Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Associations of active and passive smartphone use with measures of youth mental health during the COVID-19 pandemic

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ABSTRACT

Smartphone use provides a significant amount of screen-time for youth, and there have been growing concerns regarding its impact on their mental health. While time spent in a passive manner on the device is frequently considered deleterious, more active engagement with the phone might be protective for mental health. Recent developments in mobile sensing technology provide a unique opportunity to examine behaviour in a naturalistic manner. The present study sought to investigate, in a sample of 451 individuals (mean age 20.97 years old, 83% female), whether the amount of time spent on the device, an indicator of passive smartphone use, would be associated with worse mental health in youth and whether an active form of smartphone use, namely frequent checking of the device, would be associated with better outcomes. The findings highlight that overall time spent on the smartphone was associated with more pronounced internalizing and externalizing symptoms in youth, while the number of unlocks was associated with fewer internalizing symptoms. For externalizing symptoms, there was also a significant interaction between the two types of smartphone use observed. Using objective measures, our results suggest interventions targeting passive smartphone use may contribute to improving the mental health of youth.

1. Introduction

1.1. Smartphone use

Individuals use technology and internet services for a variety of reasons, including practical aspects such as convenience of accessing information, as well as for education, social interaction, communication, and entertainment (Erz et al., 2018; Fullwood et al., 2015; Lee et al., 2020; Ophir et al., 2021; Sung et al., 2016). Technology use has become ubiquitous and age appears to be the most important predictor of frequency of use (Büchi et al., 2016). Smartphones, an accessible type of technology, appear to be very popular with youth; they are the most intensive users of these devices, spending an increasing amount of time online daily (Boumosleh & Jaalouk, 2017; Rho et al., 2019). Previous research (Lee et al., 2020) has highlighted that youth frequently prefer to use their smartphone to access the internet, due to its portability and ease of connectivity, compared to other available devices. Moreover, it appears that youth engage with smartphones even while being exposed to other types of screen-time, such as using them while watching television to avoid paying attention to advertisements (Stiglic & Viner, 2019).

1.2. Impact of screen-time on youth mental health

As smartphone use has increased (Government of Canada, 2021) and these devices are playing a larger role in the daily lives of youth, there

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has been growing concern regarding the impact of all types of problematic smartphone use behaviour on youth mental health (Elhai et al., 2017; Kuss et al., 2018; Yang et al., 2019). Problematic smartphone use (Yang et al., 2019) is defined as uncontrolled frequent checking of the smartphone, overuse late at night, and irrelevant use during important activities (such as during class). Such problematic behaviours have further been linked to risk taking, such as dangerous driving (Kuss et al., 2018), and addictive behaviours (Liu et al., 2019).

While there appears to be mixed evidence regarding the impact of digital technology engagement on youth mental health (Jensen et al., 2019; Vuorre et al., 2021), some longitudinal investigations suggest that, for children, screen-time may be a significant factor leading to internalizing symptoms and externalizing symptoms, along with other poor socioemotional and developmental outcomes (McArthur et al., 2022; Neville et al., 2021). Overall, it appears that smartphones may be used by youth at increasingly younger ages (Fischer-Grote et al., 2019), and in a maladaptive manner (Park & Park, 2021), to distract themselves from negative emotions, often with detrimental impact on their well-being and development (Madigan et al., 2019; Twenge & Martin, 2020).

1.3. Impact of COVID-19 pandemic

Even before the COVID-19 pandemic, researchers raised concerns that screen-time may be a risk factor or marker of anxiety and depression in adolescents (Maras et al., 2015). The pandemic has only exacerbated this, triggering an increase in screen-time among both adults and children (Carroll et al., 2020; Chen et al., 2021). While most of the observed increases were for educational and entertainment purposes, children from low socioeconomic households appeared to have greater increases in use for non-educational purposes than those from higher socioeconomic backgrounds (Ribner et al., 2021). Concerningly, 85% of university students reported substantial increases in smartphone use during pandemic restrictions, with 42% of them using their phones more than 6 hours per day (Saadeh et al., 2021).

1.4. Passive and active smartphone use

Research indicates that not all types of smartphone use are equivalent and determining specific types of use and their relationships with mental health is therefore critical. Communicative or social activities are considered active and are expected to positively influence mental health (Burke & Kraut, 2016; Oh et al., 2014), whereas other types of use that are considered mainly passive or non-communicative are expected to undermine mental health (Verduyn et al., 2015; Wang et al., 2018). In line with this theory, non-social activities on smartphones have been linked to depression and anxiety (Elhai et al., 2020) and other poor mental health outcomes (Demirci et al., 2015; Sohn et al., 2019). Passively consuming content and overall duration of screen-time has been found by studies to be associated with a decrease in well-being and quality of life in young people (Stiglic & Viner, 2019). Over-use of social network apps has been found to be linked with maladaptive cognitions and rumination in college students (Mao et al., 2022); interestingly, this excessive use appeared to be driven in some cases by boredom or a fear of missing out (Elhai et al., 2020; Stiglic & Viner, 2019; Yang et al., 2019). In contrast, use of the communicative and interactive features of such apps appears to be a less damaging form of screen-time (Boers et al., 2019). In addition, multiple studies suggest that youth who utilize social media for self-expression are more likely to receive social reciprocity (Alhabash & McAlister, 2015; Seabrook et al., 2016); some youth use these apps to find sources of humor or a connection to others, all of which appeared to be protective for mental health (Hoge et al., 2017).

A recent study investigating different types of smartphone use (MacDonald & Schermer, 2021), observed that frequent checking of the smartphone linked to increased use of communication apps, was negatively associated with loneliness. Two Canadian studies conducted during pandemic lockdowns provided additional support for the beneficial effects of active smartphone use by observing that youth could significantly counteract feelings of loneliness through connecting with others virtually (Ellis et al., 2020; Parent et al., 2021) . Fewer social interactions and less device use to call or message friends and family have been found to be predictive of higher depression symptoms among youth mental health patients (Cao et al., 2020). Thus, active use of smartphone may be protective of mental health (Shaw et al., 2020) while a passive use may have detrimental effects.

1.5. Mobile sensing

Many studies have only used self-report measures, which can be problematic due to recall biases and misestimation of actual time spent on the smartphone (Wade et al., 2021). As such, objective assessments are needed and considering the omnipresence of smartphones and the recent advances in mobile sensing technology, the devices themselves may offer the unique opportunity to collect objective information continuously, in an unobtrusive manner (Ferreira et al., 2016; Torous et al., 2016). This method is low-burden for participants while providing more value to researchers and clinicians (Meyerhoff et al., 2021; Shaw et al., 2020). Smartphone use patterns have been associated with various social and behavioural manifestation of mental illness in naturalistic settings, in an unprecedented moment-by-moment quantification of disease phenotypes, presenting many opportunities for advancing research and augmenting clinical decision-making (Torous et al., 2016).

1.6. Summary and hypotheses

Most research provides supportive evidence for an association between smartphone use and youth mental health; however, many studies have only used subjective assessments which can be problematic and unreliable. Thus, we aimed to assess the impact of objectively measured smartphone use on youth mental health through a large-scale study. We utilized a mobile sensing app to objectively measure smartphone use and explored its association with mental health during the COVID-19 pandemic. We theorized that the type of smartphone use measured will have a differential association with youths' mental health. Specifically, we hypothesized that: (H1) objective screen-time, as measured by the mobile sensing app, will be correlated with self-reports of passive smartphone use behaviours (e.g. browsing the internet, passively consuming content such as videos or blogs), while objective number of unlocks will be correlated with more active smartphone use behaviours (e.g. texting and messaging friends or family). We also hypothesized that (H2) an increase the duration of smartphone-based screen-time would be associated with worse mental health, while (H3) an increase in active smartphone use, exemplified by the number of unlocks would be associated with better mental health. Finally, we hypothesized that (H4) there would be a significant interaction between these two types of smartphone use, such that in youth with an extremely high amount of passive smartphone use, active use may not be associated with better mental health. The present study aimed to gain a better understanding of the various ways in which objectively assessed smartphone use is associated with mental health, which in turn, may help researchers identify future research directions with impact on interventions and policies aimed at youth, parents, and educators.

2. Methods

2.1. Sample

Between June 2020-November 2021, we recruited 550 English-speaking youth, aged 15–25, with and without a mental disorder, who had a smartphone with an iOS or Android operating system. To comply with existing COVID-19 policies, participants were recruited using ads on established online platforms (e.g., Facebook, Instagram, Kijiji) and all

contact with participants was made remotely, through email or over the phone.

2.2. Procedure and consent

Potential participants were guided through detailed information regarding study procedure and consent via "REDCap", a platform specifically designed to conduct online studies (Garcia & Abrahão, 2021) and approved by local health authorities. To facilitate generalizability, both participants with and without a mental health disorder were included in the study. We excluded participants who were inpatients at the time of recruitment because they experience involuntary restrictions in accessing their smartphones. Through REDCap, participants were informed about the study, had the opportunity to ask questions, and consented to participate in the study. Then, they provided demographic information and completed the questionnaires. Participants then received instructions to download the mobile sensing app and use it continuously for at least 14 days. The procedures of the study were approved by the research ethics board at an Eastern Canadian University and abided by the Declaration of Helsinki regarding ethical principles involving human participants.

2.3. Assessments

2.3.1. Mobile sensing technology

The app used in this study (PROSIT-Predicting Risks and Outcomes of Social InTeractions), developed by the PROSIT lab (MacLeod et al., 2021) is a passive mobile sensing app that unobtrusively collects information about smartphone use and can be easily used by youth. The app does not interfere with usual smartphone use, is available for both Android and iOS operating systems, and has a simple, user-friendly interface. The app runs automatically in the background and it does not need user input to monitor smartphone use behaviour. It collects data on smartphone interactions, accelerometer, location, screen-time activity, ambient noise and light, and connectivity. All study participants were informed in detail about the data to be gathered by the app and could stop data collection at any timepoint. Collected data were uploaded automatically in the background to secure servers using state-of-the-art encrypted SSL connections. Although the app collects data from various sensors, for the purpose of the present study, we only focused on two types of smartphone use: screen-time (the duration the smartphone was in use) and number of unlocks (calculated based on the measured smartphone interactions).

2.3.2. Smartphone use

Objective daily duration of screen-time can be calculated by summing up screen-time time periods – the time window in which a participant is actively using the phone between turning on the display and turning off the screen. The operating system logs screen-time and, with appropriate permissions by the user, the mobile sensing app can access these logs and store them in a secure database. To assess changes in phone use, we also calculated the frequency of checking the smartphone through daily number of unlocks (how many times the user locks and unlocks the smartphone) and total time spent using the smartphone across all screen-time activity windows. This methodology is in accordance with previous research in this area (Wade et al., 2021), which highlights that passive, objective sensing more accurately reflects the daily smartphone use behaviour of youth compared to self-report measures.

2.3.3. The Strengths and Difficulties Questionnaire (SDQ)

Mental health was assessed using the Strengths and Difficulties Questionnaire (SDQ). Participants completed the questionnaire once before downloading the app to their device. The SDQ (Goodman, 1997) is a widely used measure of psychological well-being in youth and has high concurrent validity with other common measures of mental health (Goodman & Scott, 1999). The SDQ includes 25 items each rated on a 3-point Likert scale. The questionnaire has fair internal consistency ($\alpha = 0.73$) and test-retest reliability ($\alpha = 0.62$) (Goodman, 2001). The self-report SDQ has two forms, one suitable for those aged 11–17, and another form for participants who are 17 years old and above (which contains identical questions that were reworded to be developmentally appropriate); recent studies support the use of the SDQ for young adults (aged 18–25), citing similar psychometric properties (Brann et al., 2018) and ability to detect clinical symptoms (Riglin et al., 2021) to the adolescent version. In the current study, both versions were used based on the age of the participants. For the purposes of the present study, internalizing and externalizing symptomatology scores were calculated.

2.3.4. Self-reports of screen-time activity

In order to explore how the objective smartphone use data collected using mobile sensing was related to self-reports of screen-time, we also collected information about the daily habits of participants through an adapted questionnaire, similar to previous studies (Dickel, 2021; Raw et al., 2021). The questionnaire asked participants about how much time they spent on social activities with friends or family: calling, texting, video-calling, gaming or communicating via social media; moreover, the participants were asked about how much time they spent playing video or app games, watching television/Netflix/YouTube, listening to music, browsing the internet, and posting content online/blogging. The following are examples of such questions: "During the past week, how much time per day did you spend talking on the phone?", "During the past week, how much time per day did you spend browsing the internet?". The questionnaire included 6 answer options: "(a) Did not do this activity, (b) less than 30 min, (c) between 30 min and 2 h, (d) 3 to 5 h, (e) over 6 h, and (g) Prefer not to answer".

2.3.5. Covariates

We collected demographic information such as age, sex, gender, socio-economic status, ethnicity, mental health diagnosis and treatment, as well as education of parents through a self-report questionnaire adapted from a recent Statistics Canada Survey. Biological sex was included as a covariate in the analysis due to the literature pointing to different patterns of smartphone use (Godsell & White, 2019; Saadeh et al., 2021; Twenge & Martin, 2020), along with differences in prevalence of internalizing and externalizing symptoms, in males and females (Atherton et al., 2018; Yong et al., 2014). Due to differences in the availability of sensors and how they collect data, we included phone operating system type (iOS or Android) as a covariate, to rule out any potential confounding effects. As we included both participants who were currently receiving treatment for a mental health disorder in the study, we further included current mental health treatment as a covariate to account for the setting and its potential impact on mental health. Participants self-reported whether they are currently in treatment for a mental health disorder. Finally, as maternal education and family income can have a significant impact on youth mental health (Bitsko et al., 2022; Hosokawa & Katsura, 2017), we adjusted for this covariate. Specifically, we utilized maternal educational history as a proxy for socio-economic status (Jackson et al., 2017), since youth may not correctly estimate family income.

2.4. Data analysis

All statistical analyses were performed using the R programming language (version 4.1.2) and RStudio (version 2021.09.0/B351). From the initial 550 sample, 20 participants declined to participate. During quality control preprocessing, 10 participants with time windows that seemed to be caused by smartphone misuse or technical errors, such as any period of screen-time longer than 10 hours, were excluded from further analysis. Furthermore, 69 other participants had less than 14 days of app data collected, and they were also excluded. Out of the remaining 451 participants, 30 had missing values on the internalizing

symptoms factor of the SDQ or on the externalizing symptoms factor (participant flowchart depicted in Fig. 1). These missing values were due to participants choice to select the "prefer not to answer" option to a question in the SDQ, so that no adequate symptom score could be obtained. Accordingly, those participants were excluded from further analysis. There were no statistically significant differences between the remaining sample and the one initially invited to participate, based on age, biological sex, maternal education, or current treatment status.

First, descriptive statistics were computed for sample characteristics, predictors (screen-time and number of unlocks) and outcome variables (internalizing and externalizing symptoms). Next, to test our first hypothesis, we explored how objective mobile-sensed data is related to subjective self-reports of smartphone use by comparing these measures via Spearman correlations between mean duration of smartphone-based screen-time and number of unlocks and each of the self-reported screen activities described above. Correlation analyses were adjusted for multiple testing (20 tests in total performed). To test our second and third hypotheses, we ran a series of hierarchical multiple regressions to analyze the association between internalizing and externalizing symptoms (outcomes) and both types of smartphone use predictors (screen-time and number of unlocks), while controlling for the covariates described above: biological sex, phone type, mental health diagnosis, and maternal education. Regression analyses were also adjusted for multiple testing (2 tests performed, for the two different outcomes).

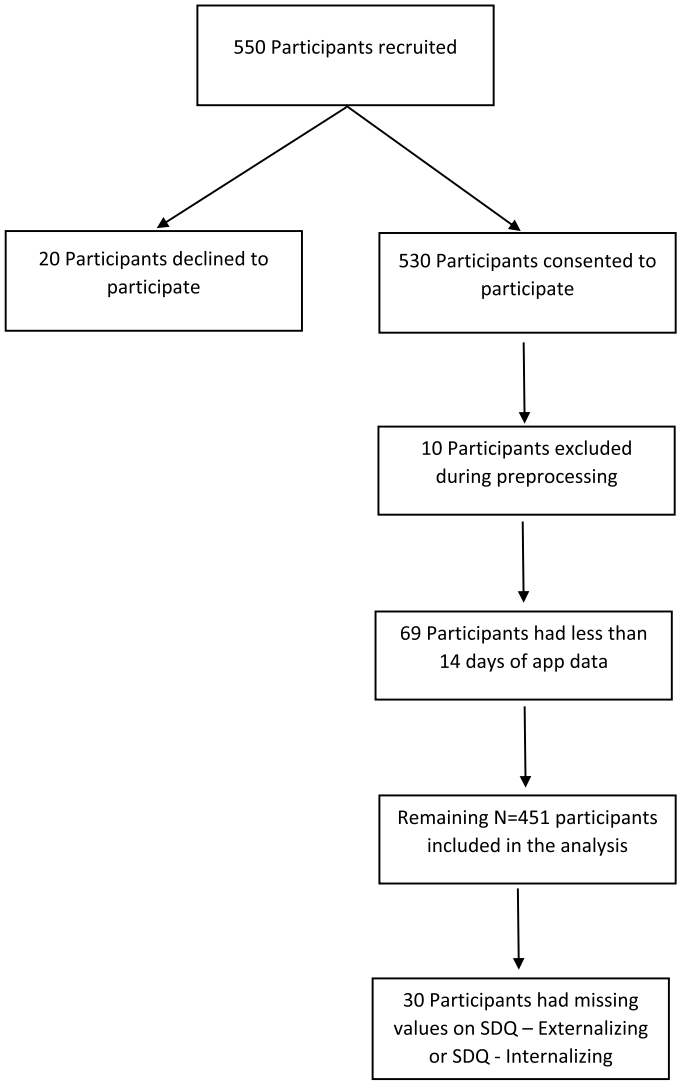

Fig. 1. Flowchart of participants.

Finally, to test our fourth hypothesis, we ran linear regression models to assess the interplay of these two types of smartphone use by including the interaction between duration of screen-time and number of unlocks. Specifically, we evaluated if adding the interaction improves the model fit and explains more variance in the outcomes of interest – internalizing and externalizing symptoms.

3. Results

3.1. Sample characteristics

The sample ($n = 451$) was predominantly female (83%), with an age range between 15 and 25 years old, and an average age of 20.97 ($SD = 2.49$). For type of phone, 118 (26%) participants reported using a smartphone with an Android operating system and 333 (74%) had a phone with iOS. Categorical characteristics are further detailed in Table 1. Participants used the app for an average of 30.63 days ($SD = 10.9$), used their phone on average for 3.49 hours per day ($SD = 1.79$) and unlocked it 55.81 ($SD = 35.13$) times per day.

3.2. Objective and subjective screen-time correlations

Spearman's rank correlation was computed to assess the relationship between the mobile sensed mean duration of screen-time and number of unlocks. There was a moderate correlation between these two variables ($r(449)=.42$, $p < .001$). To compare objective smartphone use data collected using mobile sensing with self-reports of screen-time activity, Bonferroni adjusted Spearman correlations were calculated. All results are presented in Table 2 and significant results are highlighted below.

After corrections for multiple testing, mean screen-time per day was found to be significantly correlated with self-reported time spent browsing the internet ($r(449)=.15$, $p=.02$), but none of the other self-reported screen activities. In contrast, the average number of unlocks was significantly correlated with self-reported time spent texting with friends/family ($r(449)=.18$, $p=.001$) and communicating via social media ($r(449)=.18$, $p=.001$), but not the other self-reported screen activities.

3.3. Hierarchical regression models

To evaluate the two hypotheses examining the effect of passive overall screen-time and active number of unlocks on mental health, we ran hierarchical multiple regression models to predict internalizing and externalizing symptoms, respectively, as measured by the SDQ, using mean screen-time and number of unlocks and the covariates outlined previously as predictors. The results are Bonferroni adjusted and presented in Tables 3 and 4.

Table 1
Sociodemographic categorical characteristics of participants.

Characteristic	*n*	%	Total
Biological Sex			451
Female	375	83	
Male	76	17	
Phone Type			451
Android	118	26	
iOS	333	74	
Current Mental Health Treatment			451
Yes	91	20	
No	360	80	
Mother's education			451
Did not finish High school	22	5	
Finished High school	79	18	
Further education	97	21	
University	244	54	
I don't know	4	<1	
Prefer not to answer	5	1	

Table 2
Correlations between objective and subjective smartphone use measures.

	Mean Screen-time	Number of unlocks
Talking on the phone with friends/family	-0.02	0.03
Video calling friends/ family	-0.02	0.02
Communicating via WhatsApp or text	0.11	0.18*
Communicating via social media	0.08	0.18*
Gaming with friends/ family	0.10	0.03
Time spent playing video or app games	0.02	-0.05
Watching films/Netflix/YouTube	0.08	-0.07
Listening to music	0.01	-0.04
Browsing the internet	0.15*	0.01
Posting content online (TikTok/Instagram) or blogging	-0.06	-0.05

*$p < .05$. **$p < .01$.

Table 3
Regression results depicting associations between externalizing symptoms and predictors.

Predictor	*b*	*b* 95% CI [LL, UL]	t	
Step 1				
Mental Health Treatment	0.18**	[0.08, 0.28]	3.67**	
Biological Sex	0.01	[-0.08, 0.11]	0.28	
Mother's Education	-0.17**	[-0.26, -0.07]	-3.49**	
Phone Type	0.01	[-0.08, 0.11]	0.26	R^2 = .063** 95% CI [.02,.10]
Step 2				
Duration of Screen-time	0.18**	[0.08, 0.28]	3.61**	
Number of Unlocks	-0.10	[-0.20, 0.01]	-1.77	
Mental Health Treatment	0.17**	[0.08, 0.27]	3.62**	
Biological Sex	0.01	[-0.09, 0.10]	0.09	
Mother's Education	-0.15**	[-0.24, -0.06]	-3.18**	
Phone Type	0.01	[-0.10, 0.11]	0.11	R^2 = .093** 95% CI [.04,.14]
				ΔR^2=.030** F(1,414) = 6.81

Note. b represents unstandardized regression weights. *LL* and *UL* indicate the lower and upper limits of a confidence interval, respectively.
* indicates $p < .05$. ** indicates $p < .01$.
Biological sex was coded in the analysis as: 0 – Female, 1 - Male; Current mental health treatment was coded as: 0 – Yes, 1 – No; Mother's education was coded as: 0 – Did not finish high-school, 1- Finished high-school, 2-Further education, 3 – University, 4 – I don't know, 5 – Prefer not to answer. Phone type was coded as: 0 - Android, 1 - iOS

At Step 1 of the analysis, we entered the four covariates; our results suggest that they accounted for 6.3% of the variance in externalizing symptoms and 9.5% of the variance in internalizing symptoms, respectively. Adding the two smartphone use predictors to the covariates model at the second step significantly improved the fit for both externalizing (ΔR^2=.03, F(1,414) =6.81, p <.001) and internalizing symptoms (ΔR^2=.02, F(1,414) = 5.07, p <.001).

Our results (corrected for multiple comparisons) revealed that mean duration of screen-time was significantly associated with externalizing (b=.18, t(414)=3.61, adjusted p <.001, unadjusted p<.001) and internalizing symptoms (b=.14, t(414)=2.85, adjusted p=.008, unadjusted p=.004), in such a manner that an increase in duration of screen-time was associated with worse mental health. The results for number of unlocks were more diverse. The number of unlocks were significantly

Table 4
Regression results depicting associations between internalizing symptoms and predictors.

Predictor	*b*	*b* 95% CI [LL, UL]	t	
Step 1				
Mental Health Treatment	0.21**	[0.12, 0.30]	4.39**	
Biological Sex	-0.15**	[-0.25, -0.06]	-3.14**	
Mother's Education	-0.04	[-0.14, 0.05]	-0.95	
Phone Type	-0.13**	[-0.22, -0.04]	-2.72**	R^2 = .095** 95% CI[.04,.14]
Step 2				
Duration of Screen-time	0.14**	[0.04, 0.24]	2.85**	
Number of Unlocks	-0.12*	[-0.22, -0.01]	-2.18*	
Mental Health Treatment	0.21**	[0.11, 0.30]	4.34**	
Biological Sex	-0.16**	[-0.25, -0.06]	-2.96**	
Mother's Education	-0.03	[-0.12, 0.06]	-0.66	
Phone Type	-0.15**	[-0.25, -0.05]	-2.96**	R^2 = .116** 95% CI[.05,.16] ΔR^2=.021** F(1,414) = 5.07

Note. b represents unstandardized regression weights. *LL* and *UL* indicate the lower and upper limits of a confidence interval, respectively.
* indicates $p < .05$. ** indicates $p < .01$.
Biological sex was coded in the analysis as: 0 – Female, 1 - Male; Current mental health treatment was coded as: 0 – Yes, 1 – No; Mother's education was coded as: 0 – Did not finish high-school, 1- Finished high-school, 2-Further education, 3 – University, 4 – I don't know, 5 – Prefer not to answer. Phone type was coded as: 0 - Android, 1 - iOS

associated with internalizing symptoms (b= -.12, t(414) = -2.85, adjusted p =.05, unadjusted p =.02), in such a manner that an increase in unlocks was associated with less internalizing symptoms. In contrast, the association between the number of unlocks and externalizing symptoms was not significant (b=-.10, t(413) = -1.77, adjusted p =.16, unadjusted p=.08).

3.4. Linear regression models testing the interaction

To explore the interaction of screen-time and number of unlocks, we added an interaction term to the model. Our analyses revealed a significant interaction between screen-time and number of unlocks for externalizing symptoms (b=.10, t(413) = 2.14, p =0.03), which improved the model fit (ΔR^2= .010, F(1,414)=4.59, p = 0.03). Specifically, the association of number of unlocks with externalizing symptoms varied based on the duration of screen-time. While in youth with a low mean duration of screen-time, the number of unlocks was associated with less externalizing symptoms, in youth with high mean duration of screen-time the number of unlocks was not associated with less externalizing symptoms. The model is presented in Table 5 and the interaction is shown in Fig. 2. In contrast, no interaction was observed for internalizing symptoms (F(1,414)=0.72, p = 0.40).

4. Discussion

This study explored the association between objectively measured smartphone use, using a mobile sensing app, and youth mental health. We hypothesized that (H1) objective screen-time, as measured by the mobile sensing app, will be correlated with self-reports of passive smartphone use behaviours, while objective number of unlocks will be correlated with more active smartphone use behaviours. We also hypothesized that (H2) an increase in duration of smartphone-based

Table 5
Regression results using externalizing symptoms as the criterion including an interaction term.

Predictor	*b*	*b* 95% CI [LL, UL]	t
(Intercept)	-0.04	[-0.13, 0.06]	
Duration of Screen-time	0.21**	[0.11, 0.32]	4.06**
Number of Unlocks	-0.13*	[-0.24, -0.02]	-2.29*
Mental Health Treatment	0.18**	[0.09, 0.28]	3.77**
Biological Sex	-0.00	[-0.10, 0.09]	-0.03
Mother's Education	-0.16**	[-0.25, -0.06]	-3.29**
Phone Type	0.02	[-0.08, 0.12]	0.41
Mean Screen-time X Number of Unlocks	0.10*	[0.01, 0.20]	2.14*
			R^2 = .103** 95% CI [.04,.15]

Note. b represents unstandardized regression weights. *LL* and *UL* indicate the lower and upper limits of a confidence interval, respectively.
* indicates $p < .05$. ** indicates $p < .01$.

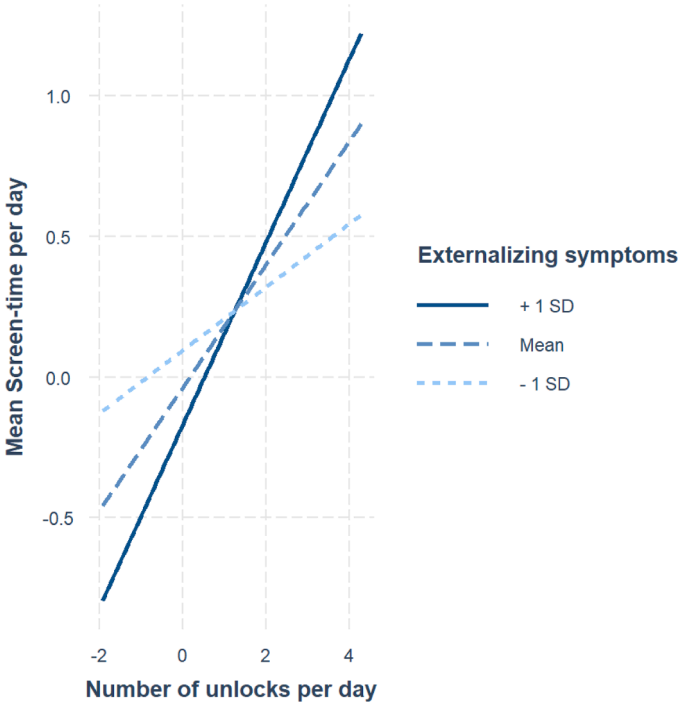

Fig. 2. The interaction between mean screen-time and number of unlocks predicting externalizing symptoms.

screen-time would be associated with worse mental health for this population and (H3) the number of unlocks reflecting social activities would be associated with better mental health. Finally, we hypothesized that (H4) there would be a significant interaction between these two types of smartphone use, such that for youth with an extremely high duration of screen-time, the number of unlocks might not be associated with better mental health. In addition, we also compared objective mobile sensed screen-time to subjective self-reports, to understand which screen activities the objective mobile sensing data is most likely to mirror.

We found that our results were, for the most part, supportive of the hypotheses and consistent with previous findings. The comparison between objective and subjective smartphone use revealed a small correlation between mean duration of screen-time per day and self-report of time spent browsing the internet, which can be considered a more passive type of screen-time activity. This type of smartphone use has also been suggested to be a more detrimental type of screen-time due to its association with worse youth mental health outcomes, such as increases in anxiety, depression, and sleep issues (Demirci et al., 2015). Moreover, general duration of screen-time has been found problematic due to being associated with stress and poor educational attainment in children and young people (Sohn et al., 2019).

While our study does not confirm a causal relationship, it demonstrates a significant association between average time spent on the smartphone per day and higher levels of both internalizing and externalizing symptoms in youth, in line with previous findings, and importantly, offers an improvement in the measurement of smartphone use that will support future research that aims to disentangle these complex relationships. In addition, our study found that current mental health treatment and level of the education of the mother are significant predictors of externalizing symptoms, while biological sex and phone type are significant predictors of internalizing symptoms. The results showed that not currently receiving mental health treatment and having a mother with a lower educational level is linked to more externalizing symptoms, in line with current research showing that maternal education can have a significant impact on youth mental health (Hosokawa & Katsura, 2017). Being a female participant was linked to more internalizing symptoms, which is often highlighted in other studies (Atherton et al., 2018; Yong et al., 2014), however there is very little data available on how type of smartphone is associated with mental health.

Previous studies have underscored that smartphone use has a complex relationship with psychopathology across youth development, for example, finding positive associations between duration of screen-time and externalizing and internalizing behaviours (Eirich et al., 2022; Neville et al., 2021). Longitudinal studies of youth that exhibit externalizing and internalizing symptoms during childhood emphasize that they are more at risk to develop other types of psychopathologies through adolescence and young adulthood and that detrimental life outcomes impact not just families but their communities as well (Atherton et al., 2018; Neville et al., 2021).

One explanation for the relationship between screen-time and poor mental health may be provided through displacement theory (Cooper, 1994), suggesting that the deteriorating effect of high duration of screen-time on mental well-being may be due to the smartphone displacing other wellness-promoting activities for youth, such as quality sleep or physical activity (Liu et al., 2019). Sufficient sleep and physical activity are imperative for the development and mental well-being of young people, and excessive screen-time can disrupt daily routines by impacting circadian rhythms and causing daytime fatigue (Touitou et al., 2016), which leads to behavioural problems and poor academic achievement.

The comparison between average number of unlocks and self-reports revealed an association with self-reported time spent communicating with friends and family using the smartphone, such as through social media and texting. Specifically, more frequent unlocking as active type of smartphone use was found to be significantly associated with lower internalizing symptom scores in youth. The literature suggests that frequency of communication with others in the close support network through smartphones can be protective for youths' mental health (Moukaddam et al., 2019). Our results indicate that there is a weak but significant association between frequency of unlocking and use of social media and texting, suggesting the possibility that frequent unlocking is an indicator of social motivations for use. We suggest that this aspect be examined more directly in future studies by examining motives for use that are associated with frequency of unlocking, along with other types of active smartphone use.

Our analysis of the interplay between the two types of smartphone use revealed a significant interaction between them for externalizing symptoms, but not for internalizing symptoms. While for youth with a lower duration of screen-time, the number of unlocks was associated with less externalizing symptoms, this potential positive effect was lost for youth with a high duration of screen-time. This finding underscores

that while overall time spent on the smartphone was consistently associated with worse mental health in this study, the associations between number of unlocks and mental health seemed to depend on the duration of smartphone use. These results could indicate that, in youth with a high duration of use, limiting any type of smartphone use may be beneficial to their mental health.

4.1. Strengths and limitations

To our knowledge, the present study is one of the first to explore active and passive smartphone use and their associations with youth mental health using mobile sensing data. While previous studies have predominantly emphasized the deleterious impact smartphone screen-time can have on youth well-being, the current research has sought to explore how other types of smartphone use could be protective. Only by investigating the impact of diverse types of smartphone use and their interactions on mental health will we be able to gain a deeper understanding of smartphone use guiding the development of potential targeted interventions.

Another strength of the current study was that it utilized an objective assessment of smartphone use through utilizing innovative mobile sensing technology, in combination with the usual self-report assessments. Recent research (Neville et al., 2021) has highlighted objective measurement of smartphone use as a significant methodological advancement for the field; as such, the present study builds on this observation through continuous objective data collection that can provide a more accurate and data-rich source of behaviour monitoring compared to self-report measures. Studies employing passive sensing of smartphone behaviour in youth underline the potential measurement biases of self-reports. A recent study using a two-informant strategy indicated that youth themselves tend to under-report smartphone use (Wade et al., 2021), while their parents overestimated the youths' smartphone activity. Thus, relying solely on subjective reports of smartphone use from youth or other informants, like parents, is likely misleading and resulting in inaccurate assessments of behaviour, which can negatively impact the validity of studies that examine the effects of smartphone use on youth well-being.

One limitation of the current research is its cross-sectional design, that can only reveal associations between the variables of interest; longitudinal investigations could help examine the direction of the relationships and their impact on youth mental health. Moreover, the representativeness of the sample may be considered a limiting factor, since it was self-selected, predominantly female and limited to English-speaking youth that owned a smartphone. Although women are more likely to participate in health research studies (Galea & Tracy, 2007), it is important for future research to ensure representativeness through a more balanced recruitment. Another potential limitation that could be addressed by future studies is to specifically examine whether particular mental health disorders or mental health treatments impact smartphone behaviours and outcomes. Additionally, considering the use of other devices (tablets, laptops, TVs, etc.) might help disentangle some of the results obtained and may provide more specific information regarding how particular behaviours impact mental health. Moreover, a systematic review conducted by (Seabrook et al., 2016) has emphasized that motives of use can moderate outcomes and that often times, the perception of support during social interactions can have significant impact, so the examination of the content of communication through technology becomes particularly salient. While this is a limitation in the present study, in the future, such investigations would provide a clearer picture of other potential moderating factors. Furthermore, while our correlational analyses offer support for our definitions of passive and active smartphone use, objective measures of screen-time and number of unlocks do not exclusively reflect these types of smartphone usage, which can be considered another limitation of the study.

The COVID-19 pandemic has significantly disrupted the daily routines of youth in many ways, with negative impact on their mental well-being (Gallagher et al., 2020; Raw et al., 2021). Although youth primarily used smartphones for entertainment and maintaining contact with others, they might also have used the devices for educational purposes (Bergmann et al., 2022). These disruptions have been accompanied by increased screen-time (Trott et al., 2022; Wagner et al., 2021), along with decreases in wellness promoting behaviours, such as more sedentary time, less healthy eating and increased sleep problems (Becker & Gregory, 2020; Carroll et al., 2020; ten Velde et al., 2021). The results of the present study, conducted during the pandemic, might not fully reflect the behaviours and the mental health of youth post-pandemic.

4.2. Future directions

Future research should consider recruiting a more representative sample, through more targeted and balanced techniques that will ensure generalizability of results. Moreover, it is important that future studies strive to disentangle active and passive forms of smartphone use and their impacts on mental health through a more fine-grained monitoring of behaviour, such as patterns of use collecting time spent on specific apps; this would enable a differentiation in how youth are using their phone, whether for productive purposes (such as education or work), entertainment, connecting with others socially, or as a distraction (to manage negative feelings or withdraw from stressors) (Nagata et al., 2021). For example, a study exploring a messaging platform (WeChat) showed that some youth benefit from increased use of the app by diversifying and increasing their social network, which brought them higher life satisfaction (Pang, 2022). In contrast, another study of that same messaging app (Mao et al., 2022) suggested that excessive use of the platform is linked to maladaptive cognitions and rumination in college students. Researchers also highlight that excessive use of one app may be reinforcing addictive behaviours for the use of other apps as well (such as WeChat and Weibo), with negative consequences for youth mental health and social skills (Hou et al., 2017). Qualitative exploration of outcomes and motives for use may be employed to explain why youth choose to use their smartphones for particular activities and quantitative research can assess frequency of use and how these aspects impact their well-being. Moreover, longitudinal studies could investigate temporal associations and directionality. Finally, the results might have direct implications for the prevention and treatment of mental health issues. For example, clinicians could utilize mobile sensing to obtain a clearer picture of how youth are using their phone naturalistically, and to examine whether this use is linked to managing negative emotions and stressors, or whether the remote social communication provides an outlet in difficult times. Clinicians would then be able to work collaboratively with youth and families to provide interventions and psychoeducation on the potential benefits and harms of smartphone use, along with coping strategies to relieve the effects of excessive or problematic use. The mobile sensing app could be further expanded to offer just-in-time interventions by informing youth of their smartphone use and providing personalized suggestions on how to better manage their usage.

4.3. Conclusions

In conclusion, the present study explored the associations between smartphone use and youth mental health through a multi-method approach. The current study addresses the lack of objective measurements of smartphone use in previous research by utilizing innovative mobile-sensing technology to assess youth behaviour in a more accurate manner compared to self-report measures. Importantly, the present study distinguished between active and passive types of smartphone use, highlighting the differentiated associations with internalizing and externalizing symptoms in this population. These findings may help inform youth, parents, clinicians, and educators: while not all forms of smartphone use are detrimental, and smartphone-based social interactions may provide some protective benefits, excessive screen-time

appears be negatively associated with mental health. Given the lack of fine-grained behavioural and motivational observations of how youth interact with their devices, we conclude that more research in this area would be beneficial to better understand how mobile device use impacts youth mental well-being.

CRediT authorship contribution statement

Silvia Marin-Dragu: Conceptualization, Methodology, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Alyssa Forbes:** Data curation, Writing – review & editing. **Sana Sheikh:** Investigation, Data curation, Writing – review & editing. **Ravishankar Subramani Iyer:** Software, Writing – review & editing. **Davi Pereira dos Santos:** Software, Writing – review & editing. **Martin Alda:** Writing – review & editing. **Tomas Hajek:** Writing – review & editing. **Rudolf Uher:** Writing – review & editing. **Lori Wozney:** Writing – review & editing. **Fernando V. Paulovich:** Writing – review & editing. **Leslie Anne Campbell:** Writing – review & editing. **Igor Yakovenko:** Writing – review & editing. **Sherry H. Stewart:** Writing – review & editing. **Penny Corkum:** Writing – review & editing. **Alexa Bagnell:** Writing – review & editing. **Rita Orji:** Writing – review & editing. **Sandra Meier:** Conceptualization, Methodology, Formal analysis, Writing – review & editing, Project administration, Supervision.

Declaration of Competing Interest

All authors have no conflicts of interest to declare.

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