Boredom Feedback Model emphasizes the underlying processes by which boredom is mitigated (Tam et al., 2021). The model posits boredom signals a need to redirect attention to internal and external sources until boredom is mitigated. Opportunity costs models view boredom as a hedonic signal to engage in another activity. The focal point of these models is value of attentional resources and their relative cost of using them for the activity at hand or another activity (Kurzban et al., 2013; Wojtowicz et al., 2020).

The majority (>90%) of adolescents have experienced state boredom at some point in their lives (Chin et al., 2017). In a typical day, adolescents are bored 30–40% of the time, (Barnett et al., 2011; Larson & Richards, 1991), although current studies are needed to understand modern adolescents. State boredom is most often studied via self-report following completion of a lab-based task designed to induce boredom but has not been studied in this way during adolescence. We asked adolescents to complete the peg turning task which requires participants to repeatedly turn a virtual circle a quarter-turn at a time for several minutes. This task was rated by adults as the most boring among a battery of tasks (Markey et al., 2014). There are several reasons to expect age-related increases in boredom under these conditions. With age, attentional control (Zelazo et al., 2013) and processing speed (Kail & Ferrer, 2007) increase. These improved abilities may make completing the task less engaging with age and result in more boredom. Lab-based tasks designed to induce boredom also constrain autonomy. People experience more boredom in environments that constrain autonomy (Chin et al., 2017). With age, adolescents have increasingly more autonomy (Wray-Lake et al., 2010) and being asked to complete mundane tasks may exacerbate feelings with boredom.

Trait Boredom

Trait boredom has been studied more extensively than state boredom during adolescence. Two types of trait boredom have been studied – boredom proneness, which refers to how frequently people experience boredom (Farmer & Sundberg, 1986), and boredom susceptibility, which refers to aversion to lack of novelty (Zuckerman, 1994). These two types of trait boredom are associated with distinct behavioral profiles. Boredom proneness is associated with anxiety and depression (Mercer-Lynn et al., 2011), whereas boredom susceptibility is associated with risk behaviors, such as gambling (Biolcati et al., 2018; Mercer-Lynn et al., 2011; Blaszczynski et al., 1990; Dahlen et al., 2005). Boredom proneness in adolescents has been associated with a host of negative outcomes, including substance use (Biolcati et al., 2018; Weybright et al., 2015), risky sexual behavior (Miller et al., 2014), delinquency (Spaeth et al., 2015), and poor academic performance (Martz et al., 2018). Moreover, trait boredom during adolescence is on the rise. A nationally representative sample of 14-, 16-, and 18-year-olds (8th, 10th, and 12th grade, respectively) indicated historical increases in trait boredom from 2010 to 2017 for females and 2014 to 2017 for males (Weybright et al., 2020). When looking at changes in trait boredom across development, few studies exist and those that have often look at a limited phase of adolescence and use different measures. A longitudinal study of early 10- to 14-year-old adolescents found modest linear growth in leisure boredom, which is one type of boredom proneness experienced specifically during leisure (Spaeth et al., 2015). A nationally representative longitudinal panel study found boredom proneness was highest among 14- and 16-year-olds and afterwards declined up to 24-years-old, the oldest age group studied (Schulenberg et al., 2012). Analysis of this same nationally representative panel study (although using different timepoints) found trait boredom decreased from 8th to 12th grade for females but increased in 10th grade for males (Weybright et al., 2020). Thus, when we look across these studies, we might expect trait boredom to rise and fall across the 12- to 17-year-old adolescents studied herein.

Neural Correlates of Boredom

Individual differences in trait boredom have been linked to individual differences in motivation and emotion regulatory processes. Boredom susceptibility and boredom proneness are thought to reflect biases toward the Behavioral Activation System (BAS) and Behavioral Inhibition System (BIS), respectively, as described in Gray's original Reinforcement Sensitivity Theory (RST; for a review, see Pickering & Corr, 2008). In the original RST, the BAS is responsible for approach toward appetitive stimuli and reward, and the BIS is responsible for avoidance and withdraw from aversive stimuli. Mercer-Lynn et al. (2014) showed higher levels of boredom proneness and higher levels of boredom susceptibility were differentially related to self-report measures of the original formulation of the BIS and BAS, respectively. In the revised RST, the BIS is conceptualized as monitoring and resolving approach and avoidance conflicts by directing behavior toward or away from a stimulus (Gray & McNaughton, 2000; Pickering & Corr, 2008).

Frontal Alpha Asymmetry (FAA) is a neural correlate of BIS and BAS activity that has been studied in the electroencephalogram (EEG). FAA is a measure of relative levels of alpha activity (8–13 Hz) in the EEG placed over left and right regions of prefrontal cortex. FAA has generally been interpreted within the approach-avoidance model (Allen et al., 2018). More relative left frontal alpha activity relates to a positive affective disposition and approach-oriented behavioral tendencies, whereas more relative right frontal alpha activity relates to a negative affective disposition and avoidance-oriented behavioral tendencies (Harmon-Jones & Allen, 1997; Tomarken et al., 1990). Relative levels of left and right alpha activity may reflect use or intention to act in approach-oriented or avoidance-oriented way (Hewig, 2018). Lateralization of frontal alpha activity has also been viewed as reflecting online regulatory or motivational processes and has been shown to shift rightward under conditions that induce more stress (Light et al., 2009; Perone et al., 2021; Zhang et al., 2018). The degree to which frontal alpha activity shifts rightward has been proposed to reflect the BIS managing conflict between approach (e.g., the need to complete a task) and avoidance (e.g., a desire to withdraw and engage in another activity; Gable et al., 2018). In the current study, we conceptualize the degree to which frontal alpha activity shifts right as an indicator of self-regulation over increaseing conflict between approach and avoidance.

Perone et al. (2019) tested whether trait boredom was associated with FAA while adults completed the peg turning task. They found higher levels of boredom proneness and leisure boredom, but not boredom susceptibility, were associated with a rightward shift in frontal alpha activity over the course of the task. This pattern of results is consistent with the capability model proposed by Coan et al. (2006) which posits people bring a capacity to regulate to a specific task context. By this view, people low in trait boredom are better able to match their response to the demands of the task, using approach to cope with the mundane experience. People high in trait boredom, by contrast, may experience more stress due to conflict between approach and desire to withdraw. We tested whether this link between self-regulation and trait boredom is already present during adolescence. On the one hand, trait boredom may reflect a chronic inability to effectively resolve a state boredom (Elpidorou, 2018; Tam et al., 2021) which should be reflected in how adolescents self-regulate during a task designed to induce boredom. On the other hand, boredom is undergoing change during adolescence (Spaeth et al., 2015) and such patterns of response to understimulating conditions may not have yet been established.

The Current Study

The goal of the current study was to add to our understanding of boredom during adolescence by addressing three specific areas. First, we examined age-related change in state boredom in 12- to 17-year-old adolescents following completion of the peg turning task. To our knowledge, no prior study has investigated state boredom across adolescence in the same lab-based task. Boredom is higher in contexts that are understimulating or constrain autonomy (Chin et al., 2017). With age, adolescents exhibit improved attentional control (Zelazo et al., 2013), faster processing speed (Kail & Ferrer, 2007), and have increasingly more autonomy (Wray-Lake et al., 2010), all of which should be expected to result in more state boredom during peg turning with age. Second, we examined age-related change in trait boredom. Prior studies indicate boredom rises early in adolescence (Spaeth et al., 2015) and declines later in adolescence into adulthood (Schulenberg et al., 2012), suggesting boredom may follow an inverted u-shaped path with age. A novel contribution of our study is we measured multiple types of trait boredom (including boredom proneness, leisure boredom, and boredom susceptibility) to determine if an inverted u-shape pattern is observed and, if so, is it observed for multiple types of trait boredom. How people respond to boredom has been hypothesized to involve learning (Tam et al., 2021). If trait boredom is changing over the course of adolescence, it is possible strong links between trait boredom and the response to boredom have not yet been established. Prior studies with adults have shown high levels of trait boredom relate to a physiological response consistent with high levels of stress due to conflict between approach and a desire to withdraw, measured via FAA. The third aim of the current study is to test whether this same link has already been established in adolescence.

Method

Participants Eighty-nine 12- to 17-year-old adolescents participated in this study. There were 24 12-year-olds (M=12.42 years, SD=0.31 years, 11 females), 19 13-year-olds (M=13.49 years, SD=0.31 years, 10 females), 14 14-year-olds (M=14.61 years, SD=0.30 years, 5 females), 12 15-year-olds (M=15.35 years, SD=0.29 years, 7 females), 10 16-year-olds (M=16.51 years, SD=0.28 years, 4 females), and 10 17-year-olds (M=17.54 years, SD=0.29 years, 6 females). Race and ethnicity were not reported for three participants. The remaining participants were identified as White (83.91%), multiracial (10.34%), Asian (2.30%), Native American / Native Alaskan (2.30%), or another race (1.15%), and 9.20% were Hispanic. The annual income of four families was not reported. More than 50% of the remaining families reported annual household income greater than $75,000. Five participants did not contribute EEG due to equipment failure (n=1), their head was too large for available EEG caps (n=1), excessive noise (n=1), or they chose not to wear the EEG cap (n=2). A few participants skipped some questionnaires used to measure boredom. Table 1 provides the sample size for all the measures. Data were collected prior to the COVID-19 pandemic between May 2018 and November 2019.

Table 1 Sample Size by Measure

Leisure Boredom	Boredom Proneness	Boredom Susceptibility	State Boredom	EEG
89	87	88	89	84

Design and Procedure Participants visited the lab for two sessions taking place within two weeks of each other. On the first visit, participants completed the trait boredom scales. On the second visit, participants completed the peg turning task while EEG was acquired and reported on their state boredom immediately thereafter.

Trait Boredom Measures of boredom proneness and boredom susceptibility were obtained. Boredom proneness was measured using the Boredom Proneness Scale (Farmer & Sundberg, 1986) which captures the tendency to experience boredom in daily life. The scale consists of 28 items with responses reported on a 5-point Likert scale from strongly disagree to strongly agree (e.g., "Many things I have to do are repetitive and monotonous," I often find myself with nothing to do, time on my hands."). Reliability reported in other studies has been good (α=0.79-0.90; Vondanovich & Watt, 2016; current study, α=0.76).

Boredom proneness during leisure was measured using the Leisure Experience Battery for Adolescents (Caldwell, Smith, & Wessinger, 1992) which construes boredom as cognitively unsatisfying and engaged in meaningless activity. Responses to 4 items are recorded on a 5-point Likert scale from strongly agree to disagree (e.g., For me, free time drags on and on"). Reliability has been acceptable in prior studies (α=0.68-0.73; Barnett, 2005; current study, α=0.70).

Boredom susceptibility was measured using the Boredom Susceptibility Scale, a subscale of Zuckerman's Sensation Seeking Scale (Zuckerman, 1994) which construes boredom as a lack of novelty. This is measured across 10 items using a forced choice format, such as (a) "I dislike people who do or say anything just to shock or upset others" or (b) "When you can predict almost everything a person will do and so, he or she is just a bore." Reliability on the BSS has been consistently low in prior studies (α=0.38-0.65; Gerristen, Toplak, Sciaraffa, & Eastwood, 2014; Perone et al., 2019; Vondanovich & Watt, 2016; current study, α=0.47). Removing items had little impact on reliability. Prior studies have shown the BSS uniquely relates to behavior and neural activity, and so we included it here (Mercer-Lynn et al., 2011; Perone et al., 2019). The mean response for all scales were used in analyses.

Peg Turning and EEG Acquisition The peg turning task requires participants to turn a peg one-quarter at a time before moving on to the next peg (Festinger & Carlsmith, 1959; Markey et al., 2014; Perone et al., 2019). The task was programmed in E-Prime 2.0. Participants were presented with a 2×4 grid of virtual pegs. One peg was illuminated with an arrow pointing upward to indicate the peg's position. Participants pushed a button on a Chronos box to rotate the illuminated peg one-quarter turn at a time. Following each click there was a 1,000–1,500 ms random jitter before the peg rotated. Participants were informed clicking prior to the rotation would have no effect. Once the peg had been fully rotated, the next peg was illuminated. Participants continued to rotate pegs across 10 blocks consisting of 32 rotations each (8 pegs x 4 rotations each). The task required 9.61 min to complete on average (*SD*=0.87 min).

Prior to the peg turning task, participants were fitted with a 128-channel Hydrocel net manufactured by Electrical Geodesics, Inc. Impedances were typically set below 50 kΩ but impedances up to 100 kΩ were accepted. The EEG was monitored visually prior to the task and electrodes were adjusted as necessary. The EEG was recorded at 1,000 Hz and high-pass filtered at 0.1 Hz and referenced to Cz online.

State Boredom State boredom was measured following the peg turning task. Participants were asked to answer the first seven items from the Multi-dimensional State Boredom Scale (Fahlman et al., 2013) immediately following the peg turning task (Markey et al., 2014; Perone et al., 2019). The seven items were: Time was passing by slower than usual", "I was stuck in a situation that I felt was irrelevant", "I wish time would go by faster", "Everything seemed repetitive and routine to me", "I felt bored", "I wished I were doing something more exciting." Responses were recorded on a 7-point Likert scale ranging from strongly disagree to strongly agree. Reliability was good (α=0.86). Mean scores were used in analyses.

EEG Preprocessing The EEG was processed in Matlab using functions from EEGLab (Delorme & Makeig, 2004), ERPLab (Lopez-Calderon & Luck, 2014), FieldTrip (Oostenveld et al., 2011), and the CSD toolbox (Kayser & Tenke, 2006). The continuous EEG was resampled at 500 Hz and a high-pass filtered at 1 Hz and a 60 Hz notch-filter was applied. Eye-blinks were corrected using Independent Components Analysis (ICA). Excessively noisy electrodes were eliminated prior to ICA and interpolated using the corrected EEG. The EEG was Laplacian transformed using the CSD toolbox (Kayser & Tenke, 2006) with default parameters (m=4, head radius=10, lambda=0.00001). This transformation increases topographical localization and reduces the contribution of cortical activity from more distant sources to that recorded at frontal sites used in the analyses (Allen et al., 2018).

The continuous EEG was divided into 1 s epochs with 75% overlap. Fast Fourier Transformation (FFT) was applied to artifact free epochs and power in the 8–13 Hz alpha range was extracted. Our analyses were based on change in FAA across the peg turning task obtained from computing FAA across four blocks. The total number of epochs for each participant was divided into four blocks of equal length. The average total number of epochs processed for block 1 was 538.92 (*SD*=57.95), block 2 was 525.36 (*SD*=66.74), block 3 was 521.19 (*SD*=63.03), and block 4 was 507.76 (*SD*=73.88). Average FAA was computed during each block by subtracting the natural log of average absolute alpha at left site F3 from the same activity at right frontal site F4. Lower levels of alpha activity reflect more activation, whereas higher levels reflect more inhibition (Klimesch et al., 2007). Thus, lower levels of FAA reflect relatively more right frontal activity. To test whether the results were specific to alpha activity recorded at frontal sites, we also computed posterior alpha asymmetry in the same way using sites P3 and P4.

Table 2 Descriptive Statistics

Leisure Boredom	Boredom Proneness	Boredom Susceptibility	State Boredom	F4/F3 Slope
2.23 (0.63)	2.67 (0.37)	0.23 (0.17)	5.01 (1.13)	–0.02 (0.05)

Table 3 Bivariate Correlations Among Age, Trait, and State Boredom

	Age	Boredom Proneness	Boredom Susceptibility	Leisure Boredom
Age				
Boredom Proneness	0.174			
Boredom Susceptibility	0.104	0.307**		
Leisure Boredom	0.061	0.522**	0.191	
State Boredom	0.240*	0.167	0.191	0.109

EEG Analyses The goal of the EEG analyses was to test whether trait boredom correlated with change in FAA over the course of the peg turning task (Perone et al., 2019). We used Regression Coefficient Analysis (Pfister et al., 2013) to estimate change in FAA by regressing FAA scores onto block (1–4) to obtain a FAA slope for each participant. We then tested whether the slopes correlated with trait boredom.

Results

The results are presented in two sections. In the first section, we present analyses examining relations among trait boredom, state boredom, and age. In the second section, we present results testing whether change in FAA relates to trait boredom in our adolescent sample. Table 2 presents descriptive statistics for all variables used in analyses.

Trait and State Boredom Our first set of analyses examined age-related change in state and trait boredom. Table 3 shows bivariate correlations among trait boredom, state boredom, and age. No correlations between age and trait boredom were observed. However, visual inspection of scatterplots depicting relations between trait boredom and age suggested a curvilinear trend might be present. These relations are shown in Fig. 1. To test this possibility, we conducted a series of quadratic regressions with each trait boredom scale as the dependent measure and age and age^2 as predictors. Results are shown in Tables 4, 5 and 6. The models were significant for the boredom proneness scale ($R^2=0.131$, $p=.003$; Table 3) and the boredom susceptibility scale ($R^2=0.120$, $p=.004$; Table 4), indicating a curvilinear trend is present. The model for leisure boredom ($R^2=0.052$, $p=.098$; Table 5) was not significant. A significant positive correlation between state boredom and age was observed, $r=.240$, $p=.024$, indicating with age adolescents report experiencing more boredom during the peg turning task. Trait and state boredom were unrelated (all $ps>0.05$).

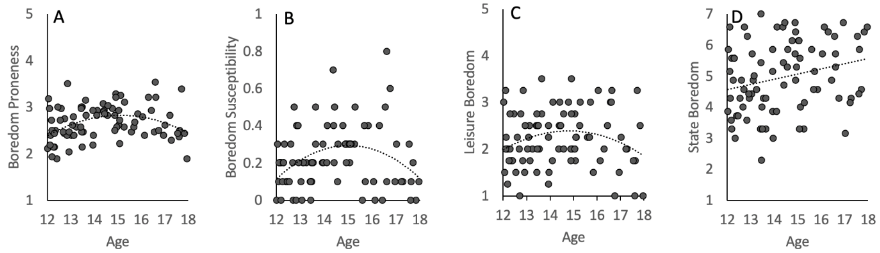

Fig. 1 Relations between age and boredom proneness (**1A**), boredom susceptibility (**1B**), leisure boredom (**1C**), and state boredom (**1D**)

Table 4 Predicting Boredom Proneness from Age

Predictors	R^2	*F*	*p*	Constant	beta	β	*p*
Age	0.131	6.346	0.003	–6.68	1.249	6.056	0.002
Age^2					–0.041	–5.891	0.002

Table 5 Predicting Boredom Susceptibility from Age

Predictors	R^2	*F*	*p*	Constant	beta	β	*p*
Age	0.12	5.782	0.004	–4.086	0.584	6.185	0.001
Age^2					–0.019	–6.09	0.002

Table 6 Predicting Leisure Boredom from Age

Predictors	R^2	*F*	*p*	Constant	beta	β	*p*
Age	0.052	2.381	0.098	–8.628	1.469	4.116	0.038
Age^2					–0.049	–4.061	0.036

Frontal Alpha Asymmetry Our second set of analyses tested whether trait boredom relates to change in FAA over the course of the peg turning task. Preliminary analyses showed no significant relations between age and slopes or intercepts for FAA or PAA were observed (all $ps > 0.10$). For analyses involving the boredom proneness scale and boredom susceptibility scale, semi-partial correlations controlling for the quadratic effect of age on trait boredom were used. The results revealed slopes in FAA were inversely related to the boredom proneness scale, $sr = -0.240$, $p = .03$, indicating higher levels of boredom proneness related to a rightward shift in FAA over the course of the peg turning task. Figure 2 shows a scatter plot depicting the relationship between slopes for FAA and the boredom proneness scale. No relations between FAA and boredom susceptibility or state boredom were observed (all $ps > 0.10$). No relations with trait or state boredom and PAA were observed (all $ps > 0.05$).

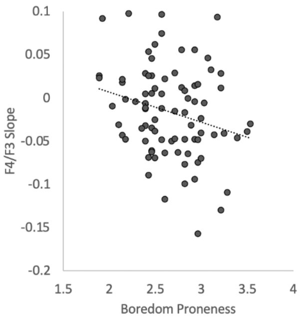

Fig. 2 Relation between FAA and boredom proneness

General Discussion

The current study examined age-related change in state and trait boredom in 12- to 17-year-old adolescents and asked whether neurophysiological correlates of self-regulation relate to boredom during adolescence in the same way that has been found in adults. There were two important age-related findings. First, we found state boredom during the peg turning task increased with age. Second, we found an inverted u-shaped relationship between age and boredom proneness and boredom susceptibility. Leisure boredom was not significantly related to age. Like adults, we found higher levels of boredom proneness related to a rightward shift in frontal alpha activity over the course of the peg turning task. Unlike adults, however, no relations between FAA and leisure boredom were observed.

One novel contribution of the current study is we measured state boredom in the same lab-based task across adolescence. Based on the MAC model (Westgate & Wilson, 2018), tasks such as peg turning induce high levels of boredom because they are under-stimulating and not attentionally engaging. Our observation that state boredom increased with age may be due to several factors, including improved attentional control (Zelazo et al., 2013), processing speed (Kail & Ferrer, 2007), or desire lack of autonomy older adolescences normally experience (Wray-Lake et al., 2010) than constrained lab tasks provide. This observation has methodological and real world implications. With age, adolescents may experience more boredom in studies that use the same task conditions which could, in turn, impact their performance (Bieleke et al., 2021). Also with age, the tasks adolescents are asked to complete in the home or classroom may need to be designed in a way that are increasingly more challenging to mitigate boredom and promote engagement. Given the lack of research on state boredom in and across adolescence, these findings are a significant contribution to the literature and point to differing developmental changes in state and trait boredom.

Unlike state boredom, we found boredom proneness and boredom susceptibility related to age in a curvilinear fashion. A longitudinal study of 10- to 14-year-old adolescents showed leisure boredom modestly increases from 10 to 14 years of age (Spaeth et al., 2015), and a nationally representative longitudinal panel study found trait boredom was highest among 14- and 16-year-olds and afterwards declined up to 24-years-old (Schulenberg et al., 2012. Together, these findings suggest an inverted u-shape relationship between age and trait boredom. However, these prior studies were with different age groups and used different measures of boredom from each other and from those used herein. One contribution of the current study is we measured trait boredom using three common measures. Similar to some international studies (e.g., Sharp et al., 2011), leisure boredom was not related to age. The leisure boredom and boredom proneness scales are thought to measure a proneness to boredom but in different contexts. The leisure boredom scale specifically addresses boredom during free time, whereas the boredom proneness scale is less context specific. We know boredom in leisure is often lower than boredom in more constrained contexts, such as school (Chin et al., 2017; Goetz et al., 2013; Larson & Richards, 1991), and therefore may be less sensitive than other general measures during the age group studied here.

There are several possible explanations for the inverted u-shape relationship between age and boredom proneness and boredom susceptibility. First, adolescents' interests shift during middle adolescence just as boredom increases. Interest plays an important role in boredom and has been described as the absence of interest (Hunter et al., 2003). Hoff et al. (2018) completed a meta-analysis of studies on interest across adolescence and found the intensity of interest for several categories (e.g., artistic, social) decreased from ages 11 to 14 before increasing from ages 14 to 18. Second, a shift in interests may result, temporarily, in a poor person-environment fit (Spaeth et al., 2015). For example, it is possible that during middle adolescence, there is poor alignment between youth's shifting interests and opportunities to engage those interests, resulting in boredom (Eccles et al., 1991; Freund et al., 2021). Third, the need for stimulation may increase with age, particularly during early adolescence. Harden and Tucker-Drob (2011) found sensation seeking from 12 to 24 years was best characterized by a curvilinear pattern, rising sharply between 12 and 14 years of age and falling more gradually to age 24. This might mean youth need more stimulation during early adolescence that, if it goes unmet, results in more boredom. With age, adolescents acquire more autonomy (Wray-Lake et al., 2010) and may be able to create environments that are more satisfying and experience boredom less. These possibilities are all speculative. More research is needed, especially longitudinal and mixed method studies to understand how boredom changes within individuals over time while also being informed about adolescent development and changing environments.

We also tested whether FAA relates to trait boredom during adolescence. This is important because it informs us about whether trait boredom relates to how adolescents respond and self-regulate in under-stimulating situations. We found higher levels of boredom proneness modestly related to a more rightward shift in frontal alpha activity. This finding can be interpreted within the capability model proposed by Coan et al. (2006) which posits individuals bring a regulatory capacity to a given situation. By this view, people high in boredom proneness experience increasing more stress and the self-regulatory demands increase as the peg turning task continues. This interpretation is also consistent with the idea relatively greater right frontal alpha activity reflects active self-regulation over conflict between approach (e.g., a need to continue the task) and avoidance (e.g., desire to quit the task; Gable et al., 2018).

We observed FAA relates to boredom proneness but not state boredom. These findings indicate that the more frequently people experience boredom in their daily life, the more likely they are to experience conflict between approach and avoidance in constraining task contexts, such as peg turning. Our findings further indicate that those who experience more conflict during the task as measured via a shift in frontal alpha activity do not necessarily experience more state boredom. Other interpretations of these findings should be considered as well. It is possible participants are not consciously aware of the processes shifts in frontal alpha activity measure. Other studies have shown rightward shifts in frontal alpha activity under stressful do not relate to subjective ratings of stress recorded afterwards (e.g., Zhang et al., 2018). It is also possible our measure of state boredom was not the most sensitive measure of participants' subjective experience during the task. More research is needed to better understand the neural basis of the subjective experience of state boredom.

The Boredom Feedback Model (Tam et al., 2021) can also add to the interpretation of relations between trait boredom and FAA. In the model, learning plays an important role between the feeling of boredom and the redirection of attention. People high in boredom proneness might not have learned effective ways to redirect attention toward an internal or external satisfying activity, particularly under mundane conditions like peg turning. It is notable that we did not find FAA to relate to boredom susceptibility or leisure boredom. Boredom proneness may capture chronic experience of boredom and inability to resolve it across contexts that FAA is more sensitive to, whereas leisure boredom is more context specific to leisure and boredom susceptibility reflects an aversion to lack of novelty. However, relations between leisure boredom and FAA have been observed in adults (Perone et al., 2019) which could indicate the connection between different types of trait boredom and the way people respond to mundane situations becomes more strongly coupled over development. Consistent with this possibility, we found trait and state boredom were unrelated in the current adolescent sample, which are related in adults (Mercer-Lynn et al., 2014; Perone et al., 2019). These findings suggest adolescence is an important window of opportunity to establish healthy patterns of responding to situations that lack optimal levels of stimulation.

In conclusion, the current study adds to our understanding of boredom during adolescence. This is an important period of development to study boredom because adolescents are more prone to experiencing boredom and those who experience boredom are more likely to engage in unhealthy behaviors (Biolcati et al., 2018; Caldwell et al., 1999). Historical rises in trait boredom may amplify these relations (Weybright et al., 2020). It is also an important window of opportunity because this is a period where behavioral health habits are thought to be established (Raphael, 2013). Understanding the mechanisms behind adolescent boredom can inform future intervention efforts to support effective coping. Our findings showed trait boredom varies with age in a curvilinear fashion and thus may be malleable, but more research is needed to understand the underlying sources of the relations. We proposed person-environment fit could play a role. Our findings showed state boredom increases with age, which we suggested may have methodological and real-world implications. Interestingly, the link between self-regulation and trait boredom is present during adolescence, but it is not related to all types of trait boredom as has been observed in other studies with adults. This further raises the possibility adolescence is a critical period to help youth acquire healthy responses to situations that induce boredom.

Author Contribution S.P. designed the study, wrote the main manuscript, prepared the figures, and performed analyses. A.J.A. designed the study, collected the data, processed the data, and commented and edited the manuscript. E.H.W. designed the study and commented and edited the manuscript.

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Data Availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval The study was approved by the Institutional Review Board at Washington State University (approval number #16421).

Consent to participate All participants consented to participate in this study.

Consent to publish The authors of this manuscript herby consent for it to be published.

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