Using mobile technologies to advance the study of psychopathology among children and adolescents

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Mobile technologies have become an integral part of children and adolescents' daily interactions and activities. This generation, often referred to as 'digital natives', have been exposed to technology since birth (Palfrey & Gasser, 2008). They have never known a world without the Internet or without access to devices such as mobile phones and tablets. The growing presence of mobile devices in the lives of children is illustrated by the recent finding that one in three children under the age of 2 have used a smartphone and 75% of all children under age 8 have access to a mobile device at home (Rideout, Saphir, Pai, Rudd, & Pritchett, 2013). Usage and ownership increases with age. 95% of all adolescents in the US have regular access to the Internet (Lenhart, 2012) and 88% own or have access to a mobile phone (Lenhart, 2015). Text messaging has become one of the most common forms of daily communication between adolescents and their friends and families (Lenhart, 2012), with adolescents spending, on average, 1.5 hours texting, and 30 minutes talking on their cell phones on a daily basis (Rideout, Foehr, & Roberts, 2010).

Given the pervasiveness of mobile technologies in the lives of children and adolescents, researchers have begun to explore how new technologies may be used to capture, understand and, ideally, respond to, their emerging mental health problems. For example, the use of smartphones and tablets are opening up novel opportunities for the intensive study of symptoms of psychopathology in the daily lives of young people. In this chapter, we review the ways in which new technologies can be used by researchers to understand the etiology, daily triggers, contexts, and developmental course of psychopathology. Specific examples of the application of mobile technologies to the study of conduct problems in adolescence and ADHD symptoms in childhood are

provided, alongside a discussion of how mobile devices can enhance existing methodologies, such as ecological momentary assessment. Special attention is paid to the unique fit – and potential misfit - between 21st century children and the use of mobile technologies within research and intervention contexts. Finally, possible applications of mobile technologies in the study and treatment of psychopathology among young people are introduced, alongside a discussion of emerging fears regarding whether the (over)use of mobile technologies may be influencing children's mental health.

Using Mobile Technologies to Study the Mental Health of Children and Adolescents in Daily Life

Mobile technologies offer a number of opportunities to capture, measure, predict, and potentially respond to symptoms of mental disorder among children and adolescents. First, mobile technologies provide an ideal platform for the delivery of diary-based studies, often referred to as ecological momentary assessment (EMA; Shiffman, Stone, & Hufford, 2008) or experience sampling methodologies (ESM; Csikszentmihalyi, Larson, & Prescott, 1977). Using mobile devices to deliver EMA protocols allows for real-time and repeated capture of individuals in their natural environments, a strategy with established value in the study of psychopathology (for a review see Myin-Germeys et al., 2009). Second, wireless sensors and other wearable devices are rapidly becoming available to capture unobtrusive physiological (e.g., sleep, heart rate), environmental (e.g., exposure to toxins, noise levels, location) and social (e.g., proximity to others and their devices) factors that may influence how and when psychological symptoms are experienced. Third, mobile technologies may provide new and potentially more effective ways to collect information from, and engage with, young people. In particular, these

tools may be helpful in reaching typically marginalized adolescents who are adopting new technologies at unprecedented rates (Lenhart, 2015; Rice, Monro, Barman-Adhikari, & Young, 2010), but who have been more difficult to reach in traditional research and intervention contexts. Fourth, there is increasing evidence that these types of ambulatory measures of symptoms and experiences have stronger associations with physiological markers of stress and related biomarkers compared to retrospectively recalled information (for a review see Conner & Barrett, 2012). Thus, ambulatory measures may be best positioned to answer questions related the complex interplay between mental health symptoms and physiology among young people.

Mobile Technologies Can Capture Symptoms in Real Time via EMA

Diary methods can provide repeated, and often momentary, assessments of symptoms, experiences and related events and are a valuable set of tools for studying 'life as lived' (Bolger, Davis, & Rafaeli, 2003). Diary methods have a rich history in the study of psychology and psychopathology (for reviews see Iida, Shrout, Laurenceau, & Bolger, 2012; Nezlek, 2012; Shiffman et al., 2008) and provide the type of data required to track rapid symptom changes and fluctuations over time (Odgers et al., 2009). The repeated assessment of an individual's symptoms within their natural contexts also provides an opportunity to identify contextual triggers and to test how the presence of others, or involvement in certain activities, may trigger or reduce the emergence of symptoms (Shiffman et al., 2008). Diary studies have traditionally been administered via pencil and paper assessments, pagers, phone calls, and palm pilots or handheld computers. More recently, mobile phones and tablets have been introduced as EMA data collection tools. EMA methods allow researchers to capture events and symptoms as they are

experienced, rather than as they are remembered, thereby minimizing recall bias. That is, diary methods can help to minimize (but not necessarily eliminate) retrospective recall biases by shortening the window of recall to minutes or hours, which can result in more accurate self-reports (see for example Shiffman, 2009). Although diary methods may be burdensome on participants, feasibility of this approach has been demonstrated in a range of participants, including children as young as 8 years old (Whalen et al., 2009) through to elderly participants (Keller-Cohen, Fiori, Toler, & Bybee, 2006).

Electronic response formats for diary data have been around since the early 1990s (for a review see Iida et al., 2012), and have become increasingly popular with the introduction of mobile phones. While there is some debate regarding the advantages of paper and pencil versus electronic response options for enhancing the accuracy of recall in diary studies, it is clear that electronic methods offer a number of advantages with respect to data entry, storage, and transfer and may provide unique ways to engage with and gather information from study participants (for a discussion of strengths and limitations of different diary formats see Iida et al., 2012). For example, with the addition of video and recording features on many mobile phones, data that have not been traditionally gathered in EMA studies can be captured along with the participants' responses, including geo-coded location information, video diaries, photos from the day, and/or information from the phone itself that captures movement, communications, and online activities. All of this data can be synced immediately with a secure database and, in some cases, used to inform the content of future protocols and individualized assessments.

Mobile devices are also often carried by individuals throughout the day, increasing the likelihood that they will respond to surveys when prompted and providing the opportunity to capture other measures of the environment as the phone travels with the individual across settings. In addition, the ability to have two-way communication channels set up with the device allows researchers to adapt assessment protocols based on participants' responses and provides a direct line to study members via text messaging, voice and/or video. Information from the participant and/or device can also be used in a recursive loop to trigger data collection protocols that are tailored to capture specific behaviors or contexts. For example, the ohmage system, an open mobile system for activity and experience sampling, can prompt participants to complete a brief survey every time they enter a particular location (e.g., a pre-specified 'stressful' environment) or the phone itself can automatically capture information (e.g., time and location stamps) whenever a participant presses a 'stress button' (Hicks et al., 2011). These features can allow for more individualized and context-sensitive data collection, while maintaining survey consistency.

One potential advantage of using mobile devices versus traditional pen-and-paper assessments is the ability to provide researchers and clinicians with opportunities to administer 'just in time' interventions (for a discussion of ecological momentary interventions (EMI) see Heron & Smyth, 2010). By tracking momentary changes in children's symptoms and identifying contextual factors that may influence symptom onset throughout the day, can help researchers to create individualized prediction models and identify windows for intervention delivery. For example, if depressive symptoms typically onset at the end of the day for an individual, supports could be offered and

targeted using that time period (e.g., prompts to call a friend, engage in physical activity, open a cognitive behavioral therapy app). Likewise, for researchers, adaptive testing protocols could be optimized to collect information only on relevant stimuli and symptoms (e.g., administering follow up questions to identify the level and types of depressive symptoms the individual is experiencing after they have passed an initial screen or when they are in a setting when symptoms are most likely to onset).

Analytically, the intensive assessment of symptoms over time provides the opportunity to more accurately describe patterns of symptom onset, co-occurrence, and expression, while also facilitating causal inference by isolating the effects of specific (and time-varying) risk factors or 'triggers' in daily life *within individuals.* That is, stable characteristics such as genetic makeup, biological sex, and ethnicity are effectively held constant (Allison, 2005; Bolger & Laurenceau, 2013), providing a test of whether exposure to a specific event or context increases the risk of experiencing symptoms for a given individual (relative to their own baseline and to times when they are not 'exposed'). The analytic advantages of delivering EMA protocols on mobile phones also include the ability to conduct 'real-time' analyses of incoming data and to use those data to make decisions about: (1) adapting or revising surveys for participants, (2) stopping data collection, such as when estimates of effect sizes have stabilized, and (3) monitoring incoming data immediately for any errors in coding or lack of response from participants.

The use of mobile phones to collect information about psychological states, especially among vulnerable populations, also raises ethical issues around how and when to intervene in the lives of study participants as streaming information about their levels of distress are received by investigators. On one hand, the ability to capture a running

film versus a snapshot of study member's symptoms is advantageous in terms of being able to effectively intervene if needed and to do so in a time-sensitive manner. In this case, extremely high levels of distress or calls for help (e.g. elevated depression or indications of self-harm) could trigger an immediate response and referral system (e.g. text or call from help-line), along with embedding referral systems and safety protocols into the phone itself. On the other hand, data are not always viewed by investigators in 'real time'. In this case specific safety protocols or alarms would need to be built into the data collection protocol to ensure that reports of distress and adverse incidents were immediately recorded and reported. It is likely that some forms of psychopathology may be more amenable to being captured and/or 'treated' using mobile platforms. For example, mobile technologies are being used to study and develop interventions to assist those with Autism Spectrum Disorders (e.g., using accelerometors and/or sensors to identify or monitor characteristic body movements: Goodwin, Intille, Albinali, & Velicer, 2011) and anxiety-related disorders (e.g., using text messages to deliver Cognitive Behavioral Therapy: Shapiro et al., 2010). However, given that most research and virtually all intervention efforts are still in their infancy, it is too early to tell where the most successful applications may be found.

In addition, study member confidentially may be more easily compromised as information about their location, behaviors, and interactions are captured intensively over time and as data are transferred back and forth between devices and data warehousing servers. Creating and maintaining secure channels for the transfer of data and de-identified storage of data on both the device and 'in the cloud' are essential steps in study design, but one which traditional academic support units may not be equipped to

adequately support. In short, there are a number of issues around participant safety and data confidentiality that are often not covered by traditional guidelines or research support mechanisms in psychology. In the field of medicine, using mobile technologies to administer assessments and deliver interventions has been called *mobile health* (or mHealth) by the National Institutes of Health (2015) and World Health Organization (Kay, Santos, & Takane, 2011). The mHealth movement has already begun to address many of these issues (e.g., ethical issues for research with persons with HIV/AIDS or substance use: Labrique, Kirk, Westergaard, & Merritt, 2013), and psychologists who intend to gather data via these new technologies will need to quickly and efficiently put these types of mechanisms for safety, privacy and technical support in place.

Small Phones Gather 'Big Data' That Can Advance the Study of Psychopathology

Mobile phones and their associated sensors can capture an incredible amount of streaming, and often unobtrusive, data on individuals' behaviors, social interactions, location, and physiological state. Momentary assessment and monitoring of biomarkers and health status is often considered the gold standard in medical research and practice. Until recently, conducting ambulatory assessments of key markers of biological functioning, stress reactivity and physiological states has been a costly enterprise reserved primarily for high-risk patients or those managing acute phases of a disease. The growing and widespread availability of commercially available wireless sensors, many of which can be held in the palm of your hand and connect seamlessly with your smartphone, are providing researchers with the ability to monitor and record real time fluctuations in our health status, stress response and physiological state. At the same time, new methods for assessing our behaviors and experiences in real time are creating new

possibilities for understanding the interplay between daily experiences, mental health symptoms and physiology. For example, strong momentary associations have been documented between ambulatory measures of self-reported stress and blood pressure and heart rate (Bhattacharyya, Whitehead, Rakhit, & Steptoe, 2008), as well as between affective state and heart rate variability (Kamarck et al., 2005). These types of studies are well positioned to trace the effects of daily triggers (events or experiences) on affect, symptoms and physiology in real time.

Self-report diaries comprise only one of many different types of assessments that can be gathered via mobile technologies. Mobile devices also have the capacity to collect more objective information from recording components (photo, video, and voice) and global positioning systems (GPS). These features not only capture information of a different type, but they also greatly increase the amount of data that can be captured as the study participant makes their way throughout the day. For example, photo and voice-recording capabilities of smartphones allow participants to more thoroughly document their daily behaviors and experiences compared to retrospective self-reports (see the Food Intake Visual and voice Recognizer or FIVR; Weiss, Stumbo, & Divakaran, 2010). GPS also provides researchers with an account of where adolescents are spending their time and the paths that they travel throughout the day. GPS features are quickly becoming standard on mobile phones, and have been used in conjunction with adolescents' self-reports to more fully measure their experiences and environments (Wiehe et al., 2008). Smart phones can also be used to capture features of the built or social environment that we believe are relevant for understanding behaviors such as smoking, alcohol use and other high-risk behaviors. For example, McClernon and Choudhury (2013) have

developed a smart phone app called ‘i see smoking’, which allows smartphone users to discretely swipe their phone and record the coordinates of where they observe smoking and related behaviors as they move throughout the day. Maps can then be over-laid to test how these features of the built and social environment may predict behavior and symptoms. The geo-spatial information can then be future probed via online tools, such as Google Street View, to code images of neighborhoods where adolescents spend their time and engage in risky behaviors and activities (see for example Odgers, Caspi, Bates, Sampson, & Moffitt, 2012).

As adolescents’ social environments are moving into the virtual realm, mobile devices can also be used to more fully capture their social relationships and networks. Social network analysis is a rapidly evolving field that has produced important findings related to child and adolescent psychopathology (e.g., Ennett et al., 2006; Mouttapa, Valente, Gallaher, Rohrbach, & Unger, 2004). For example, a study of middle school students found that the characteristics of adolescents’ peer networks (i.e., density, centrality, proximity to others) predicted how likely they were to use substances, such that adolescents with fewer friend connections, higher status in a group, and/or ties to a peer who used substances were the most likely to initiate substance use over the course of middle school (Ennett et al., 2006). Now as adolescents increasingly rely on text and online messaging to interact with their peers, many of these social network characteristics can be assessed by adolescents’ peer-to-peer virtual communication patterns.

Social support and strong friendship ties are also important predictors of positive adjustment among children and adolescents and often serve as a buffer in the face of adversity, daily stressors, and other negative life events (e.g., Galambos, Sears, Almeida,

& Kolaric, 1995; von Weiss et al., 2002). With the widespread use of mobile phones and texting among adolescents, the question of how online communication may be influencing children's mental health 'for better or for worse' has arisen (for a review see George & Odgers, in press). To address this question, Underwood and colleagues (2012, 2014) examined the content of 8th graders' text messages (over the course of 2 days among a sample of 175 adolescents they collected over 43,000 messages!). In this first study of its kind, the authors were able to describe the quantity and content of all the text messages exchanged between friends. The authors found that adolescents who sent a greater proportion of messages with negative or sexual content, also reported higher symptoms of internalizing disorders (Underwood et al., 2015). Similarly, adolescents who sent a higher proportion of messages about discussing anti-social behaviors were rated by parents and teachers as exhibiting higher externalizing behaviors (Ehrenreich, Underwood, & Ackerman, 2014). These types of studies can provide a unique view of adolescents' relationships, communication patterns, and the mapping of peer networks that influence adolescent psychopathology (e.g., identifying peers and peer groups that provide social support versus those that increase the risk for substance use initiation).

In addition, network analysis of adolescents' online or text messages can map adolescents' friendships across contexts and time. Reich et al (2012) used self-reports of adolescents' top online and offline friendships to see the overlap between the virtual and school contexts. The authors reported that, typically, online friendships are an extension of offline friendships and adolescents rarely have many strong, online-only friendships. Examining text messages versus relying solely on one-time self-report measures can supply greater information in terms of the strength of friendships, the quantity and quality

of interactions, and the chain of interactions within groups of individuals. Developing reliable measures of children's and adolescents' online communication and support is important given the central role that they have been shown to play in the determining mental health across the lifespan, combined with the fact that traditional measures of these important factors may no longer accurately reflect the reality of young teens' lives and communication patterns.

In pairing message content with the network analyses of mobile communication, a great deal of new information can be derived about children and adolescent relationships. Mobile phones can build upon prior EMA work by opening up the potential to examine communication patterns and social networks, so that we are able to 1) more fully describe adolescent's networks and online communication- including their linkages to others with mental health problems and health-seeking behaviors, 2) examine the role that social support and interactions can play in buffering contextual triggers of symptoms and 3) eventually leverage the strongest sources of social support or communication patterns in targeted interventions, some of which may involve virtual tools.

The integration of EMA surveys (described above) with sensors and ambulatory devices able to capture streaming information from the physical and social environment, as well as individuals' bodies, could provide a number of new opportunities for discovery. These tools also help to move data collection away from sole reliance on self-report information of both psychological (e.g., 'angry') and physiological (e.g., 'heart racing') states and provide opportunities to monitor key dimensions of mental health intensively over time. Indeed, one of the current claims in the mHealth space – an industry projected to be worth 58 billion by 2020 (Franco & Jeevane, 2014) - is that one

day our phones will know that we are sick before we (or our doctors) do. By integrating EMA protocols with these types of sensors, we can begin exploring the potential of real-time assessments to predict mental health status, onset, and triggers. Taking these types of ambulatory assessment out of the lab and into real-life settings allows us to capture a continuous stream of data from the daily lives of children and adolescents, and in so doing, opens up new opportunities for scientific discovery.

By pairing EMA with passive measures of the environment, studies using mobile phones have the potential to collect 'big' health and network data that can describe adolescents' social and physical environments. Moving forward, the challenges in this domain will be developing efficient means of synthesizing and protecting vast amounts of data and developing tools that can uniquely identify behavioral and contextual signatures - based on streaming data from the environment and people. To this end, interdisciplinary collaborations between psychologists, computer scientists, engineers and those with related expertise and technical skills will be required.

Digital Natives Love Their Phones and May Be More Willing Share Information about Their Psychological States Using Them

"I love my phone. I love it enough to risk my life for it," hyperbolized Walia, an adolescent girl, when asked about what lengths she would go to retrieve her missing phone (Weber & Mitchell, 2008, p. 32). Mobile technologies have become an integral piece of children and adolescents' lives, and for some, their personal identities That is, adolescents report feeling that their online presence and devices are important pieces of their identity, because of the exploration, self-expression, and intimate communication

they allow (see books by boyd, 2014; Buckingham, 2008). Phones have become a normal (bordering on essential) tool for communication in adolescent friendships. Outside of the school context, text messaging has overtaken face-to-face interactions as the most frequent form of daily communication among adolescents (Lenhart, 2012) to the point that adolescents often sleep with their phones to avoid missing a message. Among teens that own their own mobile phone, more than 80% sleep with the phone in or next to their bed (Lenhart, Ling, Campbell, & Purcell, 2010). While the average number of text messages sent per day hovers around 30 (Lenhart, 2015), some very active adolescent text messagers send upwards of 1000 messages per day (Lenhart, 2012) and will respond to message any time of the day or night, so their friends won't think they are angry (Lenhart et al., 2010).

In short, adolescents seem to be particularly motivated to use mobile technologies given the close fit between the emphasis on social relationships and communication at this stage of development. They are accustomed to always being in close reach of their mobile phone and responding to notifications promptly, which may increase the likelihood of adolescents responding to surveys and queries when prompted (as is often the case in EMA studies). Indeed, there is some evidence that individuals who use their phones regularly as part of their daily routine, have higher participation rates in mobile diary surveys than those who are not regular phone users (Hicks et al., 2011). Adolescents are likely then to have high compliance for even intensive diary studies. In our current work we observe rates of compliance that exceed 90%, even when adolescents are 'beeped' to respond to surveys multiple times per day (Russell, Wang, & Odgers, submitted). When needed, researchers can also provide additional incentives to

enhance study compliance by, for example, installing popular games on the devices themselves or providing electronic gift cards and other types of rewards delivered through the phones.

Frequent mobile technology users may be easier to target for intensive research studies, but ownership and engagement rates suggest that capturing a broader range of adolescents may also be feasible. Most adolescents (upwards of 90%) go online on a daily basis (Lenhart, 2015) most typically with mobile phones or devices. Although a digital divide still exists, some of the largest rises in mobile technology usage have been among minority and low-income adolescents (Lenhart, 2015; Rideout et al., 2010). Like most of the population, adolescents from lower socioeconomic (SES) and minority groups are increasingly relying on mobile phones as their sole source of virtual access (Lenhart, 2015).

Mobile phone ownership is growing to near saturation in the population, especially among young people. As a result, new opportunities for intensively studying the lives and mental health of children and adolescents across development are emerging. Mobile phone based interventions are also coming online as a potentially effective, and increasingly affordable way to target and deliver support for children and adolescents who are traditionally understudied and hard to reach. The type of intensive assessment data gathered via EMA methods and mobile devices are also providing new opportunities to evaluate heterogeneity in the short and long-term effects of traditional treatment studies and to embed relatively low cost supplements or 'boosters' into standard therapies and interventions (e.g., electronic supplements or supports in cognitive behavior therapies).

Applications Using Mobile Technologies in the Study of Child and Adolescent Psychopathology

Researchers in the field have started to put mobile devices into the hands of children, adolescents, and their parents to learn more about the developmental course, contextual triggers, and outcomes associated with various forms of psychopathology. A few examples of research using mobile devices with children and adolescents are provided below.

Example 1: PalmPartners Study of Family Processes and Contextual Triggers among Children with and without ADHD

A number of researchers have used EMA approaches to study family processes in daily life (for a review see Laurenceau & Bolger, 2005). When used in familial or dyadic contexts, EMA designs allow for tests of how different members of a family system or relationship drive and/or respond to the behaviors of others through fine-grained, and time ordered sequencing of assessments and shared interactions. One of the longest standing questions in the study of child psychopathology is the extent to which parenting behavior *per se* determines children's mental health and behavioral outcomes, versus the extent to which children (who also often share genetic information and predispositions towards behavioral and emotional problems) elicit parenting behaviors from their caregivers. EMA designs delivered via electronic methods can help disentangle this question by examining the interactions between parents and children intensively overtime and testing: how within dyad parenting behavior predicts changes in children's behaviors and emotions in real-time and overtime (and vice versa), while holding constant all stable

characteristics of the parent and the child that may otherwise confound the interpretation of the parenting-to-child behavior link.

Whalen and colleagues (2006, 2001) used intensive assessments of mothers and their children (every 20 minutes!) via Palm Pilot devices to test how factors such as time of day, prior risk, including mothers own levels of psychopathology, and activities influenced the ways that mothers responded to their children's behavior over the course of the day. For example, the authors reported that childhood behavioral problems, maternal negative affect and conflict were heightened among children with versus without a diagnosis of ADHD during transition times (e.g., getting ready for school) (Whalen et al., 2006). Similarly, ADHD parent-child dyads (in comparison to non-ADHD comparison dyads) were more likely to enter into patterns of negative exchanges that persisted over time (Whalen et al., 2009) and were more likely to elicit negative reactions from each other over the course of the study (Whalen, Odgers, Reed, & Henker, 2011). In this case, parents and children were driving each other's behaviors across the week, with evidence of both parent-driven and child-elicited effects on behavior. This work was important as it provided a new window into the micro-level exchanges that ADHD children and their parents engage in throughout the day, while also establishing that children as young as eight years of age could provide reliable information about their symptoms and activities using a handheld devices.

Example 2: miLife Study of Biological and Environmental Interactions in Adolescents' Daily Lives

More recently, our research team has followed a group of young adolescents using mobile phones to understand how exposure to violence and daily stressors influence mental health, substance use and related health-risk behaviors. Following baseline assessments, 151 adolescents were given mobile phones and tracked prospectively over a one-month period. Participants responded to 3 surveys per day during the initial 30 day assessment, and were then followed up 18 months later to assess the emergence or worsening of symptoms and behavioral problems during the transition from early to mid-adolescence. The use of mobile phones in this study allowed us to obtain multiple assessments of adolescents' mental health symptoms over the course of a day, alongside information about their activities and experiences. This high-resolution data allowed tests of how, for example, witnessing violence in the adolescents' home, school and neighborhood influences same and next day emotional health and risk-taking behaviors.

We are currently using the study's repeated measures of context, experience, and symptomatology in adolescents' daily lives to examine longstanding models of person-by-environment interaction, such as the diathesis-stress model. That is, we are estimating within versus between person comparisons of the effects of daily stressors on affect and behavior, guided by the hypothesis that those who carry the highest risk for psychopathology will also have heightened responses to stressful experiences in daily life. The diathesis-stress model suggests that some adolescents will be more vulnerable to stressful environments than others, by virtue of pre-existing characteristics such as their genetic makeup (Ingram & Price, 2010). The majority of research in this area, however, has relied on between-person comparisons, which cannot directly test an important

implication of the diathesis-stress model (i.e., 'vulnerable' individuals will be more *reactive* to stressful or risky environments as they experience them).

Our results suggest that adolescents with versus without the 7-repeat allele of the dopamine receptor *D4* gene (*DRD4*-7R), a gene that has received attention for as a potential vulnerability factor, may be more reactive to risky environments in daily life. Adolescents with this allele showed greater increases in externalizing symptomatology compared to themselves on high versus low risk-exposure days. Additionally, we found no evidence that adolescents with versus without the *DRD4*-7R allele experienced greater levels of risk exposure, thus ruling out gene-environment correlation as a potential counter-explanation of these results (Russell et al., submitted). Because these results are based on within-person comparisons obtained through repeated naturalistic measurement of the same individuals, they cannot be explained away by stable individual difference factors (e.g., sex, ethnicity, current family socioeconomic status) that serve as potential confounds in studies relying on between-person comparisons. As such, we are able to move one step closer to causal inferences regarding how adolescents' everyday experiences interact with their pre-existing characteristics to influence their risk for psychopathology.

Drawbacks and Limitations of Mobile Technologies for Researchers

Although mobile technologies can be valuable tools for capturing life as lived, monitoring treatment efficacy and heterogeneity effects, and delivering more individualized interventions, certain drawbacks and limitations do exist. First, there is growing concern that frequent or continuous use of mobile technologies may have negative effects on children's mental and physical health, yet the limited evidence for

technology's negative impacts to date has been mixed or inconclusive (George & Odgers, in press). It appears that adolescents' use of technology is likely to mirror their engagement in offline activity. For example, adolescents who report greater online communication also tend to have stronger in-person relationships (Valkenburg & Peter, 2007). Similarly, problems stemming from adolescents' usage of mobile technologies may also reflect pre-existing conditions and self-selection factors (e.g., poor offline social skills or high depressive symptoms). Adolescents' use of mobile technologies can also exacerbate or dampen psychopathology symptoms, depending on if it isolates or exposes adolescents to new dangers (e.g., cyberbullying), or provides new opportunities for adolescent coping (e.g., seek support from friends). Future research is required to fully understand how usage patterns, content, and online contexts amplify or dampen mental health symptoms among children and adolescents.

Second, the fast pace of the development of newer models and devices means that mobile technologies are constantly being updated or replaced, leading to obsolete devices or (if studying technology itself) behavior patterns. The devices themselves can allow for faster collection periods, but methods using mobile technologies should never be a substitute for a sound, theoretically driven study. Rather, mobile technologies should be thought of one of many tools that researchers have in fielding intensive assessment studies.

Lastly, EMA studies can be intensive or burdensome for participants, so attrition and compliance is a concern, especially in studies with long duration (see Christensen, Barrett, Bliss-Moreau, Lebo, & Cynthia, 2003 for an excellent review of these and other practical considerations inherent in diary research). However, engagement can be

enhanced by designing an incentive system for children and adolescents for their continued involvement in responding to prompts. EMA studies can also place additional burdens on researchers with respect to ensuring the protection and privacy of participant data and through the generation of, at times, massive amounts of data that require advanced skills in data synthesis and analysis (for excellent overviews of state-of-the-art methods for analyzing diary data see Bolger et al., 2003; for intensive longitudinal methods see Bolger & Laurenceau, 2013; and for dyadic data analysis see Kenny, Kashy, & Cook, 2006).

Conclusions and Future Directions

With over 6 billion cellular phones worldwide, our society and the daily lives of children and adolescents have become increasingly connected and dependent on mobile technologies. Mobile devices already keep children and adolescents in greater virtual contact with their friends and families, and may start to bring them closer to researchers as well.

The introduction and rapid evolution of mobile technologies is also transforming research opportunities, with new features that track location, monitor health and changes in affect, and provide quantitative and qualitative information about children's everyday lives. The introduction of wireless sensors, GPS tracking capabilities, and recording features into EMA studies allows for an added layer of information about the adolescents in context that would otherwise be difficult, and in some cases impossible, to gather. New tools for connecting commercially available wireless sensors and mobile phone applications to EMA protocols are now available for little to no additional cost (e.g., open

source APIs in Apple's ResearchKit, 2015). Mobile technologies continue to evolve, providing researchers with more options regarding the types of data they can collect.

Mobile technologies may also offer new ways to reach study populations that have traditionally be difficult to engage in mental health related research and interventions. While not ideal for all research designs, mobile devices can be used to collect high-resolution data on children and adolescents. In addition, these technologies are providing researchers and health professionals with new opportunities for assessment and intervention. In the health field, mHealth methods have been embraced for intervention administration for disease prevention and management, and psychological researchers may be able to use similar methods to assess and intervene earlier in the course of psychopathology (for a review see Mohr, Burns, & Schueller, 2013).

Message-based interventions for psychopathology can incorporate EMA to test – and eventually disseminate- intervention content that might promote coping strategies or reduce ineffective or maladaptive habits. For example, mobile phone delivery of intervention content could be used to supplement cognitive behavioral therapy (CBT; Beck, 1991), an intervention known to be effective among children and adolescents (James, James, Cowdrey, Soler, & Choke, 2013; McCart, Priester, Davies, & Azen, 2006). Mobile phone interventions have been shown effective in reaching and helping diverse groups of participants, such as those from ethnic minority (Napolitano, Hayes, Bennett, Ives, & Foster, 2013) and/or from harder-to-reach populations, that may be at heightened risk for psychopathology. Continuous assessments obtained by mobile technologies facilitate the development of "just-in-time" intervention—or the delivery of

interventions following environmental "cues". For example, when adolescents report stressors in their daily lives, such as an argument with a parent or conflict with a peer, intervention messages reminding youth to use positive coping strategies could be delivered via SMS messaging. Intervention messages could also be triggered using smartphone-based sensing of environments, without relying exclusively on participants' self-reports (see McClernon & Choudhury, 2013 for a discussion of these techniques in smoking research and treatment).

With respect to preventing and treating adolescents' mental health, intervention content could be delivered when smartphone sensors detect changes in stress markers (such as heart-rate variability), increases in the volume of speech sounds (possibly indicating yelling), or specific word choices suggestive of conflict or distress. In this way, the type and delivery of intervention content could be based on both the theoretical knowledge of psychopathology and the individual information provided about personal triggers of symptoms. Mobile devices could afford greater exchange between users and researchers or clinicians, so that users have greater control and input.

Mobile technologies are already providing new channels of communication between adolescents and their friends and families, and researchers could explore ways that this potential source of social support can buffer the onset of major mental health problems, including depression, anxiety disorders, and substance use difficulties. An experimental study of 72 young adults and 51 young adolescents examined the benefits of online chatting with a stranger after a social exclusion task (Gross, 2009). Adolescents and young adults who had a conversation online, compared to those who played a solitary online game, had faster recoveries of their self-esteem and positive mood. These results

suggest that virtual communication may provide avenues for intimate discussion and problem disclosure. Researchers can simultaneously provide adolescents with virtual environments that allow informal disclosure of feelings, while measuring symptoms of psychopathology, such as depression and anxiety. Mobile technologies are already being utilized by adolescents to seek information and help about their mental health and well-being, and could be leveraged in ways that increase access to, or effectiveness of, these help seeking behaviors.

Mobile technologies are not a perfect fit for all research designs or intervention efforts; yet, they can offer new research opportunities and have already provided some key insights in areas of child and adolescent development. Although there are limitations, there are also exciting possibilities for understanding and improving the mental health of children and adolescents via mobile technologies. Mobile technologies have the potential to provide high-resolution information about children and their risk for psychopathology, both in the moment and over time. At the same time, they offer new platforms for broad dissemination of tailored interventions, including among youth who may be traditionally difficult to reach and engage. Mobile technologies can be best thought of as one of many tools that can be used to study and treat mental health problems among children and adolescents.

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