Adolescent Technology, Sleep, and Physical Activity Time in Two US Cohorts, 2002-2014

Paula Fomby[a]
Joshua A. Goode[bc]
Kim-Phuong Truong-Vu[bc]
Stefanie Mollborn[bc]

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[a]Institute for Social Research, University of Michigan
[b]Institute of Behavioral Science, University of Colorado Boulder
[c]Department of Sociology, University of Colorado Boulder

ABSTRACT
This study examines time spent on electronic media consumption, physical activity, and sleep by U.S. adolescents ages 11 to 17 across two birth cohorts using time diary data. Data come from the Panel Study of Income Dynamics Child Development Supplement from 1997 (N=1,272) and 2014-2016 (N=493). Descriptive results show that electronic media use has increased by 14% since 2002, with increases occurring primarily as the result of increased technology use as a secondary activity. Multivariate results show that total technology time predicts losses in time spent on physical activity, while exhibiting no association with sleep. Latent class analysis is used to examine profiles of technology use, with four classes emerging. These technology-use profiles were predictive of losses in both physical activity and sleep.

The landscape of adolescent technology use has been transformed in the last decade by the advent of internet-enabled mobile digital devices such as smartphones and tablets (Pew). The current mobile technology regime has largely displaced the desktop computers, hand-held gaming devices, and cellular telephones that a previous generation of adolescents used for learning, video game play, and communication. The ubiquity and variety of mobile technology devices and applications have introduced questions about whether adolescents' digital and online activities impinge upon time in other activities that are related to healthy development, yet to date we lack a national profile of how technology use fits into contemporary adolescents' daily time use compared to previous cohorts. Further, while prior research has established that adolescent technology use is characterized by constellations of clustered activities and behaviors (Rideout 2015), we know little about how these varied activity sets map onto children's time use to create distinctive typologies of health-promoting or health-compromising patterns of time use. Technology use is a health-related behavior, but relatively little is known about how it fits with other aspects of adolescents' health lifestyles. These lifestyles in turn have implications for young people's future health behaviors and health outcomes (Burdette, Needham, Taylor, & Hill, 2017; Lawrence, Mollborn, & Hummer, 2017).

We address these issues using US nationally-representative weekday and weekend time diary data collected from two cohorts of adolescents aged 11-17 years in 2002-03 and 2014-16. The earlier cohort experienced adolescence prior to the emergence of internet-enabled digital devices marketed for personal use. The latter cohort grew up in a context in which such devices were not only available but had largely saturated the adolescent consumer market; by 2012, 93% of adolescents owned or had access to (a smartphone, digital tablet, or computer) at home. We compare adolescents' weekly hours spent using any type of digital device for learning activities, television, music, video game play, social media, communication, or recreation in these two cohorts to assess the extent to which the nature and frequency of adolescents' technology use has changed between cohorts. We then investigate the extent to which cohort change in adolescents' time engaged in technology use is associated with change in time spent in two activities that inform children's healthy development: physical activity and sleep. Finally, we identify distinctive clusters of technology use habits in the contemporary cohort and explore how these distinctive digital activity profiles align with patterns of sleep and physical activity, which are important facets of adolescents' broader health lifestyles.

BACKGROUND

The Changing Nature of Technology Use

Since the 2000s, the digital revolution has led to four profound shifts in the nature of technology use. During the early 2000s, technology users predominately utilized single-tasking stationary devices such as televisions, desktop computers, and gaming consoles for the purposes of entertainment and information gathering. In other words, stationary technology devices were restricted to single-use such as strictly watching television on a television set, listening to audio on a stereo system, or surfing the web on computers. Primarily due to their high costs, single-tasking stationary devices were often shared between family members (MacGill, 2007). Additionally, the majority internet users accessed the internet via slow dialup connection, with transfer speeds of 20-56 kbit/s. Dialup connection requires the exclusive use of a phone line, resulting in limited telephone access, internet interruption, and the inability to multitask. Due to the high cost of the internet at the time, only 46 percent of the US population reported having internet access[1] and would often monitor their time usage (Pew Research Center, 2018).

[1] 41% reported having no internet and 12% reported having home broadband

Together, the single-tasking stationary devices, shared use, slow dialup connection, and high costs restricted the location, length, speed, and number of tech device utilization. Nonetheless, the nature of technology use during this time was internet saturated for the primary purpose of entertainment and information gathering.

In the mid-2000s, the rise of broadband internet use and the launch of social media sites shifted the nature of technology to being more personalized and interactive. The increase use of uninterrupted, high speed broadband internet, which has a transfer speed of 700 kbit/s or higher, allowed users to quickly download and stream online files, videos, and audios, gaming content, and other internet data without previous restrictions. Consequently, an increase in visual and audio streaming sites such as Pandora, YouTube, and Netflix arose. These visual and audio streaming sites allowed users to interactively explore, customize, and control technological information and services. Additionally, the launching of social media sites, such as Facebook in 2007, provided tech users with a platform to digitally interact and network with others. As a result, technology became the principal means of communication (Sefton-Green, 2006). Technology use vis-à-vis social media allowed tech users to share personal interests, concerns, and passions. In the same vein, these tech interactions allowed tech users to receive emotional support and build and sustain social ties. Thus, virtual social media outlets mediated and altered personal and social relationships as well as identity management. For example, individuals had the ability to (dis)connect with others and control their virtual presentation of self. Thus, the nature of technology use in the mid-2000s shifted from being a unilateral form of entertainment and information gathering to an interactive, personalized form of entertainment and communication.

Between the late-2000s and early-2010s, the introduction of mobile tech devices, the pervasive use of broadband internet, and software applications[2] once again shifted the nature of technology use. Mobile devices, specifically smartphones and tablets, coupled with broadband internet access and software applications granted tech users a versatile experience at their fingertips. That is, tech users had the ability to utilize mobile devices, access the internet, and engage in interactive data from any place, at any time. Additionally, other tech devices, such as televisions, were also becoming "smarter" by allowing users to access the internet, stream audio, and engage in social media sites. By 2008, the gap between adults (77%) and adolescents (71%) owning cell phones began to narrow and mobile internet access surpassed computer internet access (Madden, Lenhart, Duggan, Cortesi, & Gasser, 2013; Rideout, Foehr, & Roberts, 2010). Relationally, more individuals began accessing the internet and utilizing tech devices on an everyday basis. Technology use during this time was highly mobile and the internet equipped tech users with the fluidity of tech use.

By 2014, multiple tech device ownership and use became embedded within everyday life. In contrast to the early 2000s when tech devices were shared between family members, tech devices became marketed for personal use. Individual ownership of multiple tech devices increased, with 97 percent of American adolescents now having at least one technology device in their (Gradisar et al., 2013). The largest increase of tech device ownership was smartphones for both adults and adolescent (Pew Research Center, 2018). As mobile devices became pervasive, desktop computer internet use and ownership began to decline. The increase in multiple tech device ownership allowed and encouraged users to multitask with multiple tech devices. That is, with an abundance of multiple tech devices within grasp, tech users had the ability to multitask

[2] Also referred to as "apps."

by using their smartphone to text a friend and interacting on a social media, while searching the news on a tablet, and playing music from a television set. This shift in technology use drastically differs from the 2000s when tech users were restricted by the location, time, and use of tech uses. Thus, with multiple forms of high speed and interactive technology devices at their fingertips, adults and adolescents began engaging in tech-saturated lives.

Technology Use in Adolescence

Adolescent technology use has undergone unique shifts within the past 15 years. During the early 2000s, adults were concerned with the potential negative impacts of adolescents' excessive television viewing and the perils of adolescents' unmonitored internet use, specifically regarding internet sexual predators. At the same time, adults viewed computers and internet usage as fundamental for the educational development of adolescents (Russ, Larson, Franke, & Halfon, 2009). Although computers and the internet were initially created for adult use (Spies Shapiro & Margolin, 2014), and adolescents' tech usage was highly monitored, adolescents were encouraged to utilize tech devices to enhance their digital competency and accrue cultural capital for achievement (Rafalow, 2018). Consequently, reports of adolescent technology use during this time was primarily for schoolwork (Victory & Cooper, 2002). Specifically, of the reported online users, 94 percent of adolescents used the internet for school research, 58 percent used a school/class website, 34 percent downloaded a study aid (Simon, Graziano, & Lenhart, 2001). While adolescents additionally utilized tech devices for things outside of school, such as communication via instant messaging (Pew Research 2001), for entertainment like surfing the web, and for gaming, adolescents' primary tech use related to educational activities.

Following the increase use of broadband internet, video gaming, social media sites, and cellphone ownership, adolescents began utilizing tech devices primarily for communication and networking. During this time, adolescent began viewing technology as means to enhance their quality of life (MacGill, 2007). The increase use of broadband internet coupled with the technological advancement of video games, allowed adolescents to engage in real-time, interactive game play. Scholars have noted how interactive video game play is crucial in the development and maintenance of adolescent boys' social network. Through voice connections devices, 59 percent of adolescent boys are able to interact with established friendships and new friends. Thus, gaming is the primary method for friend interactions. Additionally, social networking sites allowed adolescents to communicate via personal message and online posting (Spies Shapiro & Margolin, 2014). Specifically, 72 percent of adolescents reported occasionally using social media to communicate, whereas 23 percent of adolescents reported daily communications via social media (Lenhart, Smith, Anderson, Duggan, & Perrin, 2015). These virtual communication spaces provided adolescents with a platform to escape adult pressures and obtain privacy (Boyd, 2015). Lastly, the increase of cellphone ownership provided adolescents with another means of communicating friends, with 55 percent of adolescents reporting texting friends on a daily basis (Lenhart et al., 2015). Video gaming, social media sites, and texting replaced phone calls as the primary method of communication (Anderson, 2015). These tech communications became the key component of day-to-day friend interaction, while face-to-face interaction became less of a key component.

By 2014, the nature of technology use is seen as a ubiquitous part of adolescents' everyday life. Due to the marketing of tech devices for personal use, adolescents are now more likely to own personal advanced technology devices and engage in tech-saturated lives. Video game usage tripped in the past decade (Rideout et al. 2012) and 73 percent of teens had access to a smartphone (Lenhart et al. 2015). The ubiquity of tech ownership increased the use of tech devices to 7.5 to 11 plus hours per day, which encouraged adolescents to go online more often—92 percent of teens go online daily and 56 percent of adolescents are online several times a day (Lenhart et al., 2015; Rideout et al., 2010). Moreover, adolescents began to effortlessly multitask between multiple technology devices while engaging in other activities, such as studying (Kleeman, 2016; Rideout et al., 2010; Russ et al., 2009). Specifically, of the 7.5 hours of tech use per day, adolescents spent more than one-fourth of that time multitasking with media, creating a total daily screen time of 10 hours and 45 minutes. With the widespread use of personal technology devices, adolescents' pattern of technology use changed from being an educational and communication tool, to being intricately intertwined with adolescents' identities, social networks, and everyday experiences (Fitton, Ahmedani, Harold, & Shifflet, 2013).

Technology Use and Health-Promoting Behaviors

In the last 15 years, parents, health care providers, public health advocates and educators have persistently expressed concern that frequent screen time expended across a varied set of platforms and applications will contribute to adolescents' increasingly compromised health and development. At least three strands of research undergird this concern. First, even before mobile digital devices became widely available, adolescent health and health behavior had emerged as public health priorities. Indeed, the national prevalence of obesity among adolescents was 10.5% in 2001. Furthermore, between 1994 and 2005, the share of adolescents with type 2 diabetes doubled from 0.4% to 0.8% (Fagot-Campagna et al., 2000; Menke, Casagrande, & Cowie, 2016). With regard to health-promoting activity, only 8% of adolescents in 2004 engaged in physical activity for at least 60 minutes per day as recommended by the American Academy of Pediatrics (AAP) (Troiano et al., 2008). In addition, only 55% of adolescents got at least eight hours of sleep in 2005 (National Sleep Foundation, 2006). In the ensuing decade, as adolescents' screen time has increased, the share of adolescents meeting guidelines for daily physical activity has dropped to 3.9% (Owens, Crone, De Ste Croix, Gidlow, & James, 2014), while the number sleeping at least eight hours per night has decreases to 31.7% (Kann et al., 2014).

Second, frequent sedentary time is implicated in the prevalence of adolescent obesity (Russ et al., 2009), poor health (Koplan et al. 2005, Epstein et al. 2000), and limited physical activity (Epstein et al. 2000, Hancox, Milne, and Poulton 2004), and screen time is the largest contributor to adolescent sedentary activity (Tremblay et al. 2011, Olds et al. 2010). Research on sedentary screen time has largely focused on how television viewing impinges upon other activities and physical health. In the main, this work has demonstrated that frequent television viewing (i.e., more than two hours a day) is associated with higher odds of overweight/obesity, poorer physical health, compromised social and emotional adjustment, and less physical activity (Hale and Guan 2015; Russ et al. 2009, Hancox et al. 2004) and may be associated with lower-quality sleep (Van den Bulck, 2004). Yet a smaller set of studies has shown that sedentary screen time varies in its association with health outcomes and health behaviors by activity type. For example, among US children in the late 1990s, moderate amounts of time in video game play were more strongly associated with childhood obesity than was television viewing (Vandewater et al. 2004), and more frequent television viewing was predictive of a wider range of poor health outcomes compared to recreational computer use (Russ et al. 2009). (Something along these lines: Thus, research and practice should anticipate that the increasing diversity of digital activities will have varied associations with health outcomes.)

Third and relatedly, the emergence of new digital devices, platforms, and applications has renewed attention to the variety of pathways through which technology use is hypothesized to influence adolescent development. As the preceding summary suggests, much of the extant research has focused on how passive sedentary activities displace physical activity and provide a context for unhealthy eating with consequences for physical health (Russ et al. 2009, Hancox, Milne, and Poulton 2004). More recent work suggests that content delivered through devices such as smartphones and tablets impacts health and well-being through distinctive pathways, including disruption to circadian rhythms that affect sleep physiology and alertness (LeBourgeois et al. 2016). In sum, research to date anticipates that the increasingly varied mix of adolescents' technology-focused activities has as yet unknown impacts on time use and health outcomes compared to previous cohorts, through new mechanisms that are not yet fully articulated.

Finally, these anticipated relationships between adolescents' technology use and their other health behaviors likely have broader implications for adolescents' health lifestyles. Health lifestyles are comprised of interrelated health behaviors that are undergirded by social identities (Cockerham, 2005). For example, an adolescent may adopt a socially meaningful identity as a videogamer or a highly active social media personality, and this identity may drive changes in other health behaviors such as food consumption, substance use, and physical activity. Such an investment in a particular lifestyle identity can make health behaviors resistant to change, posing challenges to policy makers (Mollborn & Lawrence, 2018) Understanding how overarching technology use patterns co-occur with the health-promoting behaviors of sleep and physical activity among adolescents is a first step toward understanding how they may shape health lifestyles.

DATA AND METHOD

Data

The US Panel Study of Income Dynamics (PSID) began in 1968 with a nationally-representative sample of 4,800 US families. As the world's longest-running household panel study, it includes data collected over 40 waves (annually until 1997 and biennially since then) from up to five generations of family members descended from original PSID householders. A sample refresher in 1997 added families headed by foreign- born individuals who immigrated after 1968 (McGonagle, Schoeni, Sastry, & Freedman, 2012). Embedded in PSID, the Child Development Supplement (CDS) is a multidisciplinary study of child development and well-being. CDS began in 1997 with a cohort of children who resided in families that participated in that year's PSID main interview. Up to two children between 0 and 12 years old per family were randomly selected for inclusion (N=3,563 children, 88% response rate). Children under 18 and their primary caregivers were re-interviewed in 2002 and 2007. Beginning in 2014, a new round of CDS (CDS-2014) collected information on the well-being of children born since 1997. CDS-2014 included all eligible children 0-17 years old observed in a PSID family in the preceding year (N=4,333, 88% response rate).

Time diaries were collected for two randomly selected days (one weekday and one weekend day) at each wave from all children in the 1997 cohort and from children in a randomly subsampled 50% of families in CDS-2014 (~80% response rate at each wave). These time diaries chronicled children's primary and secondary activities over 24 hours from midnight to midnight during one randomly selected weekday and one weekend day. Respondents reported the sequence of their activities during the day and, for each primary activity, recorded its start and end time, whether they were engaged in another (secondary) activity at the same time, where the activity took place, and who else was present. Open-ended descriptions of activities were coded by professional research staff at the Institute for Social Research at University of Michigan (Panel Study of Income Dynamics, 2003, 2015). Each reported activity is a record in the time diary data file. For each child, we summed total time in each activity of interest for weekdays and weekend days separately. The analytic sample for early childhood contains adolescents 11-17 years old in 2002 (N=1,272) or 2014 (N=493).

Time diaries offer a relatively unbiased account of time use (Hofferth, 2006; Robinson, 1985), and aggregated time diary data provide a comprehensive profile of how time is allocated in a population capturing behaviors, patterns, and tradeoffs that are unlikely to be observable in survey-based measures (Hofferth & Moon, 2012; Hofferth & Sandberg, 2001; Vandewater, Bickham, & Lee, 2006; Vandewater, Park, Hébert, & Cummings, 2015; Vandewater, Shim, & Caplovitz, 2004). CDS time diaries have been used to describe the frequency of adolescents' active leisure (Stafford & Chiteji, 2012) and electronic media use (Hofferth, 2010; Vandewater et al., 2007), to establish a correlation between television viewing time and obesity (Vandewater et al., 2004), and to describe time tradeoffs between passive and active leisure (Vandewater et al., 2015). Similarly, a series of surveys about technology use during the day prior to interview supported by the Kaiser Family Foundation and Common Sense Media (Rideout, 2015, 2017; Rideout et al., 2010) have provided information about the frequency and content of US children's and adolescents' screen time as new platforms for electronic media have emerged. However, ours is the first study to use nationally representative time diary data to compare adolescents' comprehensive activity profiles under distinctive technology regimes and to investigate their association with other health-related behaviors over time.

Although survey reports of adolescents' time using technology offer fairly fine-grained measures of technology activity, they are potentially problematic for a number of reasons: First, they may allow for overreporting of time in any given activity (i.e., total time can sum to more than 24 hours). Second, to date surveys have not distinguished between technology use as a primary activity, in which the activity is the main focus of an adolescent's attention and energy (such as watching a television program) or as a secondary activity in which the activity is done in the "background" to a primary activity (such as texting while eating dinner). Similarly, they fail to distinguish between weekday and weekend activities. Finally, they do not include information about time spent in other activities such as play, exercise, sleep, or time at school. Thus, they do not allow for the assessment of time tradeoffs between technology and other activities.

Measures

Technology Time Use

Technology use is classified into six categories: 1) television programming (on any type of device), 2) video game play, 3) communication such as texting or talking by phone or video, 4) education- and employment-related activities including homework and research, 5) audio entertainment, including music, radio, and podcasts; and 6) recreation, including consuming and creating social media, surfing the Internet, and shopping. We constructed measures for each of these categories to reflect total time spent as a primary activity, as well as total time spent as a secondary activity (when another activity was primary). We then constructed a measure of total time with technology overall, which reflected the sum of time in primary and secondary technology activities but removed any periods of overlap between the two. For example, if a child spent one hour playing video games on a mobile device as a primary activity while also watching television as a secondary activity, this period was coded as one hour of total technology time.

Following other work in time diary research (Hofferth, 2010; Hofferth & Sandberg, 2001;

Vandewater et al., 2007; Williams, Zimmerman, & Bell, 2013), we constructed a synthetic week from reported weekday and weekend time use. Total weekday time in a given activity was multiplied by five and total weekend activity time by two. These products were then summed to construct a synthetic week from each child's time diary pair (totaling 168 hours). Estimates of the number of hours per week that children spent in each activity were derived from this synthetic week.

Sleep and Physical Activity

To observe how change in time in technology use across cohorts might carry over to changes in time in other health-relevant activities, we constructed measures of time spent in sleep and physical activity in each cohort. Sleep includes overnight sleep and daytime naps. Because the time diaries report on activities from midnight on one day to midnight the next, most diaries capture two spells of nighttime sleep. Physical activity includes activities such as unstructured physical play, leisure sports, and coached practice for organized sporting activities. Because of the guidelines provided to respondents about how to complete the time diary, the estimate of does not include exercise during school hours (e.g., during recess periods) or in transit (e.g., walking or cycling between home and school) and so may not be a comprehensive accounting of adolescents' moderate or vigorous physical activity.

Sociodemographic Measures

To explore sociodemographic differences in time-use in each historical period, models included indicators of child gender, race/ethnicity (restricted to non-Hispanic white, non-Hispanic black, and Hispanic children), and family socioeconomic status (coded as an adolescent's primary caregiver having at least a four-year college degree, some college, a high school degree but no college education, or less than a high school degree).

Regression models also included four control variables. Survey year was coded as 0 for 2002-03 and 1 for 2014-16. Adolescent age at time diary completion was coded in years, averaging age at the date the weekday and the weekend day time diaries were collected. Family structure was indicated by whether or not two parents coresided with the child and by the number of children in the home, including the focal child.

Method

Our analysis includes three components. First, we considered patterns of time spent in technology use in each cohort overall and by gender, race/ethnicity, and social class. In multivariate regression models, interaction terms between sociodemographic characteristics and historical period assessed whether patterns of technology use had changed unevenly in the population. Second, we assessed the extent to which adolescents' technology use displaces time in play or physical activity in each cohort and tested whether the extent of any such displacement was stronger in one cohort compared to the other. To address each question, we used negative binomial regression, which accounts for over dispersion on the dependent variable. Simulation studies have suggested that negative binomial regression (sometimes referred to as Poisson-gamma regression) is preferable to ordinary least squares (OLS) or Tobit regression when modeling time diary data (Brown & Dunn, 2011).

Third, we used latent class analysis (LCA) to identify distinctive constellations of technology-focused activities among adolescents in 2014-16 and to establish the association of class membership with time spent in sleep and physical activity. Latent class analysis (LCA) classifies individual cases into subgroups (classes) according to predominant patterns in multivariate categorical data (Clogg, Petkova, & Haritou, 1995). The latent classes are derived from the data. LCA can include many variables while retaining parsimony, and it identifies naturally occurring interactions among variables in the latent classes rather than requiring each indicator to have an isolated effect on an outcome. LCA is therefore helpful for identifying how multiple aspects of technology use co-occur in a population.

To construct indicators for LCA, we summed primary and secondary time across a variety of digital activities, including audio entertainment, television, video games, communication (including texting and talking by phone or video), and social media. Categories were constructed to identify non-use (those whose time was equal to zero), low use (lowest quartile among users), moderate use (second and third quartiles among users), and high use (highest quartile among users). Additionally, we constructed a binary indicator to identify engagement in any other technology-related activities (e.g., homework, web surfing, and online shopping) because low participation in these activities precluded us from constructing multiple categories as we did with other activities. LCA models were fitted using the PROC LCA package in SAS 9.4 (Lanza, Collins, Lemmon, & Schafer, 2007) using full information maximum likelihood estimation. All analyses were adjusted to account for sampling weights and clustering. Class enumeration was informed by the Schwarz Bayesian Information Criterion (BIC) (Schwarz, 1978) , Akaike Information Criterion (AIC) (Akaike, 1974) and deviance statistic (G^2), with special attention paid to parsimony and substantive interpretation of classes. Respondents were assigned to the latent class with the highest predicted probability for subsequent analyses.

Because data were missing for 5.9% of cases in our analysis, we used multiple imputation by chained equations to account for missing data in all analyses. Multiple imputation assumes that data are missing at random after conditioning on other observed variables in the data set, a more plausible assumption than made by listwise deletion (Little & Rubin, 2014). We used 15 multiply-imputed data sets. Results were weighted to be representative of children contemporary to each cohort in families residing in the United States at least since 1997. All analyses were completed using Stata 13 statistical software (StataCorp, 2013).

PRELIMINARY RESULTS (**Results are sensitive to sample specifications and measurement of some covariates. We will continue to refine the analysis to develop robust models prior to PAA.****)**

How has adolescents' technology use changed in time and activities since the onset of the digital revolution?

Figure 1 summarizes adolescents' weekly hours spent using any type of digital device for television viewing, video game play, communication, education or work, audio entertainment, or other recreation as a primary or secondary activity in 2002-03 and 2014-16. Overall, adolescents' technology use as a primary activity declined by about one hour per week between cohorts (22.6 hours in the earlier cohort vs. 21.6 hours in the latter cohort), but increased by over eight hours per week as a secondary activity (7.7 hours vs. 15.9 hours). In total, adolescents' engagement in technology use increased from 28.5 to 32.9 weekly hours between cohorts, an increase of 14%. The decline in technology use as a primary activity was driven largely by less time spent watching television (15.3 weekly hours in 2002-03 vs. 12 hours in 2014-16). Excluding television, adolescents' technology use as a primary activity increased from 7.2 to 9.6 weekly hours between cohorts. Time spent in video game play or in education as a primary activity and in communication, video game play, or audio entertainment as a secondary activity increased over the period.

Table 1 describes the share of adolescents in each cohort participating in these activities and reports total weekly hours engaged in each as a primary or secondary activity overall and conditional on participation. While television viewing was nearly universal in each cohort, technology use for other purposes (excluding television) reached near-total saturation only in the more recent cohort (86.8% reported any type of technology use for a purpose other than television viewing in 2002-03 vs. 97.6% in 2014-16). Between 2002-03 and 2014-16, the share of adolescents engaged in video game play, audio entertainment and communication increased by about two-thirds, one-half, and one-quarter respectively, and u*nconditional* mean weekly hours in each of those activities also increased by at least two-thirds. Weekly mean hours conditional on participation in each of these activities increased by about one-third. Overall, it appears that changes in the amount of time spent in technology use was primarily a function of increased access and uptake and secondarily a function of more intensive use among those who participated.

Figure 2 summarizes weekly hours spent engaged in technology use, sleep, or physical activity overall and by family socioeconomic status, race/ethnicity, and gender in each cohort. These estimates combine time in primary and secondary activities, removing any overlap (i.e., time where a child was engaged in technology use as both a primary and secondary activity). Across sociodemographic groups, three consistent patterns emerge: time engaged in technology use has increased, time spent in sleep has remained roughly constant, and time in physical activity has declined between cohorts. Compared to peers whose primary caregiver had at least a high school diploma, youth whose caregivers had not completed high school experienced the largest increase in time in technology use (27.8 hours in 2002-03 vs. 37.9 hours in 2014-16), but the magnitude of increase is not significantly different across caregiver education categories (see multivariate regression results controlling for sociodemographic characteristics in Appendix A1). Only Hispanic youth experienced a decline in sleep hours (67.5 hours vs. 62.9 hours per week). Time spent in physical activity dropped by over 20% overall (4.5 weekly hours in 2002-03 vs. 3.7 hours in 2014-16). Non-Hispanic white youth and boys spent about 5% less time and youth whose primary caregiver had at least a four-year college degree spent about 5% more time in physical activity in the more recent compared to the earlier cohort, but all other groups spent substantially less time in physical activity in the more recent cohort. For example, youth whose caregiver held a high school diploma spent 60% less time in physical activity in 2014-16 compared to the earlier period (declining from 4.1 to 2.5 weekly hours), and for non-Hispanic black youth and girls, time in physical activity declined 44% and 61% respectively.

Does adolescent technology time disrupt health-promoting behaviors?

To what extent are changes in time spent in sleep or physical activity a function of changes in the time adolescents spend engaged in technology use? We evaluated this question in two ways. First, time use in any given day reflects a series of tradeoffs. More time spent in one activity is necessarily less time spent in any other activity. In that case, any gain or loss in the amount of time spent in sleep or physical activity between two cohorts may result from complementary change in the time spent in technology use. Second, the relationship between time spent in technology use or in other activities may be different in the two periods. That is, if technology use were more strongly associated with a sedentary lifestyle in 2014-16 compared to 2002-03, then the same amount of time invested in technology use in the later period would be more predictive of total time in physical activity compared to the earlier period. This might occur, for example, if patterns of technology use had become increasingly embedded in children's broader lifestyles between cohorts. To test for these patterns, we estimated children's total time in sleep or physical activity as a function of time spent in technology use as a primary or secondary activity, cohort, and the interaction of those terms, controlling for sociodemographic characteristics.

Figures 3A and 3B present weekly hours spent in sleep or physical activity estimated from negative binomial regression models when all covariates were held at their respective means (see Table 2). Error bars represent the 95% confidence interval for each estimate. There was no statistically significant association between total time spent in technology use and sleep in either cohort (Figure 3A). In contrast, more frequent technology use was associated with fewer hours spent in physical activity in each cohort, and that negative relationship was stronger in the more recent cohort. For example, in 2002-03, adolescents who engaged in technology use for 20 hours per week spent nearly one hour less per week in physical activity compared to peers who engaged in technology use for 10 hours per week (5.3 hours vs. 6.2 hours per week). In 2014-16, the magnitude of difference had increased to about two hours (4.4 hours vs. 6.4 hours per week). Thus, while the amount of time adolescents spent engaged in technology use as a primary activity did not increase significantly between cohorts, the same amount of time spent in technology use among contemporary adolescents was more strongly predictive of diminished physical activity compared to peers in the preceding cohort.

Does the composition of adolescent technology use disrupt health-promoting behaviors?

The preceding presentation demonstrated that on average, adolescents' time spent in technology use has increased between cohorts, although mostly as a secondary activity, and the composition of technology use has shifted away from a nearly exclusive focus on television to a mix of other activities including video game play, communication, and audio entertainment. Overall, this re-orientation has had little impact on adolescents' time spent in sleep but is associated with less time in physical activity. Yet population averages may conceal important variation among adolescents in the constellation of their habits of technology use and in their related health behaviors.

Using latent class analysis, we identified four distinctive patterns of adolescent technology use in the 2014-16 cohort (see Table 3). The largest group, comprising about 67 percent of adolescents, frequently watched television and listened to audio entertainment but never or infrequently engaged in video game play, digital or online communication, and social media activity (i.e., reported time was in the bottom quartile of the conditional distribution). Sixteen percent of sample members were distinguished by relatively frequent video game play (i.e., in the second quartile or above). This group consumed moderate amounts of television and audio entertainment but did not use technology for communication, social media, or other online activity. Three-quarters of adolescents in this class were male, and 84% had a primary caregiver who had attended at least some college. Adolescents in this group were younger on average (13 years) compared to the sample overall (14.5 years). A third group (7.8%) were multimedia users, frequently consuming television and audio entertainment and engaging in online communication and social media activities. Adolescents in this cluster were disproportionately Latina/o or African-American, and about 53% had a primary caregiver with a high school diploma or less. The fourth group (9.6%) used technology relatively frequently for communication, audio entertainment, and web activity. Nearly 60% of adolescents in this group were female, and the group was older on average (15.9 years) compared to the sample overall. One-fifth were African-American, and nearly two-thirds had a primary caregiver with at least some college education.

Table 4 presents coefficients and standard errors from negative binomial regression models estimating time spent in sleep (Panel 1) or physical activity (Panel 2) in the 2014-16 cohort as a function of latent class membership net of sociodemographic characteristics. As expected, considering latent class membership revealed variation in time spent in these health-promoting activities. Adolescents who engaged in frequent video game play spent 7% *more* weekly hours in sleep (exp(0.07)=1.07, $p<.01$) and 57% *fewer* hours in physical activity (exp(-0.84)=.43, $p<.05$) compared to the modal class. Multimedia users spent 16% fewer weekly hours in sleep, and adolescents using technology for frequent communication spent 13% fewer weekly hours in sleep and 63% fewer weekly hours in physical activity, compared to the modal class.

Figure 4 presents estimated weekly hours in sleep and physical activity for each class when all covariates were held at their respective means. Error bars show the 95% confidence interval for each estimate. Adolescents in the modal class slept for an estimated 67.3 hours per week (approximately 9.6 hours per night, in line with American Academy of Pediatrics guidelines of 8 to 10 hours per night for adolescents between 13 and 18 years) and engaged in 3.8 weekly hours of physical activity (slightly more than half of the 60 minutes of moderate or vigorous activity per day recommended for children and adolescents by the American Heart Association). Adolescents who were multimedia users or frequent communicators slept fewer than 60 hours per week. Frequent communicators also spent the least time in physical activity – an estimated 1.7 hours per week. Frequent video game players slept almost four more hours per week but were physically active for two hours less each week compared to the modal class. This pattern highlights that any type of relatively frequent technology use was associated with less time in at least one health-promoting activity, but different types of technology use also distinguished the frequent user groups from one another. This suggests that any strategy to encourage adolescents' health-promoting behavior in the context of frequent technology use should be mindful of the heterogeneity in this population. For example, strategies to increase sleep duration may be less effective if targeted to frequent video game players than if targeted to adolescents who use technology primarily for communication or social media.

DISCUSSION

Moving beyond debates about the developmental and social effects of adolescents' technology use, in this study we adopted a time use approach that views technology use as a common health behavior that forms part of young people's health lifestyles, facilitating some types of health behaviors and crowding out others. Comparing two nationally representative cohorts of US adolescents aged 11-17, we compared adolescents' technology use and its relationship to other health behaviors before versus after the dawn of the mobile internet era.

We highlight several key findings in discussing potential implications. Adolescents' time spent using technology was already high in 2002 but increased by 40 minutes per day in 2014. Yet this change in overall time spent was less substantial than the change in the composition of adolescents' technology use. Technology use has become more frequently a secondary activity, television watching is less dominant, and the use of newer technologies has increased. Although time spent using technology was not patterned by race/class/gender at either time point, adolescents' predominant profiles of technology use are sociodemographically patterned when measured in a more multidimensional way.

Technology use is thus a widespread health behavior that likely has implications for health and development. It is associated with both physical activity and sleep in ways that have changed over time. The relationship between technology use time and physical activity has strengthened over time and is substantial at higher levels of technology use. And the different predominant profiles of technology use have distinct implications for physical activity and sleep in complex ways that motivate the need for future research.

This study's limitations include the possibility of underreporting of some types of technology use, particularly secondary activities such as texting that occur in short bursts. Thus, we have provided a conservative estimate of technology use. As of 2014, PSID excluded families headed by immigrants who arrived in the United States since 1997. Finally, the smaller sample size in the 2014 CDS cohort compared to the earlier cohort resulted in coefficients in multivariate regression models being estimated with lower precision, making it less likely that potentially meaningful group differences were statistically significant.

We argue it is time to begin studying technology use—not just in terms of time spent but in terms of activity, device type, and duration—as a health behavior that is socially patterned and related to other health behaviors. Although our findings cannot address health or developmental outcomes, they speak to the prospect that technology use will have longer-term implications in these areas. Because not only time spent using technology, but the type of technology activity an adolescent engages in, matters for other health behaviors, our findings suggest that technology use plays a crucial role in adolescents' health lifestyles. The relatively high levels of sleep but low levels of physical activity among videogame players, compared to the converse among heavy multimedia users, imply that all technology time is not the same: Technology use-related identities may form part of adolescents' health lifestyles and inform other health behaviors in distinct ways. Further quantitative and qualitative research can flesh out these evolving processes.

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Table 1. Percentage of Children Participating in Selected Activities and Weekly Time; 2002 and 2014

	1997	2014	Diff.
N			
Percent Participating			
Total Tech	99.4%	99.7%	
Total Tech (Excluding TV)	86.8%	97.6%	***
Tech Activities			
TV	95.9%	94.5%	
Videogames	33.6%	56.3%	***
Communication	42.7%	52.7%	**
Education & Work	6.4%	13.0%	**
Listening	57.9%	84.4%	***
Recreation	21.7%	15.2%	*
Sleep	100.0%	99.3%	
Physical Activity	49.8%	43.6%	
Weekly Hour Means (Overall)			
Total Tech	28.45	32.94	***
Total Tech (Excluding TV)	11.26	19.97	***
Tech Activities			
TV	18.05	15.60	*
Videogames	2.83	6.32	***
Communication	3.14	5.27	***
Education & Work	0.34	0.70	*
Listening	4.55	8.58	***
Recreation	1.27	0.79	
Sleep	65.08	65.76	
Physical Activity	4.54	3.73	
Weekly Hour Means (Conditional on Use)			
Total Tech	28.62	33.03	***
Total Tech (Excluding TV)	12.97	20.46	***
Tech Activities			
TV	18.83	16.51	
Videogames	8.42	11.23	*
Communication	7.36	10.00	*
Education & Work	5.35	5.37	
Listening	7.87	10.16	**
Recreation	5.86	5.23	
Sleep	65.08	66.23	
Physical Activity	9.12	8.56	

Note. All data are weighted.
*** p<0.001, ** p<0.01, * p<0.05. t-tests across years

Table 2. Negative Binomial Regression Models Predicting Time in Sleep and Physical Activity as a Function of Total Tech Time; 2002 and 2014

	Sleep		Physical Activity	
Total Tech	0.00	-0.00	-0.04***	-0.02**
	(0.00)	(0.00)	(0.01)	(0.01)
2014	-0.00	-0.03	-0.37	0.24
	(0.02)	(0.04)	(0.21)	(0.37)
Total Tech × 2014		0.00		-0.02*
		(0.00)		(0.01)
Male	-0.01	-0.01	0.95***	0.95***
	(0.02)	(0.02)	(0.21)	(0.21)
Race/Ethnicity [Non-Hispanic White]				
Non-Hispanic Black	0.05	0.05	-0.08	-0.08
	(0.03)	(0.03)	(0.31)	(0.31)
Hispanic	-0.05	-0.05	-0.80*	-0.80*
	(0.07)	(0.07)	(0.34)	(0.34)
Primary Caregiver Education [High School Grad]				
Less than High School	0.06	0.06	0.31	0.31
	(0.06)	(0.06)	(0.33)	(0.33)
Some College	-0.01	-0.01	-0.04	-0.04
	(0.04)	(0.04)	(0.28)	(0.28)
4-Year College Grad	-0.00	-0.00	0.60*	0.60*
	(0.03)	(0.03)	(0.30)	(0.30)
Age	-0.01	-0.01	0.09	0.09
	(0.01)	(0.01)	(0.05)	(0.05)
2 Parents in Home	-0.01	-0.01	0.31	0.31
	(0.04)	(0.04)	(0.25)	(0.25)
Kids in Home	-0.02	-0.02	0.01	0.01
	(0.01)	(0.01)	(0.08)	(0.08)
Constant	4.38***	4.40***	0.57	-0.04
	(0.11)	(0.09)	(0.69)	(0.75)
ln(Alpha)	-3.47***	-3.47***	1.31***	1.31***
	(0.47)	(0.47)	(0.16)	(0.16)
Observations	1,765	1,765	1,765	1,765

Note. All data are weighted. Standard errors in parentheses.
*** p<0.001, ** p<0.01, * p<0.05

Table 3. Technology Use Profile LCA Item-Response Probabilities and Descriptive Means; 2014

	Technology Use Profiles				Total		
	Class 1	Class 2	Class 3	Class 4	Mean	95% CI	
Item-Response Probabilities							
Listening to Music							
None	0.11	0.46	0.01	0.00	0.15	0.10	0.19
Bottom 25%	0.19	0.06	0.16	0.00	0.15	0.10	0.19
Middle 50%	0.40	0.48	0.70	0.48	0.44	0.38	0.51
Highest 25%	0.30	0.00	0.13	0.52	0.26	0.20	0.33
Television							
None	0.05	0.07	0.04	0.03	0.05	0.03	0.08
Bottom 25%	0.27	0.00	0.00	0.52	0.23	0.17	0.29
Middle 50%	0.46	0.70	0.29	0.44	0.48	0.42	0.55
Highest 25%	0.22	0.23	0.67	0.00	0.23	0.18	0.29
Videogames							
None	0.44	0.12	0.58	0.79	0.43	0.37	0.50
Bottom 25%	0.18	0.21	0.01	0.00	0.15	0.10	0.20
Middle 50%	0.28	0.28	0.38	0.15	0.28	0.22	0.34
Highest 25%	0.10	0.38	0.02	0.06	0.14	0.09	0.18
Communication							
None	0.66	0.92	0.01	0.01	0.59	0.52	0.66
Bottom 25%	0.16	0.00	0.01	0.00	0.11	0.06	0.15
Middle 50%	0.17	0.00	0.39	0.35	0.18	0.13	0.23
Highest 25%	0.01	0.07	0.59	0.63	0.12	0.08	0.17
Social Media							
None	0.70	1.00	0.02	0.60	0.68	0.62	0.75
Bottom 25%	0.10	0.00	0.00	0.36	0.10	0.06	0.15
Middle 50%	0.15	0.00	0.45	0.05	0.14	0.09	0.19
Highest 25%	0.04	0.00	0.53	0.00	0.07	0.04	0.10
Any Web/Other	0.30	0.08	0.26	0.65	0.29	0.23	0.36
Descriptive Means							
Age	14.62	13.03	15.54	15.91	14.53	14.23	14.84
Male	0.46	0.77	0.47	0.41	0.51	0.44	0.58
Race/Ethnicity							
Non-Hispanic White	0.72	0.71	0.49	0.69	0.70	0.63	0.76
Non-Hispanic Black	0.14	0.14	0.20	0.20	0.15	0.11	0.19
Hispanic	0.14	0.15	0.31	0.10	0.15	0.09	0.21
Primary Caregiver Education							
Less than High School	0.08	0.07	0.18	0.04	0.08	0.05	0.12
High School Grad	0.28	0.08	0.35	0.45	0.27	0.21	0.33
Some College	0.33	0.54	0.29	0.20	0.35	0.28	0.42
4-Year College Grad	0.31	0.31	0.18	0.31	0.30	0.24	0.36
2 Parents in Home	0.60	0.60	0.55	0.56	0.60	0.53	0.66
Kids in Home	1.19	1.83	1.05	1.35	1.31	1.12	1.49
N	371	94	31	31		527	

Note. All analyses include sampling weights to account for complex survey design.

Table 4. Negative Binomial Regression Models Predicting Time in Sleep and Physical Activity as a Function of Tech-Use Profile

	Sleep	Physical Activity
Tech-Use Profile [Class 1]		
Class 2	0.07**	-0.84*
	(0.02)	(0.35)
Class 3	-0.18***	0.08
	(0.04)	(0.25)
Class 4	-0.14*	-1.06**
	(0.05)	(0.33)
Male	0.01	1.03***
	(0.02)	(0.26)
Race/Ethnicity [Non-Hispanic White]		
Non-Hispanic Black	0.02	-0.19
	(0.03)	(0.34)
Hispanic	-0.07	-0.71
	(0.07)	(0.41)
Primary Caregive Education [High School Grad]		
Less than High School	0.10	0.31
	(0.06)	(0.35)
Some College	-0.01	-0.15
	(0.04)	(0.28)
4-Year College Grad	-0.00	0.70*
	(0.03)	(0.30)
Age	-0.01	0.05
	(0.01)	(0.05)
2 Parents in Home	-0.00	0.31
	(0.04)	(0.27)
Kids in Home	-0.02	0.11
	(0.01)	(0.09)
Constant	4.33***	-0.13
	(0.09)	(0.75)
ln(Alpha)	-3.76***	1.31***
	(0.51)	(0.14)
Observations	493	493

Note. All data are weighted. Standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05

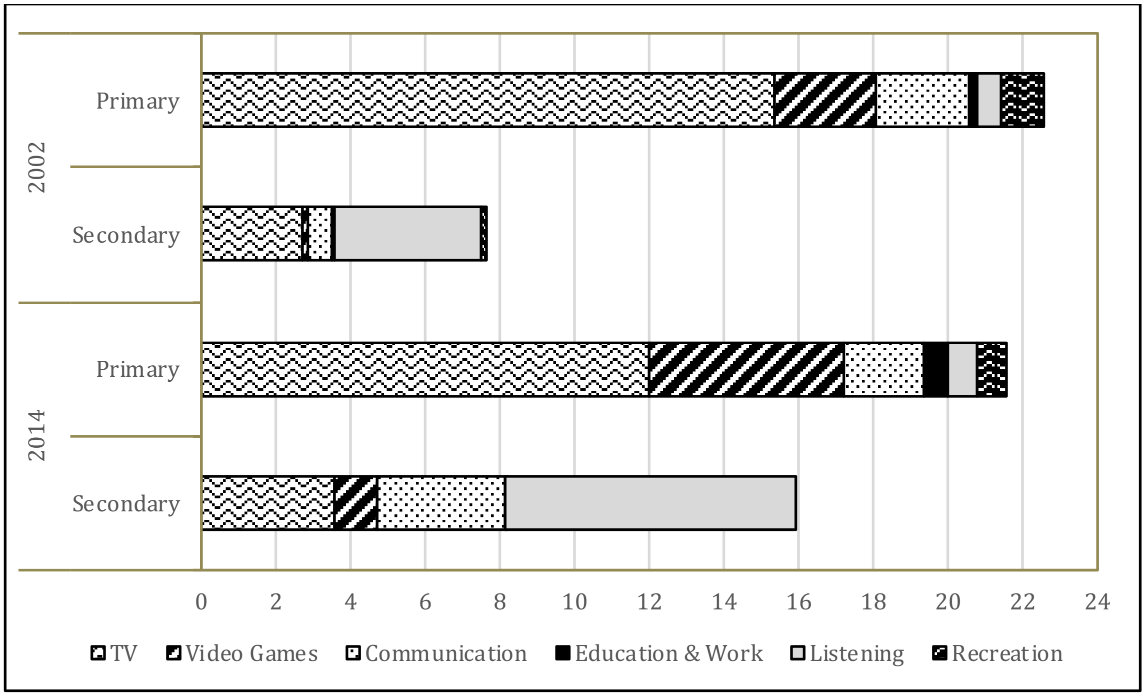

Figure 1. Technology Time as Primary and Secondary Activities; 2002 and 2014

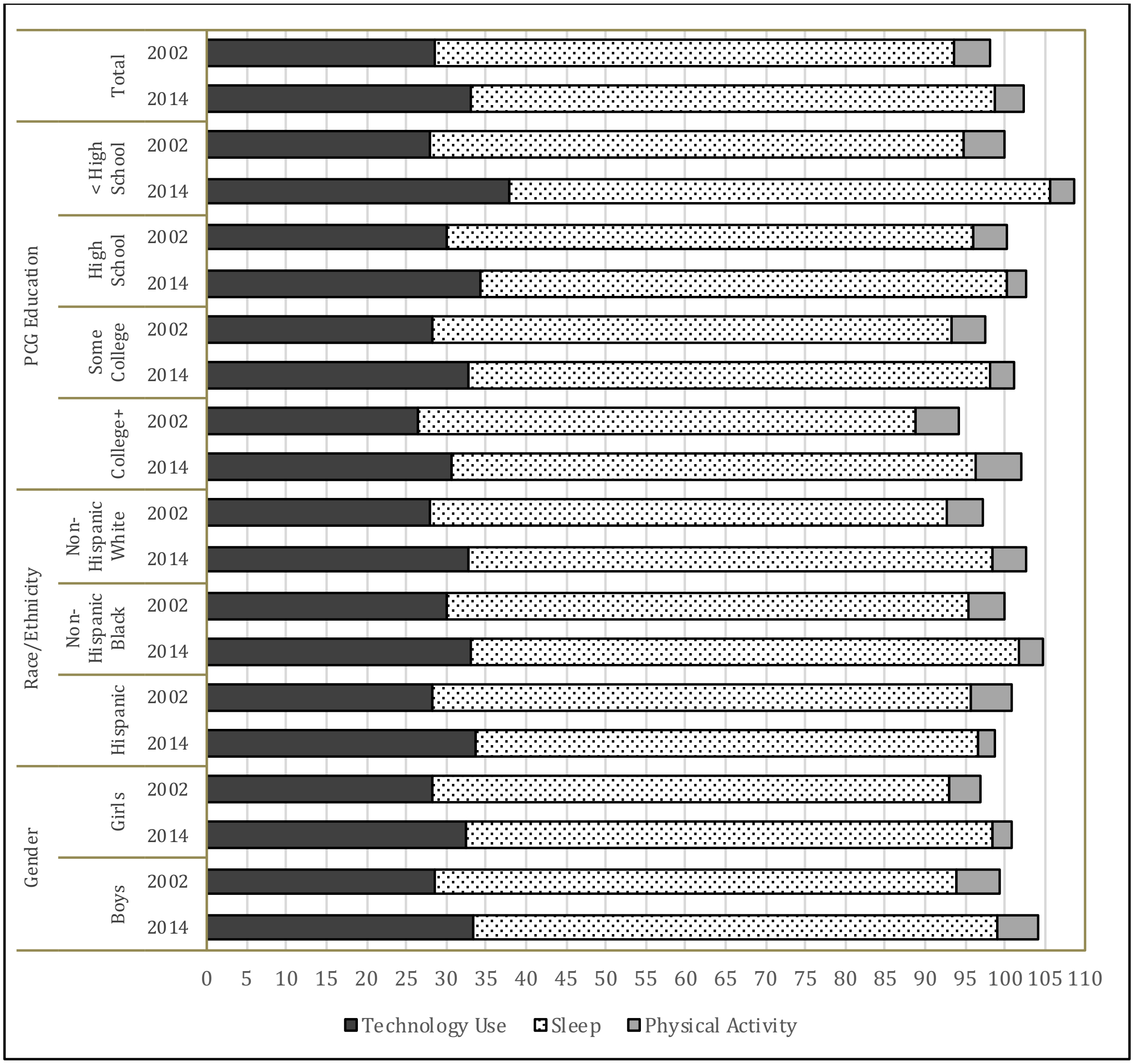

Figure 2. Technology, Sleep, and Physical Activity Time by PCG Education, Race/Ethnicity, and Gender; 2002 an 2014

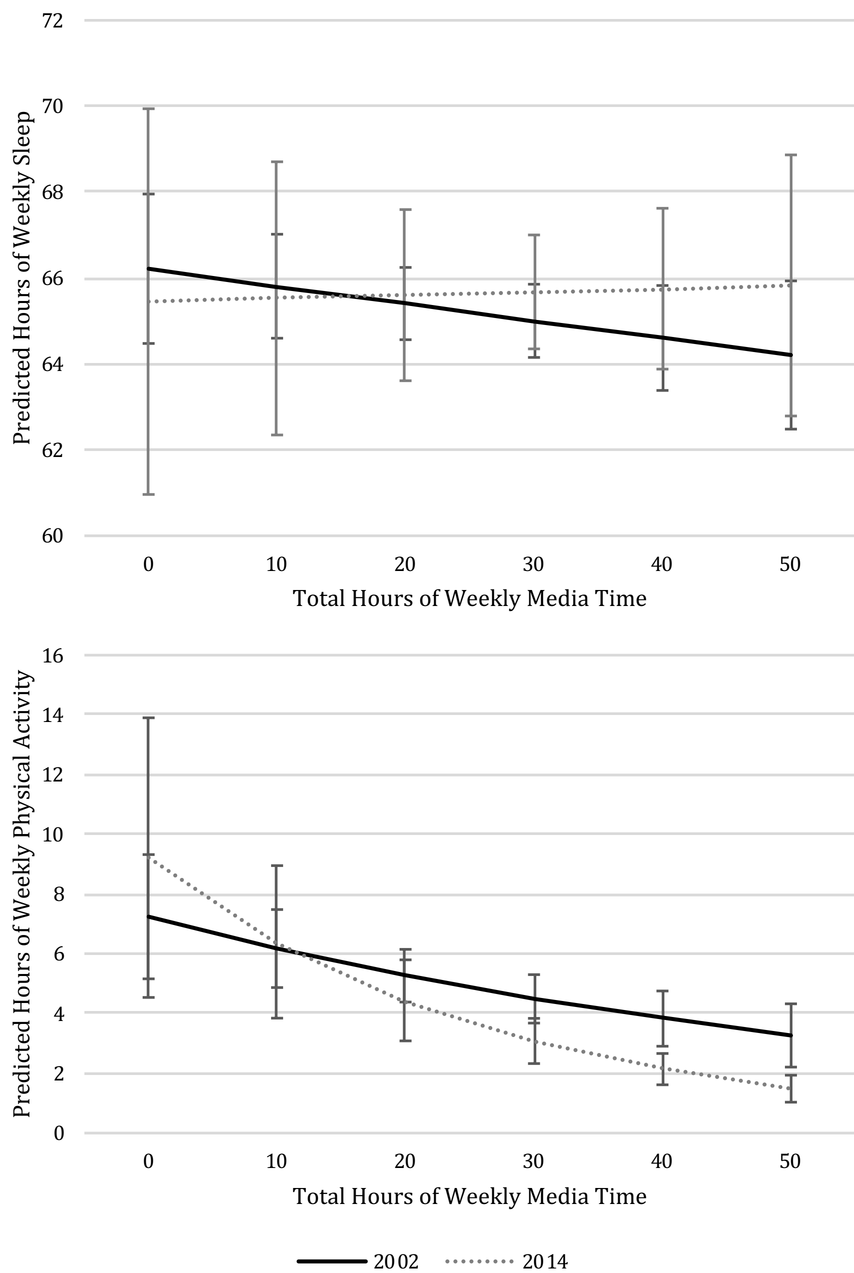

Figure 3. Predicted Values of Sleep and Physical Activity by Total Technology Time from Negative Binomial Regression Models; 2002 and 2014

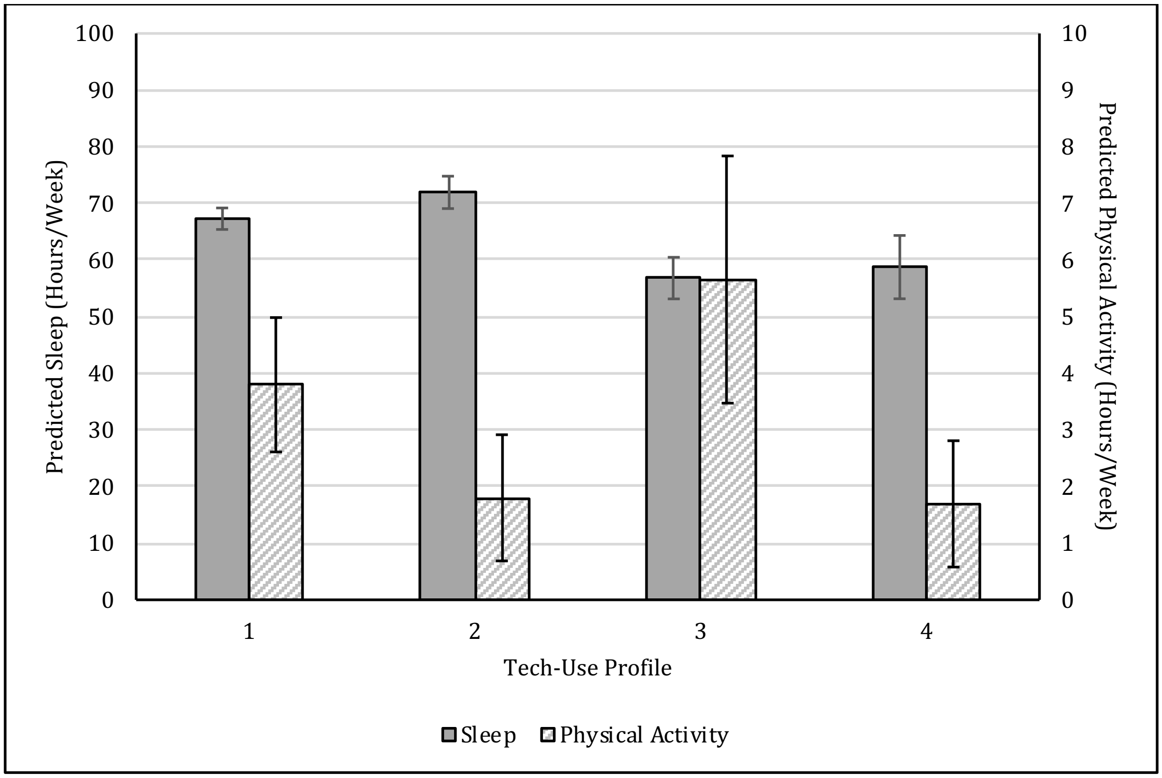

Figure 4. Predicted Values of Sleep and Physical Activity by Tech-Use Profile form Negative Binomial Regression Models; 2014

Appendix A1. Negative Binomial Regression Models Predicting Total Tech Time; 2002 and 2014

	Total Tech				
	2002	2014	2002/2014	2002/2014	2002/2014
Age	0.05***	0.05*	0.05*	0.05*	0.05*
	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)
Male	0.00	0.02	0.02	0.02	0.01
	(0.05)	(0.06)	(0.06)	(0.06)	(0.05)
Race/Ethnicity [Non-Hispanic White]					
Non-Hispanic Black	0.08	-0.03	0.02	-0.03	-0.03
	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)
Hispanic	0.01	-0.03	-0.04	-0.03	-0.03
	(0.08)	(0.13)	(0.09)	(0.13)	(0.13)
Primary Caregiver Education [HS Grad]					
Less than High School	-0.06	0.11	0.11	-0.03	0.11
	(0.08)	(0.14)	(0.13)	(0.12)	(0.13)
Some College	-0.06	-0.01	-0.01	-0.07	-0.01
	(0.04)	(0.09)	(0.09)	(0.05)	(0.09)
4-Year College Grad	-0.12	-0.06	-0.06	-0.12	-0.06
	(0.06)	(0.10)	(0.10)	(0.07)	(0.10)
2014			0.10	0.04	0.08
			(0.05)	(0.08)	(0.06)
2014 × Race/Ethnicity					
2014 × Non-Hispanic Black			-0.05		
			(0.07)		
2014 × Hispanic			0.01		
			(0.12)		
2014 × Primary Caregiver Education					
2014 × Less than High School				0.14	
				(0.15)	
2014 × Some College				0.06	
				(0.10)	
2014 × 4-Year College Grad				0.06	
				(0.11)	
2014 × Male					0.02
					(0.09)
2 Parents in Home	0.01	-0.14*	-0.14*	-0.14*	-0.14*
	(0.04)	(0.06)	(0.06)	(0.06)	(0.06)
Kids in Home	-0.02	-0.04	-0.04*	-0.04*	-0.04*
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Constant	2.66***	2.89***	2.79***	2.84***	2.80***
	(0.17)	(0.31)	(0.32)	(0.31)	(0.30)
ln(Alpha)	-1.20***	-1.58***	-1.58***	-1.58***	-1.58***
	(0.07)	(0.12)	(0.12)	(0.12)	(0.12)
Observations	1,272	493	1,765	1,765	1,765

Note. All data are weighted. Standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05