A pilot study using ecological momentary assessment via smartphone application to identify adolescent problematic internet use

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ABSTRACT

For some youth, pathologic Internet use can cause significant distress and dysfunction, a phenomenon known as Problematic Internet Use (PIU). PIU has been associated with poorer health outcomes in adolescents with existing psychiatric illness but understanding PIU has been challenging due to research methodologies using cross-sectional, self-report data. This study assessed the feasibility of using app-based ecological momentary assessment (EMA) to provide more ecologically-valid data to identify and characterize the relationship between mood symptoms and PIU in adolescents in active mental health treatment. 25 youth (aged 12–23) were recruited to use an EMA app for 6 weeks. 96% of participants completed the study and the majority of participants completed surveys at least once weekly. Youth with anxiety disorders endorsed significantly greater benefit from using the app to monitor PIU. While PIU severity was positively correlated with worsened anxiety and depression, analyses of the temporal relationships between PIU and mood symptoms showed that anxiety symptoms were significantly improved after episodes of PIU. Overall results suggest that app-based EMA may be both acceptable and feasible to understand PIU in this population. Follow-up studies should consider personalization of study protocols and use of digital phenotyping methodology to collect more objective measurements of behavior.

1. Introduction

Not counting screen time needed for completion of schoolwork either at home or at school, adolescents still spend approximately 7.5 h per day watching screens (Rideout and Robb, 2019). For the majority of adolescents, screen time does not appear to disrupt either social or academic functioning. However, for some youth, Internet use may become problematic. Problematic Internet Use, or PIU, has been broadly characterized as "overuse of the Internet with associated impairment(s) across various domains of functioning" (Restrepo et al., 2020). While its exact diagnostic category remains controversial, studies have demonstrated multiple concerning parallels between PIU and substance use disorders. For example, individuals with PIU may display behavioral changes such as Internet craving, cue-reactivity, withdrawal, and tolerance (Block, Jerald, 2008; Brand et al., 2014). PET and fMRI neuroimaging studies highlight PIU-associated changes in brain regions related to reward processing, salience, and executive functioning, similar to deficits seen in substance use disorders (Altbäcker et al., 2016; Kuss and Griffiths, 2012; M. Park et al., 2017; Sepede et al., 2016;

Yuan et al., 2011; Zhou et al., 2011).

Of significant concern, adolescents with PIU have also been found to have higher rates of psychiatric comorbidities like substance use, anxiety, depression, and non-suicidal self-injury (Kaess et al., 2014; Lee and Lee, 2017; Morioka et al., 2016; S. Park, 2014; Rucker et al., 2015; Younes et al., 2016). Unfortunately, the cross-sectional methodology used by these studies makes it challenging to determine the directionality of these relationships; some researchers hypothesize that PIU may trigger the development of mood symptoms, while others posit that adolescents with pre-existing psychiatric co-morbidities may simply be more susceptible to developing PIU. However, preliminary studies suggest that even within populations of adolescents with psychiatric illness, PIU may confer a higher degree of risk. Youth with psychiatric diagnoses and comorbid PIU are more likely to be both aggressive and engage in self-injurious behavior compared to youth with the same psychiatric diagnoses alone (Fuchs et al., 2018; Gansner et al., 2019).

Our current understanding of PIU's impact on this vulnerable population is also complicated by existing studies' reliance upon self-

report data. Researchers have expressed significant concerns that adolescents may be unable to recognize or assess their continuous Internet use (Jeong et al., 2018). Ecological momentary assessment, or EMA, is a research modality that improves upon existing research methods by repeatedly sampling participants in a naturalistic environment to limit recall bias and increase ecological validity (Stone and Shiffman, 1994). Subjects can participate in smartphone EMA through call/text surveys or applications ("apps") and the amount of time youth spend daily on their smartphones makes EMA a potentially valuable tool for understanding PIU in this age group.

To our knowledge, there are no existing studies that have piloted the feasibility of app-based EMA to assess the relationship between mental health symptoms and PIU in a clinical sample of adolescents. We addressed this research gap in an exploratory study with three aims: 1) To determine the feasibility of using a six-week, app-based EMA protocol to assess digital media use and PIU in a clinical population of adolescents and young adults (feasibility was measured by protocol adherence and response rates; 2) To determine the acceptability of using an EMA protocol for the purpose of monitoring PIU and psychiatric symptoms based on experiential feedback from participants; 3) To identify preliminary associations (including temporal) between PIU and psychiatric symptoms, as well as associations between PIU and demographic variables, using EMA technology with greater ecological validity and accuracy than current data collection methods in this field of research.

2. Methods

2.1. Participants

The study recruited 25 adolescents and young adults between the ages of 12 and 23 who had a smartphone, received current outpatient mental health care, and were English speaking. Exclusion criteria included reading below a sixth-grade reading level and lack of parental consent (if participant ≤ 18). Age criteria were determined by the outpatient mental health clinics participating in this study, who also see transitional age youth. Only 41% of children ages 8–12 own a personal cell phone (Rideout and Robb, 2019), so children under the age of 12 were excluded from recruitment. Participants were recruited from child and adolescent outpatient psychiatric clinics affiliated with an academic community health system in the greater Boston area and were compensated with a $25 Amazon gift card at the beginning and end of the study.

2.2. Procedures

Participants completed daily surveys through the mindLAMP app (Learn, Assess, Manage, Prevent) for 6 weeks. MindLAMP is a free-rein research platform that includes an online portal system for researchers to manage participants and visualize de-identified data, and a smartphone app for participants to record data (Torous, 2020). Participants received a daily survey reminder via push notification every evening and once completed, mindLAMP uploaded the survey data to a secure, HIPAA-compliant server.

Daily surveys included a modified version of the Patient Health Questionnaire-9 (PHQ-9) (Richardson et al., 2010) to assess depressive symptoms and the Generalized Anxiety Disorder-7 scale (GAD-7) (Mossman et al., 2018) to evaluate symptoms of generalized anxiety. The PHQ-9 was modified only to omit the final question assessing suicidality due to the fact that affirmative responses could not be actively monitored remotely. Both scales were scored using a four-point Likert scale, where "not at all" was 0 points and "nearly every day" was 3 points. PIU severity was rated using the Problematic Internet Use Short Form-6 (PIU-SF-6), a scale validated for measurement of PIU in youth ($\alpha = 0.77$) (Demetrovics et al., 2016). The PIU-SF-6 is structured as a five-point Likert scale, anchored at "never (1)" and "always/almost

always (5)". A score of 15 was used as the cut-off score to indicate the presence of PIU.(Demetrovics et al., 2016). While all three scales are not traditionally administered on a daily basis, daily administration of active surveys allowed for the possibility of intermittent adherence over the 6-week study period and was not considered to impact scale validity (Bauer et al., 2018). Therefore, participants were asked to answer questions based on their symptoms within the prior 24 h, with GAD-7 and PHQ-8 answer choices instead ranging from "not at all" to "nearly all the time."

An exit survey was administered following completion of the 6-week protocol that asked participants whether using the app increased reflection upon a potential connection between the participant's digital media use and mood symptoms, and if app use increased discussion about this potential connection during mental health visits. Participants were also asked whether they would use the app again with their clinicians to assess and understand the relationship between digital media use and mood symptoms. Possible answer choices to these questions were a binary "yes" or "no." Additionally, to gather information about variables that may have limited our study's response rate, participants were asked to rate ease of app use as "not at all easy" "somewhat easy" and "very easy" and an open-ended question about variables that may have limited participant engagement.

Each participant's demographic information and psychiatric diagnoses were obtained through electronic health record at the beginning of the study. Gender was categorized as male, female or transgender because gender non-conforming youth appear to be at higher risk of psychiatric illness (Becerra-Culqui et al., 2018) and may also be more likely to rely upon digital media for support (Rideout and Fox, 2018). While all of a patient's psychiatric diagnoses were recorded, we only assessed associations with diagnostic categories represented by ≥ 5 participants (i.e. anxiety disorders, depressive disorders and attention deficit disorders) due to our small sample size. Diagnoses were obtained from the most recent outpatient mental health encounter notes.

App feasibility was measured both in comparison to average response rates from other EMA studies on adolescents with psychiatric illness as well as to current clinical standard to care wherein a patient typically engages in assessment of psychiatric symptoms related to digital media use at most once per week. Preliminary acceptability was measured based on response to the three qualitative "yes/no" exit survey questions.

Study procedures were approved by the hospital's institutional review board and comply with the latest revision of the Declaration of Helsinki. Study investigators explained the study procedures in detail to participants and guardians (when participant was < 18) and subsequently obtained informed consent and assent (when participant was < 18).

2.3. Data analyses

Statistical analyses were run on Rstudio Version 1.2.5033 (RStudio, 2020). Demographic characteristics were calculated as percentages. Overall response rates were determined for each individual participant as the percentage of completed total surveys over the 42-day study period. Average response rate for the study sample was calculated as the mean of the overall response rates for all participants. Average PIU-SF-6, PHQ-8, and GAD-7 scores were determined for each participant by calculating the mean of each participant's scale scores over the course of the study.

Feasibility based on response rate: One-way ANOVAs were performed to test for significant relationships between response rate and gender. Student's t-tests assessed for differences in response rate based on diagnostic category, type of phone used in the study, and current use of mental health apps. Linear regression models assessed for a potential relationship between participant age and rate of response as well as average scale scores (PIU-SF-6, GAD-7, PHQ-8) and rate of response.

2.4. Acceptability based on exit survey responses

A one-way ANOVA was performed to assess relationship between gender and percentage of affirmative answers for each exit survey question. Student's t-tests were used to determine whether there was a significant difference in mean age or average scale scores based upon "yes/no" responses to each exit survey question. Chi-square tests were used to examine the relationship between each diagnostic category and the proportions of 'yes/no' responses to each exit survey question. A post-hoc analysis was performed using a student's *t*-test to clarify relationship between mean response rate and Exit Survey Question #1.

2.5. Factors associated with PIU severity

A one-way ANOVA was performed to assess relationship between gender and PIU severity as measured by PIU-SF-6 score. Relationships between diagnostic category and PIU severity were assessed using student's t-tests. Linear regression was used to assess the relationship between participant age and PIU-SF-6 score. Overall associations between PIU severity and depression or anxiety symptoms were assessed using linear regression models to estimate correlations between participant's average PIU-SF-6, PHQ-8, and GAD-7 scores. To assess the temporal relationship between PIU onset and mood symptoms, paired t-tests compared PHQ-8 and GAD-7 scores during and after episodes of PIU (PIU-SF-6 ≥ 15) (Demetrovics et al., 2016). PIU episodes were defined as time points where a participant's PIU-SF-6 moved at or above the cut-off score of 15. Because PHQ-8 and GAD-7 scales may be more useful as measures of symptoms severity in youth with existing psychiatric illness, the study used the PIU-SF-6 cut-off score of 15 to identify, and assess psychiatric symptoms surrounding, discrete episodes of PIU. Participants who experienced more than one PIU episode had their "before PIU" and "after PIU" PHQ-8 and GAD-7 scores averaged.

3. Results

Of the 25 participants, 24 (96%) completed the 6-week study. Descriptive statistics regarding participant demographics and technology use can be found in Table 1. A sample of a participant's individual feedback data obtained via the app platform is displayed in Fig. 1.

Measurement of Application Feasibility based on Protocol Adherence (Measured via Mean Response Rate) (Tables 2 & 3)

The overall mean response rate for participants was calculated at 39.8%. There were no statistically significant demographic differences

Table 1
Participant Demographics and Technology Use.

Demographics	
Gender,% [n]	
Male	32.0% [8]
Female	48.0% [12]
Transgender	20.0% [5]
Ethnicity/Race,% [n]	
Asian	0.0% [0]
Biracial	12.0% [3]
Black	12.0% [3]
Hispanic/Latino	24.0% [6]
White, non-Hispanic/Latino	52.0% [13]
Age (mean)	15.5 years
Technology Use	
Type of Phone,% [n]	
iPhone	64.0% [16]
Android	36.0% [9]
Current Mental Health App Use,% [n]	
Yes, n = 5	20.8% [5]
No, n = 19	79.2% [19]

between group means as determined by one-way ANOVA (gender) or linear regression (age). There was no significant difference in response rate between those participants who reported using other mental health apps during the study period and those who were not using other mental health apps. While the severity of anxiety, depressive or PIU symptoms did not impact rate of response, participants with anxiety diagnoses had significantly higher response rates than participants without anxiety diagnoses ($p < 0.01$). 80% of participants reported that the app was very easy to use, with only one participant reporting that it was "not at all" easy. The most commonly cited reasons for non-adherence were technical glitches with the app and time needed for completion (both 40% of reasons cited).

Acceptability of Using an EMA protocol via Smartphone Application to Monitor Digital Media Use and Psychiatric Symptoms (Table 4)

The majority of participants reported an increased awareness of the relationship between their mood symptoms and digital media use (83.3%) and stated that they would use this app again to share information with their mental health providers (70.8%). One-third (33.3%) of participants talked more with their providers about their digital media use during the 6-week study period. Similar to response rates, answers to exit survey questions did not appear to change significantly based on demographic and symptom variables. Again, the exception to this was the group of participants with anxiety disorders, who were significantly more likely to report increased attunement to their psychiatric symptoms in relation to their digital media use during the study period ($p < 0.05$).

To determine whether or not the increased attunement found in participants with anxiety disorders was related to their more frequent app utilization (i.e. higher app response rate), a post-hoc analysis was performed. Using a student's *t*-test, we compared mean response rates between those who reported increased reflection on their digital media use and those that did not. A significant relationship was found ($t = -2.77$, $p < 0.05$) between these two variables. Taken together, these analyses suggest that youth with anxiety disorders may have been more reflective upon their digital media use and mood symptoms because of their more frequent use of the app.

Characterizing PIU based on Demographic Variables, Psychiatric Comorbidities and Symptoms (Table 5)

There appeared to be no correlation between PIU severity and a participant's age or gender. Notably, while participants with anxiety disorders had significantly lower average PIU scores, participants endorsing greater anxiety and depression symptomatology had significantly higher PIU scores ($p < 0.05$, $p = 0.05$, respectively). No significant differences were observed between participants with and without depression or between participants with and without ADHD regarding PIU scores. (Fig. 2). Examining the temporal relationship between psychiatric symptoms and onset of PIU, symptoms of anxiety (although not depression) were significantly improved after episodes of PIU ($p < 0.05$).

4. Discussion

4.1. Acceptability and feasibility

Based on our findings, EMA via smartphone app does appear to be a feasible method for adolescents with psychiatric comorbidities to assess the relationship between their digital media use and psychiatric symptoms. Our response rate of 39.8% fell within the range reported in adolescent EMA literature (Kenny et al., 2016; Wen et al., 2017) and improved upon the current standard of care wherein patient clinical information is obtained at most once per week (a once per week response rate translates to an overall protocol response rate of approximately 14.3% vs. our 39.8%). However, our response rate does fall below the adherence rate recommended when using EMA methodology (Shiffman et al., 2008). While the app itself appeared acceptable to youth given that 80% of participants found it "very" easy to use, time
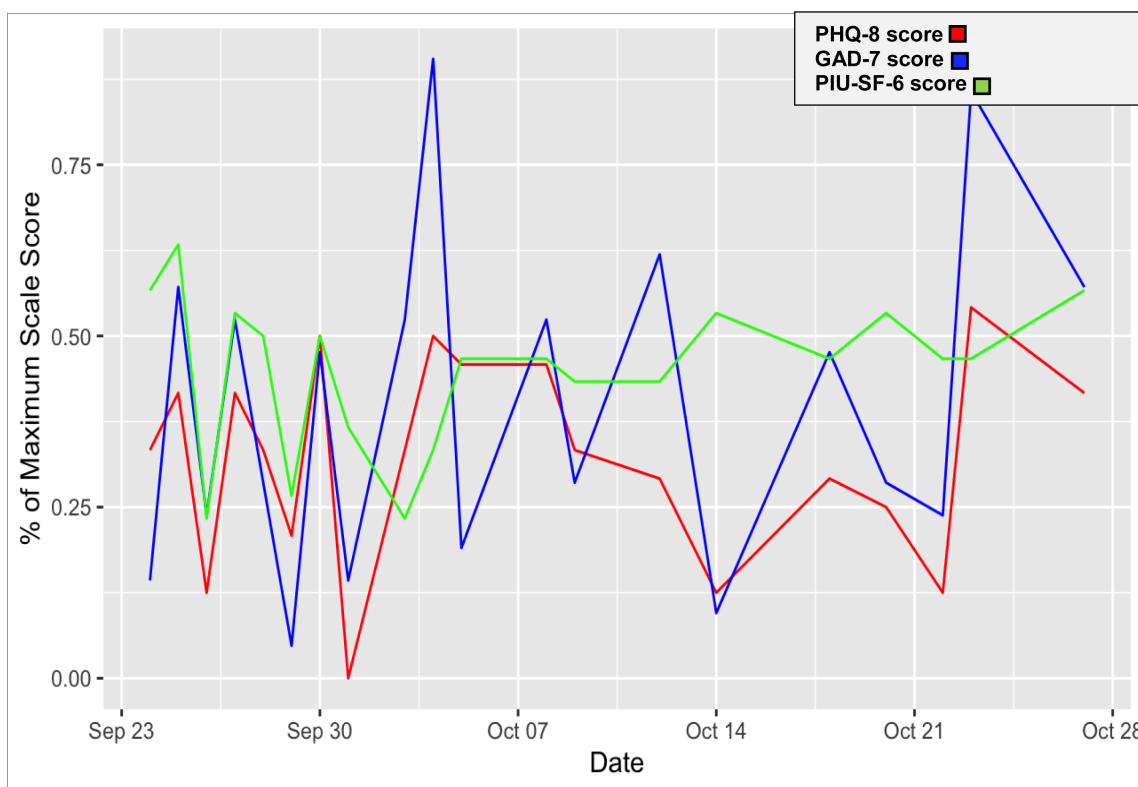
Fig. 1. Real Feedback Example of Participant's Longitudinal Active Data Using EMA.

Table 2
Application Feasibility based on Protocol Adherence (Measured via Mean Response Rate).

Factor	Mean Response Rate,% [SD]	t-stat or F-stat	p-value
Technology Use			
iPhone	47.3% [19.9]	−2.45	0.02*
Android	26.5% [21.3]		
Mental Health App Use			
Yes	42.3% [24.2]	−0.16	0.87
No	40.2% [22.8]		
Gender			
Male	45.5% [23.5]	1.26	0.30
Female	41.7% [22.4]		
Transgender	30.1% [19.4]		
Diagnosis			
Anxiety/No Anxiety	51.9% [14.8] / 28.7% [22.9]	−2.98	0.007*
Depression/No Depression	43.4% [20.0] / 33.3% [26.2]	−1.08	0.29
ADHD/No ADHD	36.9% [24.2] / 41.2% [22.2]	0.43	0.55
	β-Coeff.		**p-value**
Age	−0.002		0.89
Symptom Severity			
(Depression) PHQ-8	−0.007		0.46
(Anxiety) GAD-7	−0.005		0.68
(PIU) PIU-SF-6	−0.02		0.078

Table 3
Participant Feedback Concerning Response Rate/Adherence.

Factor	N [%]
How Easy Was it to Use the App? (*n* = 24)	
Not At All	1 (4.2%)
Somewhat	8 (33.3%)
Very	15 (62.5%)
Reasons Impacting Adherence (*n* = 10)	
Took Too Much Time	4 (40.0%)
Application Technical Issues	4 (40.0%)
Questions Were Too Hard	2 (20.0%)

addressing problematic digital media use in this population. The majority of participants across demographic groups and psychiatric diagnoses reported an increased awareness of their digital media habits and emotions as well as stated that they would use this app again as a way to communicate with mental health clinicians about their digital media use. Patient ability to reflect upon maladaptive behaviors in the treatment setting is a crucial component of motivational enhancement therapy, or MET, (Naar-King, 2011) a therapeutic modality that has shown early success in PIU treatment (Sharma and Palanichamy, 2018). This app could allow patients to track the relationship between digital media use and psychiatric symptoms, providing tangible, objective, and behavioral data for clinicians to help patients identify triggers for excessive use and work towards patient-specific solutions. Therefore, our findings may also support a potential role for app-based EMA in treating PIU.

Despite our protocol's overall generalizability, our results do highlight factors that may make this app-based EMA protocol more beneficial for certain adolescents. Youth with anxiety disorders had significantly higher response rates, leading to greater recognition of psychiatric symptoms related to their digital media use. It is not immediately evident why youth with anxiety disorders demonstrated higher protocol adherence but their increased participation could be

was a significant limitation, and also likely the reason that technical glitches disincentivized adherence, as a youth might choose not to spend time finishing the survey if the app closes out in the middle of the activity. Future app studies should consider optimizing surveys with less intensive question formats (e.g. multiple choice instead of fill-in-the-blank) or else incentivizing youth to invest more time in the app through gamification or personalized protocols (Russell and Gajos, 2020).

Our qualitative data suggest that this technology is acceptable for

Table 4

Acceptability of Using an EMA protocol via Smartphone Application to Monitor Digital Media Use and Psychiatric Symptoms, Exit Survey Responses.

1) Did using this app make you think more about how digital media use might impact your mood?				
		% Responded Yes	% Responded No	χ^2 or F-stat	p-value
Gender	*Male*	75.0	25.0	0.66	0.53
	Female	81.8	18.2		
	Transgender	100.0	0.0		
Diagnosis	*Anxiety/No Anxiety*	100.0 / 66.7	0.0 / 33.3	4.80	0.03*
	Depression/No Depression	93.3 / 66.7	6.7 / 33.3	2.88	0.09
	ADHD/No ADHD	75.0 / 87.5	25.0 / 12.5	0.60	0.44
Average Scale Scores		**Yes Responses [SD]**	**No Responses [SD]**	**t-stat**	**p-value**
(Depression) PHQ-8		8.1 [5.3]	4.0 [3.7]	−1.46	0.16
(Anxiety) GAD-7		6.8 [4.2]	4.2 [3.9]	−1.12	0.28
(PIU) PIU-SF-6		10.4 [3.2]	12.8 [6.3]	1.17	0.26
Mean Age		**Yes Responses [SD]**	**No Responses [SD]**	**t-stat**	**p-value**
		15.7 [2.7]	13.8 [2.0]	−1.38	0.18
2) Did you talk more about your digital media use with mental health providers while using this app?					
		% Responded Yes	% Responded No	χ^2 or F-stat	p-value
Gender	*Male*	37.5	62.5	0.20	0.82
	Female	36.4	63.6		
	Transgender	25.0	75.0		
Diagnosis	*Anxiety/No Anxiety*	25.0 / 41.7	75.0 / 58.3	0.75	0.39
	Depression/No Depression	33.3 / 33.3	66.7 / 66.7	0.00	1.00
	ADHD/No ADHD	25.0 / 37.5	75.0 / 62.5	0.38	0.54
Average Scale Scores		**Yes Responses [SD]**	**No Responses [SD]**	**t-stat**	**p-value**
(Depression) PHQ-8		7.9 [5.9]	7.2 [5.1]	−0.32	0.66
(Anxiety) GAD-7		6.4 [4.0]	6.4 [4.4]	−0.02	0.98
(PIU) PIU-SF-6		10.8 [2.6]	10.7 [4.4]	0.10	0.92
Mean Age		**Yes Responses [SD]**	**No Responses [SD]**	**t-stat**	**p-value**
		15.8 [2.9]	15.2 [2.6]	−0.48	0.63
3) Would you consider using this app again with your mental health clinician to help understand the relationship between your digital media use and your mood?					
		% Responded Yes	% Responded No	χ^2 or F-stat	p-value
Gender	*Male*	87.5	12.5	0.77	0.48
	Female	63.6	36.4		
	Transgender	60.0	40.0		
Diagnosis	*Anxiety/No Anxiety*	83.3 / 58.3	16.7 / 41.7	1.82	0.18
	Depression/No Depression	66.7 / 77.8	33.3 / 22.2	0.34	0.56
	ADHD/No ADHD	62.5 / 75.0	37.5 / 25.0	0.40	0.53
Average Scale Scores		**Yes Responses [SD]**	**No Responses [SD]**	**t-stat**	**p-value**
(Depression) PHQ-8		7.0 [3.2]	8.6 [5.9]	0.71	0.49
(Anxiety) GAD-7		6.1 [4.6]	7.0 [3.4]	0.45	0.66
(PIU) PIU-SF-6		10.2 [3.1]	12.2 [5.1]	1.22	0.23
Mean Age		**Yes Responses [SD]**	**No Responses [SD]**	**t-stat**	**p-value**
		15.8 [2.7]	14.4 [2.4]	−1.14	0.89

attributable to the greater amount of time individuals with anxiety spend online compared to their non-anxious peers (Riehm et al., 2019), potentially increasing their likelihood of noticing daily push notifications in an app-based EMA protocol.

Lastly, 33% of participants talked more with mental health providers about their digital media use during the study period and increasing this percentage would likely further this protocol's utility. While many adolescents now prefer digital over face-to-face communication (Lenhart et al., 2010), youth with active psychiatric symptoms also appear more likely to use digital technology to communicate with their healthcare providers (Rideout and Fox, 2018). Future qualitative

studies may be helpful in clarifying whether the adolescents in our study population would prefer the incorporation of provider/patient digital communication within the EMA protocol to facilitate discussion of digital media use.

4.2. PIU characterization

The vast majority of PIU research has been performed in non-clinical samples of adolescents, likely causing both conflicting results in the accurate measurement of PIU's psychiatric comorbidities and a lack of understanding about how PIU specifically manifests in our study

Table 5

Characterizing PIU based on Demographic Variables, Psychiatric Co-morbidities and Symptoms.

	Factor	Average PIU-SF-6 Score [SD]	F-stat/t-stat	p-value
Gender	*Male*	11.2 [5.2]	0.66	0.80
	Female	10.3 [3.2]		
	Transgender	12.0 [2.4]		
Diagnosis	*Anxiety/No Anxiety*	9.32 [2.8] / 12.4 [4.0]	2.20	0.04*
	Depression/No Depression	10.0 [4.2] / 12.4 [3.3]	1.53	0.14
	ADHD/No ADHD	12.5 [4.4] / 10.0 [3.2]	−1.53	0.14
Age	**β-Coeff.**	**p-value**		
	−0.41	0.18		
Scale	**Mean Score During PIU Episodes [SD]**	**Mean Score After PIU Episodes [SD]**	**t-stat**	**p-value**
PHQ-8	10.6 [5.9]	9.05 [6.9]	2.40	0.31
GAD-7	8.98 [5.8]	6.11 [5.5]	1.05	0.03*
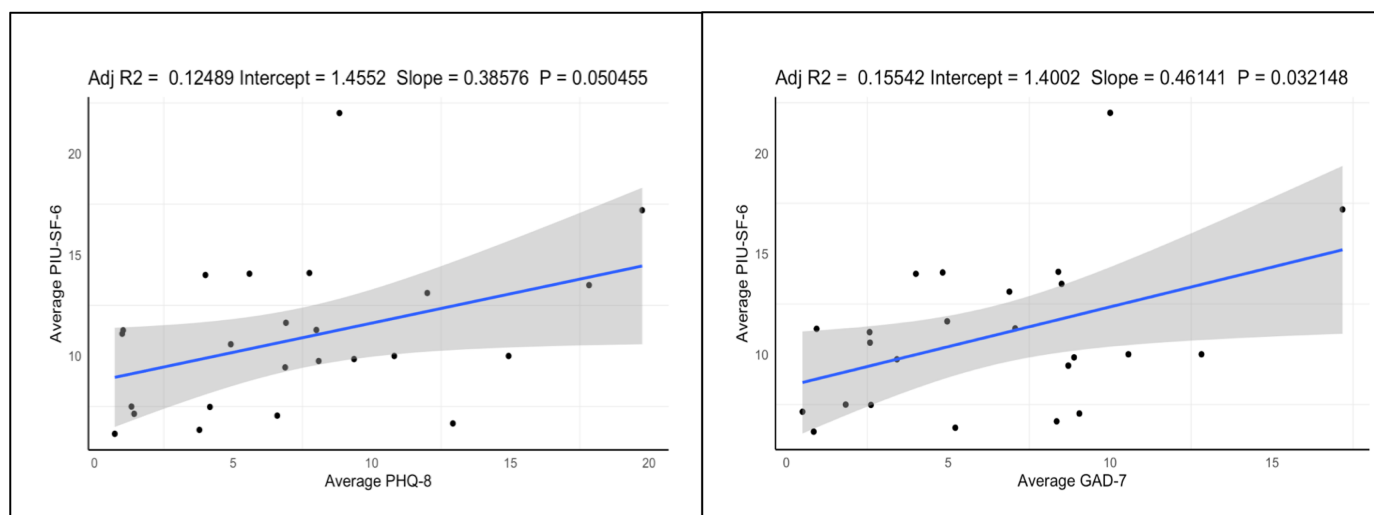
Fig. 2. Associations between PIU severity (as measured by PIU-SF-6) and Depression and Anxiety Symptoms (as measured by PHQ-8 and GAD-7 scale scores respectively).

population. For example, cross-sectional studies estimate a wide range of PIU prevalence, between 0.8 and 8.8%, in the general adolescent population (Kuss and Lopez-Fernandez, 2016). 62.5% of our participants met PIU criteria (PIU-SF-6 score ≥ 15) on one or more days over the course of the 6-week study period, suggesting that PIU may be more prevalent than previously noted, especially in adolescents with psychiatric comorbidities. The small sample size of our study limits the generalizability of this finding to the overall clinical population, especially given the heterogeneity of psychiatric symptoms and diagnoses. However, repeated sampling through smartphone EMA may offer a better approximation of PIU symptomatology for all adolescents, allowing researchers to capture times where adolescents' digital media use tends to be more frequent or problematic (e.g. at night, weekends).

Notably, our results do not support prior research findings of significant relationships between PIU severity, male gender and older adolescents (Choi et al., 2014; Kaess et al., 2014; Karacic and Oreskovic, 2017; Strittmatter et al., 2016; Sugaya et al., 2019). Our inability to replicate such findings may reflect the growing heterogeneity of the Internet's role in the lives of today's youth. The increasing popularity of video-streaming applications may be increasing the amount of time spent on the Internet by younger teenagers, who prefer watching videos online to social networking (Rideout and Robb, 2019) Concerning gender, expanding social media applications may be increasingly driving female PIU as females are more likely to go online for social networking purposes, in contrast to males with PIU, who prefer online gaming (Strittmatter et al., 2016). These different "subtypes" of PIU may mean that PIU may be characterized differently depending on age or gender, and these subtypes may have different associations with specific psychiatric symptoms. For example, males with mobile gaming addiction may be more likely to suffer from social anxiety, depression, and loneliness (Wang et al., 2019). While balancing the need for a brief app protocol to optimize adherence, future studies should consider adding active survey questions to discern content of Internet use in order to explore PIU subtypes based on sociodemographic variables.

Our study's methodology did allow us to begin to clarify the temporal relationship between PIU and mood symptoms, specific to the timepoint where a youth meets criteria for PIU. Studies phenotyping PIU have posited the existence of a compulsive, anxious subtype that uses the Internet as a "coping skill" to distract from the discomfort of anxiety (Hoge et al., 2017; Jung et al., 2019) and this hypothesis has been bolstered by the finding of initial improvement in anxiety symptoms directly following youth use of digital media (Thom et al., 2018). Using repeated sampling, our study demonstrated that despite the

positive correlations between PIU, anxiety and depression scale scores, anxiety symptoms specifically became significantly better directly after a participant met criteria for PIU. While this finding does not preclude the possibility of a bidirectional relationship between mood symptoms and PIU, the demonstrated pattern of lowered anxiety immediately following spikes of uncontrollable Internet use has tremendous implications for parental guidance surrounding digital media use in general. If nearly 10% of digital media-related psychiatric hospitalizations are secondary to device removal by parents or guardians (Gansner et al., 2019), mental health providers should advise caregivers that an adolescent may be demonstrating PIU in order to alleviate anxiety. Youth may be using the Internet for passive distraction from anxiety-provoking interpersonal conflicts or to bring about an active resolution to real-life conflicts that cannot be managed via face-to-face contact. Identifying the reasons behind PIU symptomatology may help caregivers guide children towards alternative coping skills or anxiety treatment.

Finally, current treatment guidelines recommend addressing PIU through the treatment of existing psychiatric disorders (Pluhar et al., 2019), but the apparent discrepancy between symptoms endorsed and current psychiatric diagnosis may represent a unique challenge when addressing PIU in adolescents in mental health treatment (e.g. the positive association we found between PIU and anxiety symptoms despite a significant negative correlation between PIU and anxiety disorder diagnosis). Screening tools like the PHQ-8 and GAD-7 are designed to identify existing anxiety or depressive disorders but these measures are less disorder-specific in adolescents, especially in the presence of multiple psychiatric co-morbidities (Richardson et al., 2010). Therefore, because psychiatric diagnoses may not always match endorsed psychiatric symptoms in our specific study population, it may be more effective for mental health providers to treat PIU through the identification and targeting of symptoms, rather than diagnoses, associated with an individual's PIU (e.g. targeting trauma related-anxiety for which an adolescent with PTSD is using social media as a coping skill).

4.3. Future directions and limitations

This study has several limitations that may restrict the generalizability of its findings. First, despite comprising an estimated 2% of the adolescent population (Rideout and Robb, 2019), 20% of our sample identified as transgender. It is unclear to what extent this percentage over-represents non-gender conforming youth in the outpatient mental health setting, however, considering that transgender youth are

significantly more likely to struggle with serious mental health issues than their cis-gender peers (Becerra-Culqui et al., 2018; Connolly et al., 2016). While one 2019 study suggested that LGBTQ youth may be more likely to seek health information online, their use of mental health apps appears similar to that of gender conforming youth, supporting the finding of no significantly different response rate in our transgender sample. Thus, while future studies should consider a unique pattern of digital media use dependent on gender or sexual identity, our preliminary results do not suggest that EMA app adherence would be different in these youth.

Additionally, the sample of size of this pilot study was small, and while EMA provides more ecologically valid data, it is still vulnerable to self-report bias. Future studies should look to increase sample size to provide more conclusive evidence surrounding the feasibility of using smartphone-EMA to assess a patient's PIU as well as to investigate further the nuanced relationships between PIU and psychiatric symptoms in this population. To address issues with data subjectivity, digital phenotyping is a growing research methodology that leverages the collection of active data through EMA with the passive collection of more "objective" behavioral data like step-count or phone power state (Onnela and Rauch, 2016). Supplementing our EMA protocol with passive data collection from a participant's smartphone may help to provide both greater personalized detail about a youth's digital media use and related psychiatric symptoms and behaviors, as well as additional evidence clarifying PIU phenotypes within this high-risk population.

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Author contribution statement

Dr. Gansner was involved in conceptualization, methodologic design, data collection and curation, formal analysis, funding acquisition, writing the original manuscript draft and subsequent revisions. Ms. Nisenson was involved in data collection and curation, formal analysis, writing the original manuscript draft and subsequent revisions. Drs. Carson and Torous were involved in conceptualization, methodologic design, and writing and revising the manuscript.

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.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.psychres.2020.113428.

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