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Preference for digital media use, biobehavioral attention bias, and anxiety symptoms in adolescents

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Abstract

Adolescence is a critical developmental period of biological and social change during which 1 in 3 youth experience significant anxiety symptoms. The social-emotional lives of the majority of adolescents are largely conducted via digital media use (DMU; e.g., social media, text messaging). Yet the past decade of research on DMU and anxiety has yielded mixed results (e.g., Keles et al., 2020 review), leaving the complex role that DMU might play in the emergence and maintenance of anxiety poorly understood. A key step forward is to leverage psychophysiology to identify individual differences in cognitive and emotional processes that confer vulnerability to potential negative effects of DMU. Further, given the ubiquity of DMU, a greater focus is needed on measurements that move beyond sheer frequency to capture DMU in comparison to face-to-face (FTF) social interactions. This study examined attention bias (AB), characterized by selective and exaggerated attention toward or away from threat, as a moderator of the link between DMU and anxiety in adolescents ($N = 75$; 42 female) aged 12–14 years ($M = 13.28$, $SD = 0.87$). AB was indexed during a dot probe task using reaction time metrics (i.e., trial-level bias) and via ERPs capturing attentional selection and discrimination (N170) and cognitive control (N2) to threat compared to neutral faces. AB moderated associations between DMU and anxiety. A greater preference to use DMU vs FTF predicted greater anxiety among those with a greater

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Sarah Myruski: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Jennifer de Rutte:** Writing – review & editing, Writing – original draft, Data curation, Conceptualization. **Abigail Findley:** Writing – review & editing, Writing – original draft, Data curation. **Amy K. Roy:** Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization. **Tracy A. Dennis-Tiwary:** Writing – review & editing, Writing – original draft, Supervision, Resources, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data
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behavioral bias away from threat, blunted N170, and blunted N2 in the presence of threat. Future research should examine potential causal and bidirectional links between DMU and anxiety and explore whether preferences for technology-mediated interactions and individual differences in threat processing increase risk.

Keywords

Digital media; Communication preference; Adolescence; Attention bias; Event-related potentials

1. Preference for digital media use, biobehavioral attention bias, and anxiety symptoms in adolescents

Anxiety disorders are the most common mental illness in the US and affect nearly a third of adolescents aged 13–18 years old (Essau et al., 2018; Kessler et al., 2005; Merikangas et al., 2010). Brain-related changes during adolescence put individuals at increased risk for the onset of anxiety disorders (Somerville et al., 2010; Spielberg et al., 2019), and anxiety in adolescence predicts debilitating anxiety (Beesdo et al., 2009; Essau et al., 2018) and other adverse psychological outcomes [e.g., depression and substance abuse (Essau et al., 2014);] in adulthood. Further, rates of subthreshold levels of anxiety are even higher, reaching more than 40% (Roberts et al., 2015), which represents significant risk for functional impairment in adolescents (Karsten et al., 2013). Thus, it is important to understand how salient contexts of this developmental period relate to adolescent anxiety and its prevention.

1.1. Digital media use

One context of the developmental period of adolescence that has become increasingly relevant in recent decades is digital media use (DMU). Following Steele et al. (2020), DMU refers to the use of technologies (i.e., smartphones, tablets, computers) and platforms (e.g., social media, texting apps, online gaming) that allow for interpersonal communication and/or individual broadcasting. Indeed, 95% of teenagers use a mobile device, with 45% who report being online “almost constantly” (Anderson & Jiang, 2018), and the average adolescent spending over 7 h on screens daily (Rideout & Robb, 2019). DMU serves many purposes in adolescents’ lives, including identity exploration (Middaugh, 2019) and socializing with peers (Nesi et al., 2018; Spies Shapiro & Margolin, 2014), which are essential developmental goals of adolescence (Dahl et al., 2018).

Given that so much of adolescents’ lives are spent online, research has drawn attention to the ways in which DMU might be linked with anxiety. Research suggests that DMU use is associated with higher levels of anxiety in youth (Barry et al., 2017; Keles et al., 2020; Seabrook et al., 2016; Tsitsika et al., 2014; Yan et al., 2017). However, these studies tend to focus on overall trends associating sheer screen time with anxiety, leaving the contexts, goals, and preferences of youth DMU unexplored (Keles et al., 2020; Orben & Przybylski, 2019). Further, this research fails to consider how views of face-to-face (FTF) social-emotional communication may interact in conjunction with DMU. This is an important consideration given that research suggests that those dissatisfied with their in-person social connections may turn to DMU to fulfill their social-emotional goals (Caplan, 2003). Thus, a more promising direction for research on DMU and youth anxiety is to characterize DMU in terms of preferences and beliefs, and to identify underlying processes that might contribute to the detrimental effects of DMU among vulnerable youth.

1.2. Communication preference

The preference to communicate via DMU versus FTF may be an important determinant of how DMU impacts youth. According to the “transformation framework” (Nesi et al., 2018), social interactions via DMU versus in-person are fundamentally different in several ways, including greater asynchronicity and controllability offered by online modalities. Anxious adolescents, or those who are psychosocially distressed or lonely, might prefer communication via DMU because it is perceived as less threatening and more easily accessible compared to FTF interactions (Bargh & McKenna, 2004; Caplan, 2003; Madell & Muncer, 2007). Although communicating online might offer increased access to low-demand social interactions for those with difficulty socializing in person (Chen & Li, 2017; Clark et al., 2018), a preference for online socializing might inadvertently reinforce psychological distress (Caplan, 2003), including depression and loneliness (Stepanikova et al., 2010), and disrupt existing in-person relationships (Kraut et al., 1998; Nie, 2001). Indeed, one study found that clinically anxious individuals reported greater comfort socializing online, but the more frequently they communicated online, the lower their self-reported well-being (Weidman et al., 2012). Therefore, preference to communicate via DMU versus FTF may be an important aspect of DMU to capture when examining the impact of use, especially for anxious youth.

One domain of communication preference salient in DMU is the social-emotional domain. Research suggests that emotional expression (both positive and negative) and support seeking via DMU may have negative consequences given that the social-emotional support received online may not be as immediate (McKenna & Bargh, 2000) and may be lower in quality compared to FTF support (Seltzer et al., 2012). Accordingly, the Social Media Communication Questionnaire (SMCQ; Babkirk et al, 2016) was designed to assess preferences for communicating social-emotional goals such as keeping in touch with friends, seeking emotional support, communicating anger, etc. Indeed, research using this measure revealed that a preference for communicating emotions, both positive and negative, via DMU over FTF was related to greater depressive symptoms, more emotion regulation difficulties, and less satisfaction with social support in daily life (Babkirk et al, 2016; Myruski et al., 2019). The current study uses the SMCQ to test whether overall preferences for conducting social-emotional communication via DMU versus FTF were related to greater anxiety symptoms in a sample of anxious teens.

1.3. Attention bias as a vulnerability factor

The links between DMU preferences and anxiety symptoms might be greater among those with anxiety-related vulnerabilities. The differential susceptibility to media effects model (Piotrowski & Valkenburg, 2015) posits that individual differences in cognitive and affective processes constitute vulnerabilities that act as moderators of DMU effects on well-being. Threat-related attention bias (AB), or selective and exaggerated attention toward or attentional avoidance of threat relative to non-threat information (Bar-Haim et al., 2007;

Hakamata et al., 2010; MacLeod et al., 1986), may be one such vulnerability that warrants investigation as a moderator of the DMU-anxiety link. AB in the presence of threat has been documented across anxiety disorder subtypes among adolescents (Dudeney et al., 2015; Koster et al., 2006; Roy et al., 2015; Waters et al., 2008, 2010), and theoretical frameworks emphasize the need to investigate heterogeneous patterns of dysregulated attentional processing in the presence of threat including threat discrimination and cognitive control (Dennis-Tiwary, Roy et al., 2019). Further, interventions that target AB (i.e., AB modification training) have been shown to be successful in reducing symptoms of anxiety (Hakamata et al., 2010) making AB an important individual difference to examine, with implications for intervention.

AB serves as an attentional filter of social-emotional information which can get tuned and re-tuned by social interactions and affective experiences (e.g., Todd et al., 2012). Anxious individuals may turn to DMU due to fewer threatening social cues and greater controllability and predictability (Bargh & McKenna, 2004; Caplan, 2003; Madell & Muncer, 2007) than face-to-face interactions, which may be further “tuning” their AB processes. Although AB has yet to be tested as a potential moderating factor in the relation between DMU preference and anxiety, other affective processing individual differences have been linked to DMU preference. For example, one study found that youth who reported greater preferences to communicate emotions via DMU, relative to FTF, exhibited more sensitive emotion detection evidenced by faster and more accurate identification of threatening facial expressions in a facial morphing task (Myruski et al., 2020). Further, a study using event-related potentials (ERPs) measured via EEG found that youth who reported greater preference for communicating emotions via technology (versus FTF) showed greater attention capture by emotional images (measured via the N1), and poorer emotion regulation (measured via the late positive potential; (Babkirk et al., 2016). It is possible that individuals with heightened affective processing or sensitivities may be more likely to prefer DMU, as it is a less emotionally demanding or risky form of social interaction (Caplan, 2003; Madell & Muncer, 2007). Problematically, this may lead to worsened distress given previous research and hypotheses outlining the risks of developing a preference for communicating online (Caplan, 2003). Further, individuals with heightened affective processing or sensitivities might be particularly vulnerable to negative effects of DMU given that a pervasive goal of digital media is to capture and modify attention of its users (e.g., via the attention economy; Atchley & Lane, 2014; Bhargava & Velasquez, 2021). Thus, the current study aims to test AB as a vulnerability factor and individual difference that may moderate the relationship between DMU and anxiety symptoms.

To assess affective processing tendencies related to AB, the current study employed scalp-recorded event-related potentials (ERPs). ERPs provide excellent temporal sensitivity (Banaschewski, 2007), and can isolate specific cognitive processes underlying AB (Fox et al., 2001; Thai et al., 2016). Rapid attentional processes in the presence of threat may represent biobehavioral vulnerabilities associated with a preference for the controllability and predictability of DMU versus face-to-face interactions. The current study leveraged two ERPs as biobehavioral AB measures: the N170 and the N2, which we describe in more detail below.

The N170 peaks in amplitude between 150 and 200 ms and occurs over posterior temporal-occipital regions of the scalp (Vogel & Luck, 2000). The N170 reflects visual detection and discrimination in the context of facial processing (Batty & Taylor, 2003; Eimer, 2011; Wronka & Walentowska, 2011) and thus in part underlies early attention selection and facilitates further perceptual processing (Gauthier et al., 2003; Luck et al., 2000). The N170 has been shown to predict anxiety in childhood for those who show enhanced N170 amplitudes to angry versus happy faces (O'Toole et al., 2013). Enhanced N170 is also associated with greater anxiety symptoms and attention bias to threat (Torrence & Troup, 2017; Bechor et al., 2019). However, there is some evidence of blunted N170 to threat in socially anxious individuals (Mueller et al., 2009) which may be due to facial processing being avoided or disrupted among those with fear of negative social evaluation or rejection (Chen et al., 2002; Horley et al., 2004). These social worries may be more salient in FTF contexts and thus may drive motivations to prefer DMU for social-emotional communication. Studies examining other ERPs indexing attentional selection (i.e., N2pc) and suppression (i.e., P_D; during lateral presentation of non-face images) have suggested that anxious individuals may show suppressed neural processing of threat as opposed to enhanced (Kappenman et al., 2021). Regardless, this research suggests individual differences in early attentional selection and discrimination of threat that may underlie development and maintenance of anxiety disorders for some youth.

Emerging later, the N2 peaks in amplitude between 200 and 350 ms and occurs over frontal-midline regions of the scalp. The N2 reflects the recruitment of later-emerging cognitive control capacities that support the strategic control of attention (Folstein & Van Petten, 2008; Van Veen & Carter, 2002). The N2 is larger under conditions in which cognitive control is required (i.e., incongruent flanker displays in a visual flanker task) and during tasks that require inhibition of responses (Kopp et al., 1996; Van Veen & Carter, 2002). The N2 is clearly detectable in the dot-probe task (Eldar & Bar-Haim, 2010; O'Toole & Dennis, 2012) and has been shown to be related to AB in youth, where youth demonstrating a blunted N2 show a greater bias toward threat, whereas those with an elevated N2 demonstrating a bias away from threat (Fu & Pérez-Edgar, 2019; Thai et al., 2016). Together, the N170 and N2 are strong candidate measures of both early and later affective processing tendencies related to anxiety-related disruptions in attention to threat.

1.4. Current study

The current study first aimed to examine associations between DMU and anxiety symptoms among anxious adolescents by measuring preferences for social-emotional communication via DMU versus FTF modalities, rather than simply measuring sheer DMU frequency. This aim is grounded in the theoretical framework that DMU fundamentally transforms social-emotional interactions, making DMU-based communication distinct from FTF (i.e., "transformation framework"; Nesi et al., 2018). Second, the study investigated how individual differences in biobehavioral measures of AB might moderate the negative effects of DMU. Guided by theoretical frameworks from the AB literature (i.e., Dennis-Tiwary et al., 2019) and the differential susceptibility to media effects model (Piotrowski & Valkenburg, 2015), we reasoned that disruptions in threat processing at the level of behavior or neurophysiology might represent a particular vulnerability to negative outcomes of DMU.

Using this multi-method approach, we tested the hypothesis that a DMU preference (versus FTF) will be associated with greater anxiety severity, particularly among adolescents evidencing exaggerated AB. We operationalized DMU as a self-reported preference to use technology versus face-to-face interactions to communicate emotions in the service of social-emotional goals. We used two metrics of biobehavioral AB quantified during the dot probe task: bias toward or away from threat was measured via trial-level reaction time metrics (behavioral); and attentional disruptions in the presence of threat were captured as ERPs (biological) reflecting early attentional selection and discrimination (N170) and cognitive control (N2).

2. Method

2.1. Participants

Participants were recruited from the community and through school guidance counselors and school psychologists at New York City middle schools. Adolescents with parent-reported Multidimensional Anxiety Scale for Children - 2nd Edition (MASC 2; March, 2013) scores of 60 or greater (mild to severe anxiety symptoms) were included in the study. Adolescents with a current diagnosis of ADHD or a current or past diagnosis of autism spectrum disorder or psychosis were excluded from the study (all assessed via parent-report).

Seventy-six adolescents aged 12–14 years were invited to participate, along with one parent for each adolescent. One participant did not meet inclusion criteria due to IQ assessment.[1] The current sample includes 75 adolescents [42 (56.0%) females] ranging from 12.03 to 14.95 years ($M = 13.28$, $SD = 0.87$). Of these participants, 76% of adolescents self-identified as Not Hispanic or Latino. The self-reported racial breakdown is as follows: 46% White, 18% Black or African American, 20% more than one race, 11% other, 4% Asian, and 1% American Indian/Alaska Native.

A post hoc power analysis was conducted to compute achieved power for the main analyses using G*Power 3.1.9.7. For our moderation models consisting of two primary predictors and 3 covariates, at an alpha-level of 0.05 and achieved effect sizes ($f^2 = 0.28$), our achieved power was acceptable at 98.5%.

2.2. Procedure

Data were collected as part of a study examining the heterogeneity of AB across adolescents using biobehavioral and clinical assessments. The study consisted of two laboratory visits, in which parent consent and child assent were obtained in the beginning of Visit 1. The current study uses data from Visit 1, in which both parent and youth completed self-report assessments. Youth additionally completed computer tasks while EEG was recorded. The second visit occurred one month later and involved functional magnetic resonance imaging (fMRI) measurements, which were not of interest for the current study. The study protocol was approved by the Hunter College Institutional Review Board.

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[1] The excluded participant did not complete questionnaire or EEG measures.

2.3. Materials

2.3.1. Anxiety—The current study used the adolescent self-report version of the Screen for Child Anxiety Related Emotional Disorders (SCARED; Birmaher et al., 1999; Birmaher et al., 1997), which has been widely used to capture a range of anxiety symptom subtypes in youth, including social anxiety, generalized anxiety, panic symptoms, school avoidance and separation anxiety. This measure consists of 41-items pertaining to anxiety symptom severity and frequency, answered on a scale of (0) not true or hardly ever true, (1) somewhat true or sometimes true, and (2) very true or often true. A sum score was computed to quantify total anxiety symptoms, the target outcome. This total anxiety symptom scale demonstrated excellent internal consistency ($\alpha = 0.91$). To contextualize the magnitude of means reported below, total score values of 25 or above may indicate the presence of an anxiety disorder (Birmaher et al., 1999).

2.3.2. Social media communication preferences and perceptions—Adolescents completed the Social Media Communication Questionnaire (SMCQ) (Babkirk et al., 2016; Myruski et al., 2020), a self-report measure capturing a variety of DMU preferences and perceptions designed to reflect respondents' habitual attitudes about their social-emotional communication across contexts. Youth responded to 27 items regarding their preferences for DMU versus FTF interactions to serve social-emotional goals (e.g., "communicate anger", "seek advice") on a scale ranging from (1) only DMU/never FTF to (7) never DMU/only FTF. These items yield an overall social and emotional communication preferences scale ($\alpha = 0.89$), with lower scores indicating a greater DMU preference, and higher scores indicating a greater FTF preference.

2.3.3. Dot probe task—The dot probe task (MacLeod & Mathews, 1988; MacLeod et al., 1986) was administered to derive behavioral and ERP measures of AB. This task includes 20 pictures of individuals (10 males, 10 females) from the NimStim (Tottenham et al., 2009) and Matsumoto and Ekman's (1989) stimulus sets. Stimuli were presented using E-Prime version 2.0 (Schneider et al., 2012).

On each trial, a pair of faces of the same individual were presented above and below a fixation point in each trial 14 mm apart. These faces exhibited either a neutral or angry face and pairings were either neutral-neutral or angry-neutral. The task included 120 trials including: 1) 500ms fixation period, 2) 500ms face-pair cue (80 angry-neutral, '; 40 neutral-neutral trials), 3) a target probe indicating the direction the participant needs to respond on their mouse (an arrow < for left or > for right), and 4) 500 ms inter-trial interval. Participants were instructed to respond as quickly and as accurately as possible to indicate the direction of the arrow. Probes were equally likely to appear on the top or the bottom of the fixation cross where the angry or neutral face cues were presented and pointing to either direction.

2.4. Data recording and processing

2.4.1. Reaction time data processing—As an alternative to traditional reaction-time based measures of AB, particularly those derived from the dot-probe task which often show poor test-retest and split-half reliability (MacLeod et al., 2019; Price et al., 2019; Schmukle, 2005), trial level bias scores (TLBS) create AB scores that reflect dynamic changes from trial to trial, and over the course of an assessment paradigm (Zvielli et al., 2014). Trial-level metrics are often more reliable (Loomis et al., 2023; Naim et al., 2015; Price et al., 2019; Dennis-Tiwary et al., 2023) and more sensitive to anxiety-related individual differences (Zvielli et al., 2015).

RT data was first cleaned to remove extremely fast (i.e., RT < 150 ms) or slow (i.e., RT > 2000 ms) trials, as well as within-subject outliers ± 2.5 *SD* from each participant's mean response time (e.g., Price et al., 2015). We computed trial-level bias scores (TLBS; Zvielli et al., 2015) using the following procedure. For each participant separately, we first identified all pairs of correct trials that 1) consisted of one angry-incongruent and one angry-congruent trial and 2) these trials occurred within ± 5 trials of each other. Trial-level scores were then computed for each pair (i.e., RT for angry-incongruent trial – RT for angry-congruent trial). All positive trial-level scores were then averaged to generate the *mean positive* TLBS metric, with greater scores indicating a greater bias toward threat. Similarly, all negative trial-level scores were averaged to generate the *mean negative* TLBS metric, with more negative scores indicating a greater bias away from threat.

2.4.2. EEG recording and data reduction—

A Biosemi system (BioSemi; Amsterdam, NL) was used to continuously record EEG activity during the dot probe task. Electrodes (i.e., 64 Ag/AgCl scalp electrodes) were fixed into an elasticized nylon cap and arranged according to the International 10/20 system. Electro-oculogram (EOG) signals from electrodes were used to monitor eye movements, via an electrode placed 1 cm above and below the left eye (for vertical eye movements) and 1 cm on the outer edge of each eye (for horizontal eye movements). To improve the signal-to-noise ratio, preamplification of the EEG signal was done at each electrode (with a sampling rate of 512 Hz). The voltage from each of the 64 electrodes was referenced online with respect to the common mode sense active electrode and driven right leg electrode during EEG acquisition, which produces a non-differential channel. Brain Vision Analyzer (Version 2.2, GmbH; Munich, DE) was used to process and prepare the acquired EEG data. All offline data were re-referenced to the average of the scalp and filtered with high (0.1 Hz) and low (30 Hz) pass frequencies.

Stimulus-locked EEG data to faces (event-related potentials; ERPs) were segmented into epochs from 200 ms before stimulus presentation to 500 ms after stimulus onset. Each epoch included a 200 ms baseline correction (−200 ms–0 ms before the onset of stimulus). Following ocular (Gratton, Coles, & Donchin, 1983) and baseline corrections, artifacts were identified and removed from further analyses using the following criteria: 1) greater voltage steps than 50 μV, 2) changes within a segment greater than 300 μV, and 3) lower activity than 0.5 μV per 100 ms. Additional artifacts were subsequently removed via visual inspection.

2.4.3. Event-related potentials—

For ERP components, electrodes were selected by visual inspection of the topographical distribution of the data, and the grand average was calculated across all stimulus conditions and participants. Artifact-free EEG trials were used to generate ERPs for each participant separately for face presentations including angry faces (“threat” trials) and those containing only neutral faces (“neutral”) trials. Electrode and time window selection was accomplished by creating grand-grand averages (i.e., averages for all participants across all conditions) and identifying sites and time periods at which amplitudes were maximal (i.e., following recommendations from Kappenman & Luck, 2016; Keil et al., 2014). The N170 was calculated as the average amplitude between 170 and 200 ms at CP3, CP4, CP5, and CP6. The N2 was calculated as the average amplitude between 300 and 390 ms at FCz.[2] See Fig. 1 for grand-average waveforms.

2.5. Analytic approach

2.5.1. Missing data—Missing data analysis and multiple imputation was conducted via SPSS Version 26. Overall, 2.77% of data values were missing, and Little's MCAR test indicated that data was likely missing completely at random, χ^2 (223) = 207.78, p = 0.76. Thus, multiple imputation was appropriate to account for missing data. Main analyses reported below were also replicated with the original data (i.e., with missing data), and all results remained consistent regarding significance.

2.5.2. Main analyses—Moderation analyses were conducted via the SPSS PROCESS Macro Version 3.5 (Hayes, 2018). DMU vs FTF preference was entered as the predictor, AB variables were moderators (N170 to threat, N2 to threat, mean negative TLBS, mean positive TLBS), and total adolescent-reported anxiety symptoms was the outcome variable, for a total of four models. To account for multiple comparisons, we used the Benjamini-Hochberg procedure (Benjamini & Hochberg, 1995), applied to both the model-level p-values and the target interaction p-values, and all <0.05 p-values reported below remained significant after this procedure was applied. To account for documented sex differences in DMU and anxiety symptoms (Neira & Barber, 2014) and given sex differences and age associations detected in the current sample reported below, adolescent sex and age were entered as covariates. In models including ERPs, the corresponding ERP to neutral was also included as a covariate. This approach allows us to focus on ERPs in the presence of threat while accounting for ERPs in the absence of threat (i.e., neutral-neutral trials). All predictors were mean-centered for moderation analyses, however actual (non-mean-centered) values of predictors are reported for conditional effects below to aid in interpretation.

3. Results

3.1. Descriptive statistics

Descriptive statistics for all study variables, including DMU versus FTF preferences, anxiety symptoms, and biobehavioral AB metrics are presented in Table 1.

3.2. Dot probe task: reaction time metrics reliability

Following prior studies examining reliability of reaction time metrics from the dot probe task (e.g., Kappenman et al., 2014; Meissel et al., 2022; Zvielli et al., 2016), we used both Cronbach's alpha and split-half reliability. Cronbach's alpha showed acceptable reliability for both mean positive TLBS (α = 0.91) and mean negative TLBS (α = 0.89). To examine split-half reliability, TLBS were separately computed from even and odd trial-level pairs. Pearson correlations were conducted between the resulting scores for each metric, and the

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[2] For the N170, trial counts ranged from 19 to 40 (M = 37.59) and for the N2 trial counts ranged from 19 to 40 (M = 37.54).

Spearman-Brown correction was applied to r correlation coefficients. A corrected r value of > 0.70 was considered acceptable reliability, and this criterion was met for both mean positive TLBS ($r = 0.90$) and mean negative TLBS ($r = 0.89$).

3.3. Age and sex effects

Pearson correlations were conducted to examine associations between adolescent age and target variables. As shown in Table 2, greater age was significantly associated with AB such that as age increased, mean positive TLBS were lower, mean negative TLBS were higher, and N2 to threat was blunted. No significant associations emerged between adolescent age and DMU variables or anxiety symptoms.

Independent samples t-tests were conducted to compare males and females regarding target variables. As shown in Table 3, females showed significantly greater mean positive TLBS and marginally lower mean negative TLBS, compared to males. Also, females reported significantly higher anxiety symptoms compared to males. Thus, age and sex were included as covariates in all models presented below.

3.4. Moderation by RT-derived AB

Mean negative TLBS significantly moderated the association between DMU vs FTF preference and anxiety symptoms [Model: $R^2 = 0.22$, $f^2 = 0.28$, $F(5, 69) = 3.92$, $p = .004$; DMU*TLBS: $\Delta R^2 = 0.06$, b = 0.002, SE = 0.001, $F(1, 69) = 4.92$, $p = .030$, LLCI = 0.0002, ULCI = 0.004]. A greater DMU social and emotional communication preference predicted significantly greater anxiety symptoms among those showing more negative TLBS [−1SD = −232.12, b = −0.28, SE = 0.10, $t = -2.65$, $p = .010$, LLCI = −0.48, ULCI = −0.07; Fig. 2]. Johnson-Neyman regions of significance analyses indicated that the moderator became significant at a mean negative TLBS value of −183.41 and below (b = −0.16, SE = 0.08; $t = -2.00$, $p = .05$, LLCI = −0.33, ULCI = −0.001).

There were no significant moderation effects for mean positive TLBS scores. There were no significant main effects of TLBS scores or DMU preferences as independent predictors of anxiety symptoms. See Supplemental Tables 1 and 2 for full moderation models statistics for negative and positive TLBS predictors, respectively.

3.5. Moderation by ERP-derived AB

The model with N170 to threat moderating the association between DMU vs FTF preference and anxiety symptoms was significant [Model: $R^2 = 0.22$, $f^2 = 0.28$, $F(6, 68) = 3.28$, $p = .007$], and the DMU*N170 interaction was marginally significant [$\Delta R^2 = 0.04$, b = −0.09, SE = 0.05, $F(1, 68) = 3.90$, $p = .052$, LLCI = −0.19, ULCI = 0.001]. A greater DMU social and emotional communication preference predicted greater anxiety symptoms among those with blunted N170 to threat [+1SD = −0.39, b = −0.22, SE = 0.09, $t = -2.38$, $p = .020$, LLCI = −0.41, ULCI = −0.04; Fig. 3, top]. Johnson-Neyman regions of significance analyses indicated that the moderator became significant at an N170 value of −1.03 and above (b = −0.17, SE = 0.08; $t = -2.00$, $p = .05$, LLCI = −0.33, ULCI = −0.001).

Similarly, the N2 to threat significantly moderated the association between DMU vs FTF preference and anxiety symptoms [Model: $R^2 = 0.22$, $f^2 = 0.28$, $F(6, 68) = 3.21$, $p = .008$; DMU*N2: $\Delta R^2 = 0.05$, b = −0.08, SE = 0.04, $F(1, 68) = 4.15$, $p = .045$, LLCI = −0.16, ULCI = −0.002]. A greater DMU social and emotional communication preference predicted significantly greater anxiety symptoms among those with blunted N2 to threat [+1SD = −2.65, b = −0.32, SE = 0.12, $t = -2.63$, $p = .011$, LLCI = −0.56, ULCI = −0.08; Fig. 3, bottom]. Johnson-Neyman regions of significance analyses indicated that the moderator became significant at an N2 value of −4.59 and above (b = −0.16, SE = 0.08; $t = -2.00$, $p = .05$, LLCI = −0.33, ULCI = −0.001).

There were no significant main effects of ERPs or DMU preferences as independent predictors of anxiety symptoms. See Supplemental Tables 3 and 4 for full moderation models statistics for N170 and N2 predictors, respectively.

4. Discussion

4.1. Summary

Despite intense interest and a growing body of evidence, it remains unclear how DMU confers risk or resilience among a group of the most avid users of these technologies, adolescents. This study was among the first examine whether biobehavioral indices of AB, or disruptions in attention to and processing of threat, could help account for associations between DMU and anxiety severity among adolescents already struggling with elevated symptoms of anxiety (Barry et al., 2017; Keles et al., 2020; Seabrook et al., 2016; Tsitsika et al., 2014; Yan et al., 2017). We found that AB moderated associations between DMU and anxiety severity, such that a greater preference to use DMU versus FTF for social and emotional communication predicted greater anxiety severity among those who also evidenced disruptions in attention to and processing of threat – attentional avoidance of threat measured behaviorally, and blunted ERP responses in the presence of threat (the N170 and N2). This suggests that one factor making anxious youth vulnerable to sustained or increasing anxiety over time is both preferring DMU for social-emotional communication and responding in a dysregulated manner to threat-related information.

4.2. Interpretation

There were two key aims of the study. First, we measured DMU in terms of preferences for social-emotional communication via digital versus FTF modalities, rather than simply measuring sheer frequency of DMU, and our findings highlight the utility of DMU preference as a predictor of anxiety. We measured the preference for communicating via DMU about social and emotional experiences, rather than preferences for more general types of communication, given prior studies showing its links with individual differences in emotional adjustment (Babkirk et al., 2016; Myruski et al., 2020). These kinds of communication, such as expressing emotions (e.g., happiness, sadness), socializing with friends, and seeking/offering emotional support serve to connect with others, facilitate and maintain relationships, as well as share and regulate one’s own emotional experiences. From a theoretical standpoint, preferring DMU for social and emotional communication might reflect experiential avoidance among anxious individuals. This in turn could create opportunity costs for developing effective affect regulation, which amplifies AB away from threat and even drives subsequent experiential avoidance in a vicious cycle. This cycle of avoidance and affect dysregulation is typical of disruptions seen in the context of anxiety disorders (Salters-Pedneault et al., 2004). Indeed, if emotional communication is distressing or challenging, communicating via DMU has been shown to reduce physiological arousal (Wise et al., 2010) and be perceived as less socially demanding (Valkenburg & Peter, 2009).

Further, online social interactions may be less in-depth or satisfying for anxious individuals or those with a high need of social assurance (Casale & Fioravanti, 2015; Lee-Won et al., 2015). In a recent study of adolescents (Hamilton et al., 2021), in comparison to affective consequences of FTF interactions, negative interactions with peers online led to greater sustained negative affect whereas positive online interactions were followed by relatively blunted positive affect. Together, this work suggests that those who turn to DMU for social-emotional communication may be missing out on benefits that are unique to in-person interactions, and anxious individuals are likely particularly vulnerable in this regard.

A second aim was to measure individual differences in a biobehavioral diathesis related to anxiety – disrupted attention to threat – at multiple levels of analysis to more fully examine how it might confer vulnerability to negative effects of DMU (Babkirk et al., 2016; Myruski et al., 2020). We found that dysregulation of threat, whether measured via the behavioral metric of AB or in terms of blunted visual threat detection (N170) and cognitive control (N2), significantly moderated the association between preferences to use DMU versus FTF and self-report of anxiety symptom severity. Behaviorally, teens expressing a DMU preference and who showed a greater bias away from threat, i.e., attentional avoidance, also showed greater anxiety symptom severity. Attentional avoidance of threat is a hallmark of anxiety disorders (Brown et al., 2013), and thus might be a marker of a broader general affective vulnerability. Additionally, we did not find this same vulnerability for youth exhibiting a behavioral bias *towards* threat (i.e., mean positive TLBS scores). Therefore, behaviorally assessed avoidance of threat, as opposed to vigilance, might be a more pertinent risk factor for anxious youth engaging in DMU. Further research with additional metrics of AB, such as eye-tracking, should directly test this hypothesis given that other factors and fine-grained processes might impact the measurement of attentional avoidance, such as disengagement of attention (e.g., Hilt et al., 2017; Keil et al., 2018; Kleberg, Högström, et al., 2021; Schmidtendorf et al., 2022), general disruptions in the scanning of facial emotion (e.g., Kleberg, Löwenberg, et al., 2021), Kleberg, Löwenberg, et al., 2021nd the context of measurement, like stress inductions (e.g., Lidle & Schmitz, 2021).

The two complementary ERP metrics of threat processing, the N170 and N2, were employed to measure attentional selection and cognitive control, respectively. We found that when these two ERPs were blunted in response to threat relative to neutral faces, the association between DMU preference and anxiety severity was strengthened. Blunting of these ERPs have been linked to greater anxiety-related AB (e.g., Thai et al., 2016; Fu & Pérez-Edgar, 2019; Mueller et al., 2009) and might mark a more general affective vulnerability. Our findings suggest that DMU predicts elevated anxiety not only in the context of blunted recruitment of cognitive control, measured via the N2, but that even earlier dysregulation of attention selection (i.e., N170) in the presence of threat can play a similar role. Together, these findings are congruent with previous ERP research (Babkirk et al., 2016) examining the association between DMU preference and individual differences in affective stimuli processing in a sample of healthy young adults, which found that a DMU preference was associated with enhanced early emotional reactivity and blunted later emotional modulation. This prior work used complex picture stimuli which were predominately non-social and thus is not a direct comparison to the current study but does highlight a pattern of emotional vulnerabilities captured across the early to later time course of neurophysiology.

4.3. Limitations and future research

4.3.1. Study sample and methods—Limitations of the present study include a relatively small sample and a lack of longitudinal data. Moreover, by only measuring the preference to use DMU for social and emotional communication, we did not explore the potential impact of other types of preferences, such as for spending leisure time or seeking information, and thus cannot confirm that findings are specific to preferences for social and emotional communication. Additionally, the current study measured *relative* preferences for communication via DMU versus FTF. However, given that anxious individuals may have lower desire for social communication (both via FTF and DMU) future research would benefit from measuring and controlling for *absolute* preference for both types of communication. This could be added in the future development of the SMCQ scale. In addition, our measure of DMU captured general, retrospective preferences rather than indexing content of adolescents' actual social interactions either FTF or online. While direct observations of youth's online behavior offer greater precision, such approaches introduce ethical and practical concerns (e.g., invasive supervision, impeding naturalistic behavior). Recent research (e.g., Dienlin & Johannes, 2022 review) leverages ecological momentary assessment and daily diary techniques to capture within- and between-person fluctuations in behavior and social-emotional experiences embedded in daily life, and such approaches provide promising avenues for more ecologically-valid and precise DMU measurement.

4.3.2. Theory and implications—Despite growing empirical evidence pointing to the importance of investigating preference for DMU, AB, and anxiety, theoretical models are needed to further specify how DMU social-emotional communication preferences shape online behavior and relations with well-being. Specifically, future theoretical models should include potential individual differences/risk factors such as differences in emotional vulnerability that can be addressed with interventions. Given the scope of the current study, we are unable to determine whether these individual differences in emotional vulnerability are attributable to differences solely among anxious youth or to emotional vulnerability in general and across ages. Future research should examine these connections using person-centered approaches in a sample with broader levels of anxiety severity to determine whether differences in AB act as a vulnerability factor for DMU the general population.

4.3.3. Future directions—Several future research directions should be considered. First, future research should examine how disruptions across multiple stages of the threat response and broader emotion regulation processes contribute to the interplay between DMU and anxiety, perhaps via the ability to effectively regulate how social-emotional information is perceived and presented when using these digital platforms. Further, ecological validity of future work could be improved by developing paradigms which incorporate both facial *and* more complex threat-relevant stimuli (e.g., images and text) reflecting what youth might encounter in both online and in-person contexts.

Next, it is possible that our biobehavioral metrics of AB - attentional avoidance and blunted threat responding - signify a broader affective vulnerability, such as a tendency towards experiential avoidance, that is a specific risk factor for anxious youth in the context of DMU. This potential link should be explicitly tested. Building on that, it will be important to examine whether and how processes like experiential avoidance *during* DMU, rather than a general tendency, predict anxiety severity over time. This is plausible given that experiential avoidance is a well-documented mechanism underlying a range of anxious pathology (Hayes et al., 2004; Kashdan et al., 2006), which has been shown to increase distress over time (Spinhoven et al., 2014). Simultaneously, anxious individuals gravitate towards DMU to relieve emotional distress (Bargh & McKenna, 2004; Caplan, 2003; Madell & Muncer, 2007). Thus, experiential avoidance is a logical candidate process underlying the moderating role of threat bias in the link between DMU preference and anxious distress. Longitudinal research that can directly measure experiential avoidance and related processes in the context of DMU in relation to the emergence of anxiety symptoms in teens over time will be able to tease apart these effects, including bidirectional and iterative patterns between DMU and anxiety.

4.4. Conclusion

In summary, the present study documented that a preference to communicate via DMU versus FTF relates to elevated anxiety symptoms among those evidencing biobehavioral AB vulnerabilities, namely behavioral attentional avoidance of threat and blunted ERP responses to threat (the N170 and N2).

This work highlights the importance of considering both online and in-person interactions and lays the groundwork for future investigations of key biobehavioral individual differences in cognitive and affective functioning that underlie the DMU-anxiety link. Theoretically, the present study expands on the body of empirical evidence highlighting the importance of (1) considering a more nuanced view of DMU, measuring use in terms of preferences for social-emotional communication via digital versus FTF modalities, rather than simply measuring sheer frequency of DMU; and (2) the role of individual differences in emotional vulnerabilities, namely AB, in how DMU is experienced by anxious youth.

Practically, findings have implications for identifying adolescents who may be most at risk for problematic DMU that exacerbates anxiety symptoms, elucidating possible treatment targets (e.g., attention-bias modifications), as well as informing recommendations for balancing FTF and DMU interactions in pursuit of healthy technology use.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Data availability

Data will be made available on request.

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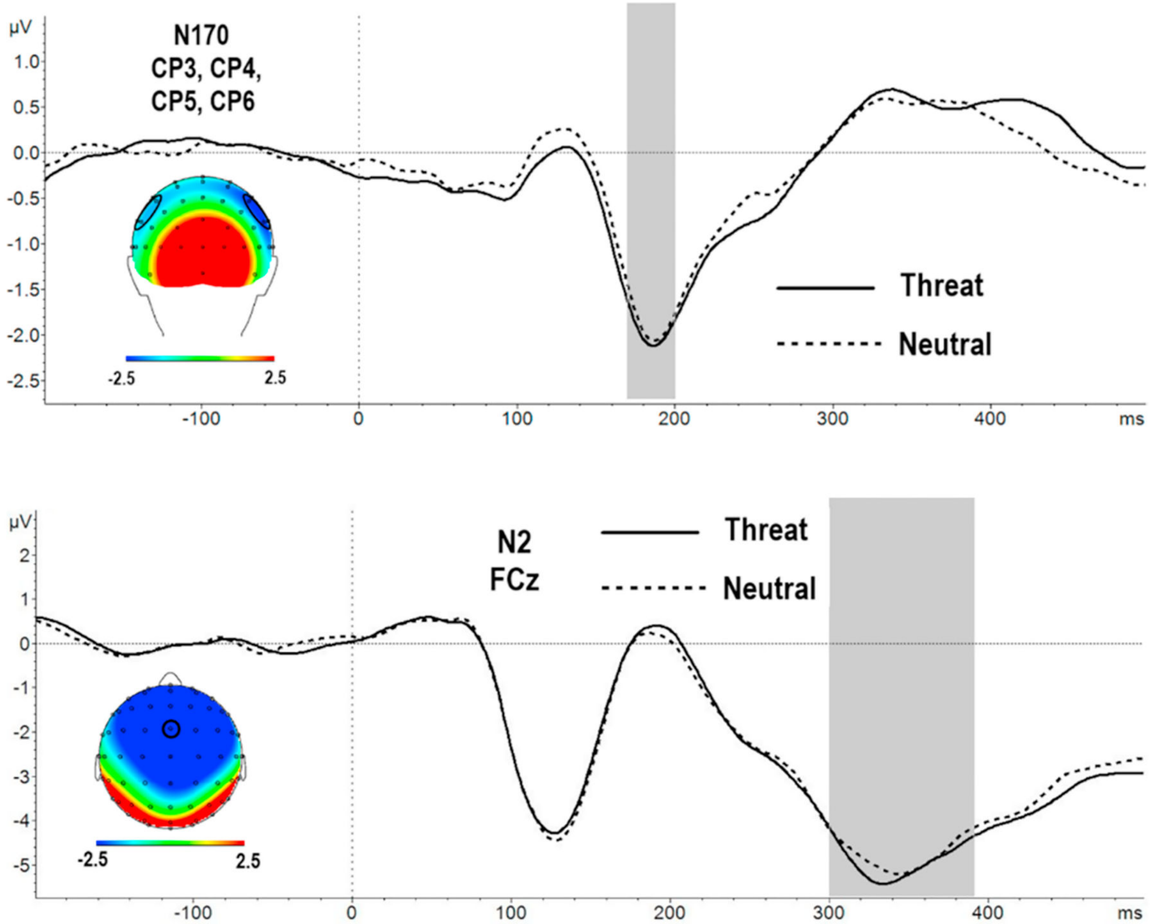

Fig. 1.

Grand average waveforms and topographic maps of the N170 and N2.

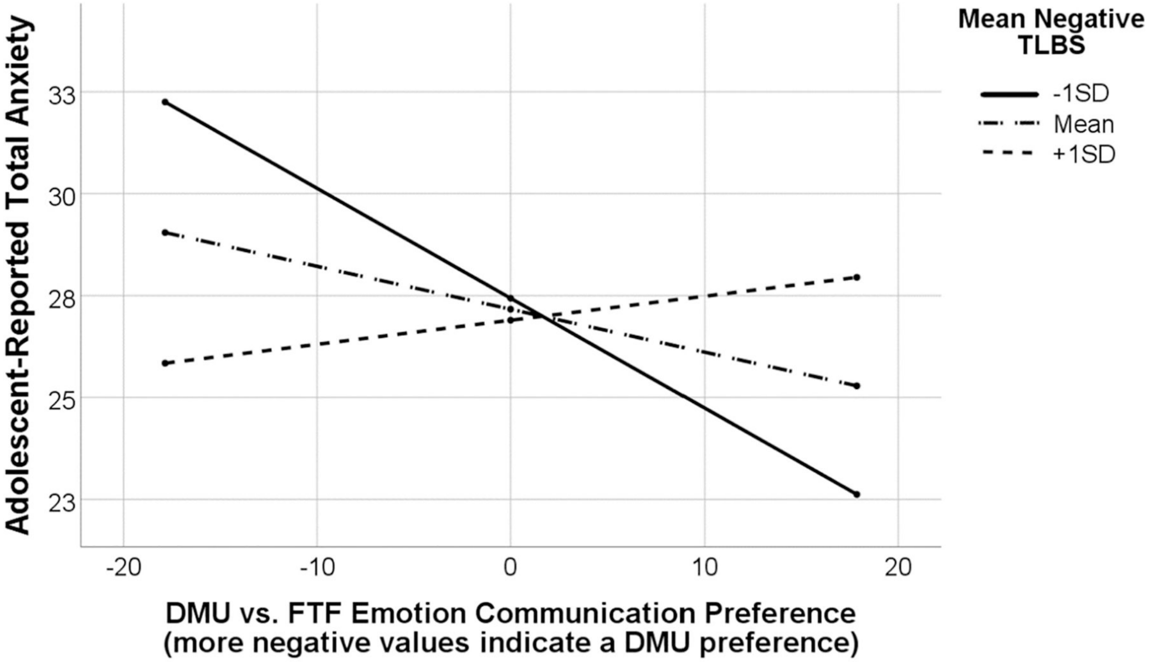

Fig. 2.

Mean negative TLBS moderated the association between DMU vs FTF preferences and adolescent anxiety symptoms.

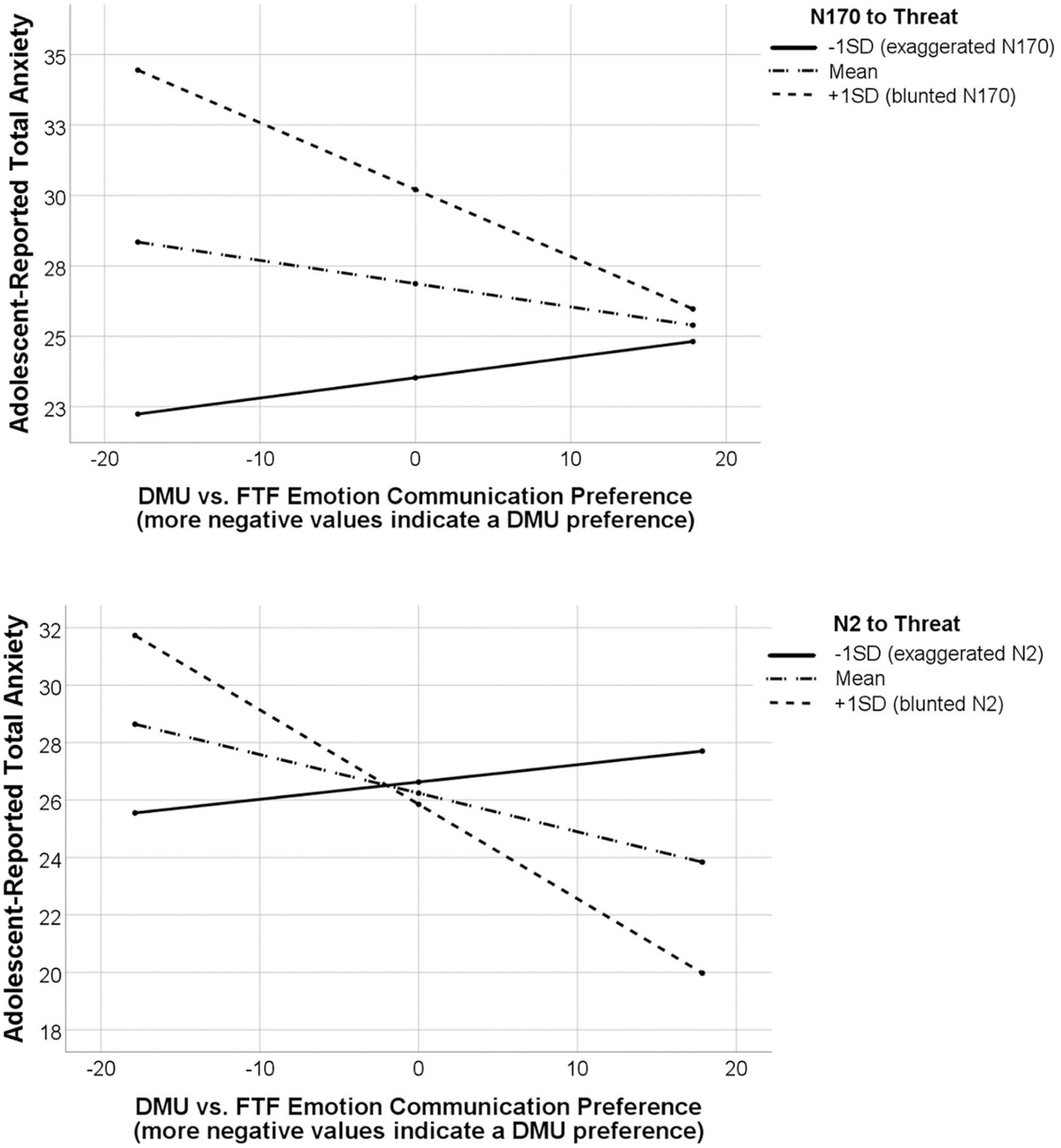

Fig. 3.

N170 (top) and N2 (bottom) to threat moderated the association between DMU vs FTF preferences and adolescent anxiety symptoms.

Table 1

Descriptive statistics for demographics and study variables.

	M (SD)	**Min**	**Max**
Age	13.29 (0.87)	12.03	14.95
N170-threat	−1.96 (1.57)	−7.62	1.48
N170-neutral	−1.83 (1.75)	−8.64	2.41
N2-threat	−4.99 (2.34)	−10.69	2.31
N2-neutral	−4.91 (2.58)	−12.69	−0.74
Pos TLBS	153.75 (76.35)	48.50	364.30
Neg TLBS	−157.5 (74.59)	−370.19	−62.45
DMU vs FTF Preference	105.32 (17.86)	51.00	158.00
SCARED-C	26.60 (13.22)	2.00	57.00

Pos TLBS = Positive trial-level bias scores; Neg TLBS = Negative trial-level bias scores; DMU = digital media use; FTF = face-to-face; SCARED-C = Screen for Child Anxiety-Related Disorders – Child Report; units for N170 and N2 ERPs is μV; units for TLBS is ms.

Table 2

Bivariate Associations Between Study Variables (r values reported with p values in parentheses).

	1	2	3	4	5	6	7	8	9
1. Age	–								
2. N170-neutral	0.16 (.170)	–							
3. N170-threat	0.14 (.234)	**−0.84 **(< .001)**	–						
4. N2-netural	**0.23 *(.043)**	0.12 (.295)	0.20 (.094)	–					
5. N2-threat	**0.35 **(.002)**	**0.33 **(.004)**	**0.30 **(.008)**	**0.72 **(< .001)**	–				
6. Pos TLBS	**−0.42 **(< .001)**	−0.10 (.387)	−0.14 (.907)	0.01 (.960)	−0.13 (.271)	–			
7. Neg TLBS	**0.37 **(.001)**	−0.01 (.955)	−0.11 (.348)	−0.11 (.372)	0.02 (.866)	**−0.73 **(< .001)**	–		
8. DMU vs FTF Preference	−0.07 (.573)	0.09 (.433)	0.10 (.395)	−0.11 (.361)	−0.11 (.369)	0.13 (.271)	−0.20 (.093)	–	
9. SCARED-C	0.17 (.157)	−0.08 (.475)	−0.01 (.973)	−0.01 (.955)	−0.08 (.496)	0.10 (.393)	−0.02 (.853)	−0.12 (.288)	–

* $p < .05$;

** $p < .01$;

Pos TLBS = Positive trial-level bias scores; Neg TLBS = Negative trial-level bias scores; DMU = digital media use; FTF = face-to-face; SCARED-C = Screen for Child Anxiety-Related Disorders – Child Report; units for N170 and N2 ERPs is μV; units for TLBS is ms.

Table 3

Sex differences.

	Female		Male			
	M	***SD***	***M***	***SD***	***t***	***p***
N170-neutral	−1.98	2.05	−1.64	1.27	− 0.82	.413
N170-threat	−2.03	1.86	−1.88	1.12	−0.42	.678
N2-netural	−4.92	2.79	−4.89	2.33	−0.04	.967
N2-threat	−5.29	2.49	−4.61	2.12	−1.28	.212
Pos TLBS	171.10	80.80	131.68	63.40	2.30	**.024** [*]
Neg TLBS	−172.41	76.57	−138.59	68.50	−2.01	**.051** [*]
DMU vs FTF Preference	107.71	20.13	102.30	14.19	1.36	.195
SCARED-C	30.69	13.64	21.39	10.78	3.30	**.002** [**]

[*] $p < .05$;

[**] $p < .01$;

Pos TLBS = Positive trial-level bias scores; Neg TLBS = Negative trial-level bias scores; DMU = digital media use; FTF = face-to-face; SCARED-C = Screen for Child Anxiety-Related Disorders – Child Report; units for N170 and N2 ERPs is μV; units for TLBS is ms.