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

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Abstract (100-150 words)
The advent of internet-enabled mobile digital devices has transformed US adolescent technology use over the last decade, yet little is known about how these changes map onto other health-related behaviors. We provide a national profile of how contemporary technology use fits into adolescents' daily health lifestyles compared to the previous generation, with particular attention to whether and for whom technology use displaces time spent in sleep or physical activity. Time diaries were collected from 11-17 year olds in 2002-03 (N=1,139) and 2014-16 (N=527) through the US Panel Study of Income Dynamics Child Development Supplement. Contemporary adolescents spent 40 minutes more per week in technology-focused activities, but their composition was more varied compared to the earlier cohort. Contemporary technology use was predictive of less time in physical activity, and adolescents engaged in frequent video game play spent less time in physical activity compared to peers with other technology use profiles.

Keywords
Computer and media use; adolescence; health behaviors

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Adolescents' technology use has recently been transformed by internet-enabled mobile digital devices including smartphones and tablets (Madden, Lenhart, Duggan, Cortesi, & Gasser, 2013). These mobile technologies have largely displaced desktop computers, hand-held gaming devices, and cellular telephones that adolescents previously used for learning, video gaming, and communication.

The ubiquity and variety of mobile technology have introduced questions about whether adolescents' digital 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. Although 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 activity sets map onto other 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 future health behaviors and outcomes (Burdette, Needham, Taylor, & Hill, 2017; Lawrence, Mollborn, & Hummer, 2017).

We used 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 to consider the evolving relationship between adolescents' technology use and other health-related activities. The earlier cohort experienced adolescence before the emergence of internet-enabled digital devices marketed for personal use. The latter cohort grew up when such devices were not only available, but had begun to saturate the adolescent consumer market. In 2012, 47 percent of adolescents owned or had access to a smartphone, and 23 percent of adolescents owned or had access to a tablet (Madden et al., 2013). By 2018, adolescent ownership of or access to a

smartphone had increased to 95 percent, and 88 percent of adolescents owned or had access to a desktop or laptop computer at home (Anderson & Jiang, 2018). We compared adolescents' weekly hours spent using any digital device for learning activities, television, music, video gaming, social media, communication, or recreation in these two cohorts to assess how the nature and frequency of adolescents' technology use has changed. We then investigated whether cohort change in adolescents' time spent using technology was associated with change in time spent in two important facets of broader health lifestyles that contribute to healthy development: physical activity and sleep. Finally, we identified distinctive technology use profiles in the contemporary cohort and explored how they aligned with patterns of sleep and physical activity.

BACKGROUND

The Changing Nature of Technology Use

The digital revolution has led to profound shifts in technology use. During the early 2000s, technology users predominantly used single-task stationary devices such as televisions, desktop computers, and gaming consoles for entertainment and information gathering. Primarily due to cost, these devices were often shared among family members (MacGill, 2007). The internet was typically accessed via slow dialup connections, resulting in limited telephone access, internet interruptions, and an inability to multitask (Kleinrock, 2008). In that period, only 59 percent of US households reported having internet access and often restricted their time usage (Pew Research Center, 2018).

In the mid-2000s, the rise of broadband internet and social media sites made technology use more personalized and interactive. Access to high-speed internet facilitated use of video, audio, and gaming content. Social media sites provided digital platforms to interact and network with others. Thus, emerging technology provided increasingly pervasive and immersive

communication (Sefton-Green, 2006). By the early 2010s, the introduction of mobile devices, widespread broadband internet, and mobile applications had once again shifted technology use. Familiar devices such as televisions were also becoming "smarter" by allowing users to access the internet, stream audio, and use social media. By 2008, the gap in adult and adolescent cell phone ownership was narrowing (Lenhart, Smith, Anderson, Duggan, & Perrin, 2015; Rideout, Foehr, & Roberts, 2010), and mobile internet access surpassed computer internet access (Madden et al., 2013; Pew Research Center, 2018). As multiple device ownership has become more common in the 2010s (Rideout, 2015), adults and adolescents have become increasingly engaged in technology-saturated lives.

Technology Use in Adolescence

The changing landscape of technology use has had distinctive implications for adolescents. In the early 2000s, parents were concerned with the potential negative impacts of adolescents' excessive television viewing and the perils of unmonitored internet use, specifically regarding internet sexual predators. Parents also viewed computers and internet usage as essential for educational development (Russ, Larson, Franke, & Halfon, 2009), and adolescents were encouraged to use devices to enhance their digital competency and accrue cultural capital (Rafalow, 2018).

With high-speed internet and readily available personal technology devices, adolescents' technology use changed from focusing on education and passive entertainment to being intertwined with identities, social networks, and everyday experiences (Fitton, Ahmedani, Harold, & Shifflet, 2013). The virtual communication spaces of gaming and social media helped adolescents escape adult pressures and obtain privacy (Boyd, 2015), while texting became a primary means of communication (Lenhart et al., 2015).

Technology Use and Health-Promoting Behaviors

Parents, health care providers, public health advocates, and educators have persistently expressed worry that sedentary screen time compromises contemporary adolescents' health and development (Costigan, Barnett, Plotnikoff, & Lubans, 2013; Mark & Janssen, 2008; Sisson, Broyles, Baker, & Katzmarzyk, 2010). Research on the consequences of contemporary technology use as a health behavior has focused on addiction (Jorgenson, Hsiao, & Yen, 2016), social isolation (Turkle, 2011; Twenge, Martin, & Campbell, 2018), hearing loss (Vogel, Brug, Hosli, van der Ploeg, & Raat, 2008), and exposure to violence through media content and cyberbullying (Olson, Kutner, & Warner, 2008; Patchin & Hinduja, 2013). To date, there has been little attention to how new constellations of technology use may shape adolescents' broader health lifestyles by promoting or impinging on time engaged in other health-related activities. We consider four strands of research that motivate this focus.

First, even before the mobile internet era, adolescent health was a public health priority. Between 2001 and 2009, the share of adolescents diagnosed with type 2 diabetes increased by 30.5 percent (Dabelea et al., 2014). Adolescent obesity rates also increased, with 13.9 percent of adolescents considered obese in 2009-10 (Ogden, Carroll, Kit, & Flegal, 2012). In response, the objectives of the Healthy People 2020 plan included a focus on child health, but its ambitious goals remain out of reach (US Department of Health and Human Services, 2014).

Second, frequent sedentary time is implicated in adolescent obesity (Russ et al., 2009; Tremblay et al., 2011), poor health (Epstein, Paluch, Gordy, & Dorn, 2000; Institute of Medicine, 2005), and limited physical activity (Epstein et al., 2000; Hancox, Milne, & Poulton, 2004). Screen time is the largest contributor to adolescent sedentary activity (Olds, Maher, Ridley, & Kittel, 2010; Tremblay et al., 2011). Only 8% of adolescents in 2003-04 engaged in

physical activity for at least an hour daily as recommended by the US government (Troiano et al., 2008). In the ensuing decade, the share of adolescents meeting these guidelines dropped to 3.9% (Owens, Crone, De Ste Croix, Gidlow, & James, 2014). Research on sedentary screen time has largely focused on how frequent television viewing (i.e., more than two hours a day) impinges on other activities such as sleep and exercise and on physical health (Hancox et al., 2004; Russ et al., 2009; 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, Shim, & Caplovitz, 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). Thus, the increasing diversity of digital activities may yield 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. Much research has examined how passive sedentary activities displace physical activity and provide a context for unhealthy eating with consequences for physical health (Hancox et al., 2004; Russ et al., 2009). More recent work suggests that content delivered through smartphones and tablets impacts health and well-being through distinctive pathways, including potential addiction (Spies Shapiro & Margolin, 2014) and disruption to circadian rhythms that affect sleep physiology and alertness (Cajochen et al., 2011; Chang, Aeschbach, Duffy, & Czeisler, 2015). In sum, the increasingly varied mix of adolescents'

technology-focused activities has unknown impacts on time use and health outcomes compared to previous cohorts, through mechanisms that are not yet fully articulated.

Finally, these anticipated relationships between adolescents' technology use and other health behaviors likely have broader implications for health lifestyles. Health lifestyles comprise interrelated health behaviors that are undergirded by social identities (Cockerham, 2005). For example, an adolescent may identify as a "video gamer" 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 (e.g., Ream, Elliott, & Dunlap, 2011). Investment in a particular lifestyle identity can make individual health behaviors harder to change (Mollborn & Lawrence, 2018). Exploring how technology use patterns co-occur with health-promoting behaviors among adolescents is a first step toward understanding how they collectively shape health lifestyles.

We focused on two activities, characterized as health-promoting, that are expected to be diminished with frequent technology use: sleep and physical activity. Adolescents' sleep duration has decreased, with 63% of 15-year-olds reporting getting at least seven hours of sleep in 2012 compared to 71.5% in 1991 (Keyes, Maslowsky, Hamilton, & Schulenberg, 2015). Technology use, especially in the late evening (Calamaro, Mason, & Ratcliffe, 2009), is associated with delayed bedtimes (Eggermont & Bulck, 2006; Fuligni & Hardway, 2006), shorter overall sleep time (Cain & Gradisar, 2010), and inconsistent weekday and weekend sleep schedules (Van den Bulck, 2004). Adolescents have also reported insufficient and disruptive sleep patterns due to being woken up by text messages (Calamaro et al., 2009; Van den Bulck, 2003, 2007).

Technology use may also impact adolescents' physical activity and sedentary behavior. During adolescence, time spent in physical activity declines and sedentary activity increases (Gunnell et al., 2016). In recent cohorts, this life course change has occurred against a long-running secular decline in young people's physical activity levels (Hallal et al., 2012; Knuth & Hallal, 2009). In prior generations, technology use – particularly television consumption and video game play – was associated with more sedentary activity, with screen-based activities the largest contributor to adolescents' sedentary time outside of school (Olds et al., 2010; Tremblay et al., 2011). But we have little information about whether contemporary technology use, characterized by activity on a variety of mobile devices and performed as both a focal and background activity, detracts directly from physical activity.

DATA AND METHOD

Data

The US Panel Study of Income Dynamics (PSID) began in 1968 with a nationally representative sample of 4,802 US families. The world's longest-running household panel study, it includes data collected from 40 waves with 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). Within 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 residing in families that participated in that year's PSID main interview. Up to two children 0-12 years old per family were randomly selected for inclusion (N=3,563 children, 88% response rate). Children and their primary caregivers were re-interviewed in 2002-03 and 2007. In 2014-

2016, a new round (CDS-2014) collected information on 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 from midnight to midnight on each assigned day. Respondents reported the sequence of activities and, for each primary activity, recorded its start and end time, whether they were simultaneously engaged in another (secondary) activity, 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 2002-03 (N=1,139) or 2014-16 (N=527). The fieldwork period in the earlier period spanned the 2002-03 academic school year. Fieldwork in the latter period ran from October 2014 to April 2015 and November 2015 to February 2016. Families did not complete time diaries during the summer months.

Time diaries offer a less biased account of time use than retrospective survey questions (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 measures (Hofferth & Sandberg, 2001; Vandewater, Bickham, & Lee, 2006; Vandewater et al., 2004). CDS time diaries have been used to describe

the frequency of adolescents' active leisure (Stafford & Chiteji, 2012) and electronic media use (Hofferth, 2006; Vandewater et al., 2007), to establish a correlation between television viewing time and obesity (Vandewater et al., 2004), and to describe tradeoffs between passive and active leisure (Vandewater, Park, Hébert, & Cummings, 2015). 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.

Time diary data complements available survey data that characterize children's usual technology use. 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) has provided information about the frequency and content of US children's and adolescents' screen time. Although survey reports of adolescents' technology use offer fairly fine-grained measures, they are potentially problematic. First, they 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 or as a secondary activity in which the activity is done in the "background" (such as texting while eating dinner). They have not distinguished between weekday and weekend activities, nor have they collected information about time spent in other activities such as play, exercise, sleep, or time at school.

Measures

Technology Time Use

We classified technology use into: 1) television programming on any device, 2) video

game play on any device, 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 web surfing and shopping. Social media consumption and production were combined with other types of communication in these analyses for comparison with a pre-social media cohort but were coded separately in the latent class analysis of technology use profiles among adolescents in CDS-2014 (described below).

We constructed measures for each of these categories to reflect total time spent as a primary activity and as a secondary activity (when the primary activity was not technology use). We then constructed a measure of total time with technology overall as the sum of time in primary and secondary technology activities, removing any periods of overlap. For example, a child spending one hour playing video games while also watching television was coded as one hour of technology time.

Following other time diary research (Hofferth, 2010; Vandewater et al., 2007; Williams, Zimmerman, & Bell, 2013), we derived adolescents' time use from 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).

Sleep and Physical Activity

We constructed measures of time spent in sleep and physical activity. Sleep included overnight sleep and daytime naps. Because the time diaries report activities from midnight on one day to midnight the next, most diaries capture two spells of nighttime sleep. Physical activity included activities such as unstructured physical play, leisure sports, and coached practice for

organized sporting activities. Because of time diary guidelines, the estimate does not include exercise during school hours (e.g., during recess) or in transit between home and school, and so may not comprehensively account for physical activity.

Sociodemographic Measures

To explore sociodemographic differences in time use, models included indicators of gender, race/ethnicity (non-Hispanic white, non-Hispanic black, Hispanic, and other), 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 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. Family structure was indicated by whether or not two parents coresided with the child and by the total number of children in the home.

Method

Our analysis included three components. First, we considered 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 displaced time in sleep or physical activity in each cohort and tested whether the extent of any such displacement was stronger in one cohort compared to the other. We used negative binomial regression, accounting for overdispersion on the dependent variable. Simulation studies suggest that negative binomial regression (sometimes referred to as Poisson-gamma regression) is preferable to ordinary least squares 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). Latent classes are derived from the data. LCA can include many variables while retaining parsimony and 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 LCA indicators, we summed primary and secondary time separately for each of the following digital activities: audio entertainment; television; video games; communication (including texting and talking by phone or video); and social media. Categories distinguished non-use (time equal to zero), low use (bottom quartile among users), moderate use (second and third quartiles), and high use (top quartile). We constructed a binary indicator to identify engagement in other infrequent technology-related activities (e.g., homework, web surfing, and online shopping). LCA models were fitted using PROC LCA in SAS 9.4 (Lanza, Collins, Lemmon, & Schafer, 2007; SAS Institute Inc., 2013) using full information maximum likelihood estimation. Analyses accounted for sampling weights and clustering. Class enumeration was examined through the adjusted Bayesian Information Criterion (BIC) (Sclove, 1987), which has been shown to outperform other information criteria particularly when sample sizes are small (Yang, 2006), 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.

Total weekly hours in sleep and physical activity were estimated as a function of latent class membership and control variables. Because information on at least one independent variable was missing in 5.9% of cases, we used multiple imputation by chained equations creating 15 multiply imputed data sets to account for missing data (Little & Rubin, 2014). Results were weighted to be representative of children contemporary to each cohort in families residing in the United States at least since 1997. Regression models were estimated using Stata 15 statistical software (StataCorp, 2017).

RESULTS

How has adolescents' technology use changed in the mobile internet era?

Figure 1 summarizes adolescents' weekly hours spent using digital devices 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. Table 1 shows that in total, adolescents' engagement in technology use increased 17% between cohorts, from 28.2 to 33.0 weekly hours ($p<.001$). Adolescents' technology use as a primary activity declined by about one hour per week between cohorts (22.3 hours in the earlier cohort vs. 21.4 in the latter cohort; not significant) but increased by over eight hours per week as a secondary activity (7.6 hours vs. 16.2; $p<.001$). The decline in technology use as a primary activity was driven largely by less time spent watching television (Figure 1; $p<.001$). Excluding television, adolescents' technology use as a primary activity increased from 7.1 to 9.6 weekly hours between cohorts ($p<.001$). Time spent playing video games or on education as primary activities and on communication, video game play, or audio entertainment as secondary activities increased over the period ($p<.001$).

Table 1 describes the share of adolescents in each cohort participating in these activities and reports total weekly hours engaged in each overall and conditional on participation. While television viewing was nearly universal in each cohort, technology use for other purposes reached near-saturation only in the more recent cohort. 87% reported any type of technology use for a purpose other than television viewing in 2002-03 vs. 98% in 2014-16 ($p<.001$). Between 2002-03 and 2014-16, the share of adolescents engaged in video game play, audio entertainment, and communication increased by about two thirds ($p<.001$), one half ($p<.001$), and one quarter ($p<.01$) respectively, and unconditional mean weekly hours in each of those activities also increased by at least two thirds. Weekly mean hours conditional on participation in each activity increased by about one third. Overall, changes in technology use were a function primarily of increased access and uptake and secondarily of more intensive use among those who participated.

We also considered how changes in overall time spent in technology use aligned with changes in sleep and physical activity overall and by family socioeconomic status, race/ethnicity, and gender in each cohort. Across sociodemographic groups, three consistent patterns emerged: time engaged in technology use increased, time spent in sleep remained roughly constant, and time in physical activity 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 technology use (27.8 hours in 2002-03 vs. 37.3 in 2014-16; $p<.05$), but the magnitude of increase was not significantly different across caregiver education categories. Time spent in physical activity dropped by 16% overall (4.4 weekly hours in 2002-03 vs. 3.7 in 2014-16; not significant). Decreases were largest among Hispanic youth (60.8%;

p<.05) and girls (31.6%; p<.05). Complete regression results and a figure summarizing group and cohort differences are available at [site].

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 adolescents' technology use time? Time use in any given day reflects a series of tradeoffs. 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. The relationship between time spent in technology use or in other activities may also differ between cohorts. That is, if adolescents' technology use were more strongly associated with sedentary time in 2014-16 compared to 2002-03, the same amount of time in technology use in the later period would be more predictive of lost total time in physical activity compared to the earlier period. This might occur, for example, if patterns of technology use became 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.

Figure 2 presents predicted values from regression models estimating total weekly hours of sleep and physical activity as a function of total time spent using technology with all covariates held at their respective means. Values for the 2002-03 cohort are displayed as solid lines, and those for the 2014-16 cohort are dashed. The 95% confidence interval of the estimates for each cohort is presented in the shaded regions. There was no statistically significant association between total technology use time and sleep in either cohort (upper panel). In contrast, more frequent technology use was associated with fewer hours spent in physical activity

in each cohort (lower panel), and that negative relationship was stronger in the more recent cohort. For example, in 2002-03, adolescents who used technology 20 hours per week spent nearly one hour less per week in physical activity compared to peers who used technology 10 hours per week (4.6 vs. 5.4 hours per week). In 2014-16, the magnitude of difference had increased to about two hours (4.6 vs. 6.5 hours). Thus, in addition to the overall increase in technology time 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.

In supplemental analysis, we considered the association between each type of technology use and sleep and physical activity to assess whether there were countervailing influences of different types of technology use that potentially suppressed any observed association when time in all types of technology use was combined into a single measure. (Results are available upon request.) We did not find any such countervailing patterns. In both cohorts, learning activities, audio entertainment, and recreation were negatively associated with sleep, while time spent watching television, playing video games, or in communication were negatively associated with physical activity. The magnitude of these associations did not change across cohorts.

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

In sum, adolescents' average time spent in technology use increased between cohorts, although mostly as a secondary activity, and the composition of technology use shifted away from a nearly exclusive focus on television to a mix of other activities including video gaming, communication, and audio entertainment. Overall, this reorientation had little impact on adolescents' sleep time but was associated with less time in physical activity. Yet population

averages may conceal important variation in the constellations of adolescents' technology use habits and in related health behaviors.

Using latent class analysis, we identified four distinctive patterns of adolescent technology use in the 2014-16 cohort. The adjusted BIC suggested a six-class solution, but we selected the four-class solution for substantive interpretability and to ensure large enough class sizes for subsequent analyses. (Item-response probabilities and descriptive statistics for each technology use profile are available at [site], with complete model fit information available upon request.) The largest group, comprising about 74% of adolescents, were traditional users. These individuals exhibited moderate levels of television viewing (i.e., middle two quartiles), low levels of engagement with audio entertainment and video games (i.e., lower quartile), and were disproportionately likely to avoid digital or online communication and social media. Twelve percent of adolescents were gaming-focused. These individuals were distinguished by high frequency of video game play (i.e., upper quartile) and avoided electronic communication, social media, and other online activity. Approximately two thirds of adolescents in this class were male, and 66% had a primary caregiver who had attended at least some college. A third group, communicators (8%), was distinguished by frequent online communication and consumption of audio entertainment. These individuals were unlikely to play video games and infrequently consumed television and social media (none or lowest quartile). Adolescents in this class were disproportionately female (70%) and had a primary caregiver who was a college graduate (46%). The fourth group, media-saturated (7%), used technology the most frequently and were the heaviest consumers of television, communication, and social media. These individuals were disproportionately female (57%), Hispanic (27%), and had primary caregivers with a high school diploma or less (55%).

Figure 3 presents estimated weekly hours of sleep and physical activity for each class with all covariates held at their means. Average weekly sleep hours (represented by light gray bars with values on the left axis) were highest among those in the media-saturated group at 66.4 hours per week and lowest among communicators at 64.1. However, there were no significant differences across groups, with all average values in line with the American Academy of Pediatrics guidelines (2016) of 8 to 10 hours per night for adolescents aged 13-18. Weekly hours of physical activity (dark gray bars with values on the right axis) were highest among adolescents in the traditional class, who engaged in 3.5 weekly hours (approximately half of the 60 minutes of moderate or vigorous activity per day recommended for children and adolescents by the US Department of Health and Human Services [2018]). Physical activity time for the gaming-focused class was significantly lower than all other groups, with adolescents in this group engaging in only 1.2 hours per week (approximately 10 minutes per day). This pattern highlights that any type of relatively frequent technology use was associated with less time in physical activity, but different patterns of technology use also distinguished the frequent user groups from one another. This suggests that strategies to encourage adolescents' health-promoting behavior in the context of frequent technology use should be mindful of the heterogeneity in this population. Different strategies may be required to increase physical activity among more sedentary video game players compared to adolescents who use technology primarily for communication or social media.

DISCUSSION

Moving beyond debates about developmental and social effects of adolescents' technology use, we adopted a time use approach that views technology use as a frequent health

behavior that forms part of young people's health lifestyles, facilitating some health behaviors and crowding out others. Comparing two nationally representative cohorts of US adolescents aged 11-17 using time diary data, we compared adolescents' technology use and its relationship to other health behaviors before and after the dawn of the mobile internet era.

We highlight several key findings. Adolescents' time spent using technology was already high in 2002-03 but increased by 40 minutes per day in 2014-2016. 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 new technologies distinguish the activities of contemporary adolescents compared to the earlier cohort. Together, these patterns suggest paradigm-shifting changes in how adolescents' technology use fits into other ways they spend their time. Although time spent using technology was not significantly patterned by race, class, or gender at either time point, adolescents' predominant profiles of technology use were 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, and its association with physical activity has strengthened over time and is substantial at higher levels of technology use. Further, the different predominant profiles of technology use have distinct implications for physical activity that motivate the need for future research. In contrast, we did not find evidence that sleep duration varies by technology use profiles.

This study has some limitations. Perhaps most critically, some types of technology use, particularly activities such as texting that occur in short but frequent bursts, may be underreported. Thus, our technology use estimates are conservative. Recent innovations in

passive data collection from electronic devices have enabled accurate measurement of adolescents' total time actively engaged with technology as a background activity to other primary activities such as travel, shared meals, and socializing with family or friends—although no nationally representative data are available. Capturing that information can uniquely characterize the quality of how children experience their primary and secondary activities. Here we have considered technology use as a focal activity contributing to how children organize and apportion their time in sleep and physical activity. To the extent that children or their caregivers self-report these activities as primary, we expect that unmeasured technology use may be concurrent with but not substituting for those activities. Second, as of 2014, PSID excluded families headed by immigrants who arrived in the United States since 1997; thus, our findings are not representative of first-generation immigrant youth or those raised in families that recently entered the US. Nevertheless, our findings are consistent with other research on technology use, health behaviors, and their relationship in contemporary US youth populations. Further, the latent classes we identified and the demographic composition of each class are consistent with the media use typology identified by Rideout (2015) among youth aged 8 to 18 years who reported usual screen time activities in a 2015 national web survey, although Rideout's analysis was also able to distinguish mobile gamers from other video game players and identified a separate group of frequent readers. Finally, the smaller sample size in the 2014 cohort compared to the earlier cohort resulted in coefficients in multivariate regression models estimated with lower precision, making it less likely that potentially meaningful group differences were statistically significant.

We argue it is time to study 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 both time and the type of technology activity an adolescent engages in matter for other health behaviors, our findings suggest that technology use plays a crucial role in adolescents' health lifestyles. The comparable levels of sleep but low levels of physical activity among video gamers, 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. Beyond future time-diary and survey-based studies, qualitative observational and interview research characterizing how adolescents integrate technology use with other health behaviors could inform a more nuanced and holistic approach to understanding the organization of adolescents' everyday lives and begin to point to potential implications for health and development.

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Table 1. Percent Participating, Overall Weekly Mean Hours, and Conditional Weekly Mean Hours for Selected Activities, 2002-03 and 2014-16

	2002-03	2014-16	Diff.
N	1,339	527	
Percent Participating			
Total Tech	0.99	1.00	
Total Tech (Excluding TV)	0.87	0.98	***
Tech Activities			
TV	0.96	0.95	
Video Games	0.33	0.56	***
Communication	0.43	0.53	**
Education & Work	0.06	0.13	**
Listening	0.57	0.85	***
Recreation	0.23	0.15	*
Sleep	1.00	0.99	
Physical Activity	0.48	0.43	
Weekly Hour Means (Overall)			
Total Tech	28.24	32.98	***
Total Tech (Excluding TV)	11.05	20.13	***
Tech Activities			
TV	18.01	15.42	*
Video Games	2.75	6.28	***
Communication	3.04	5.25	**
Education & Work	0.34	0.72	*
Listening	4.50	8.91	***
Recreation	1.29	0.78	*
Sleep	65.19	65.81	
Physical Activity	4.35	3.65	
Weekly Hour Means (Conditional on Use)			
Total Tech	28.40	33.07	***
Total Tech (Excluding TV)	12.73	20.60	***
Tech Activities			
TV	18.80	16.30	*
Video Games	8.42	11.15	***
Communication	7.03	9.93	**
Education & Work	5.34	5.55	*
Listening	7.85	10.42	***
Recreation	5.67	5.24	*
Sleep	65.19	66.27	
Physical Activity	9.05	8.46	

Source: Panel Study of Income Dynamics Child Development Supplement Time Diaries. *Notes*. All data are weighted. *** p<0.001, ** p<0.01, * p<0.05; t-tests comparing 2002-03 to 2014-16.

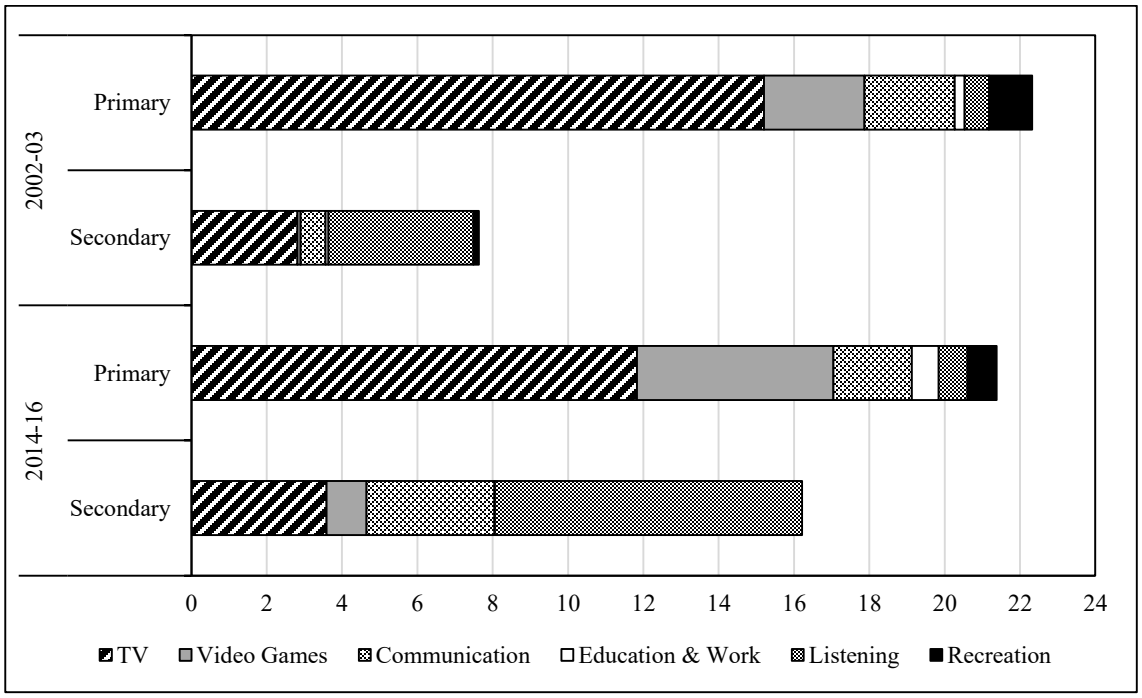

Figure 1. Adolescents' Primary and Secondary Technology Time by Activity; 2002-03 and 2014-16
Source: Panel Study of Income Dynamics Child Development Supplement Time Diaries. N = 1,866.

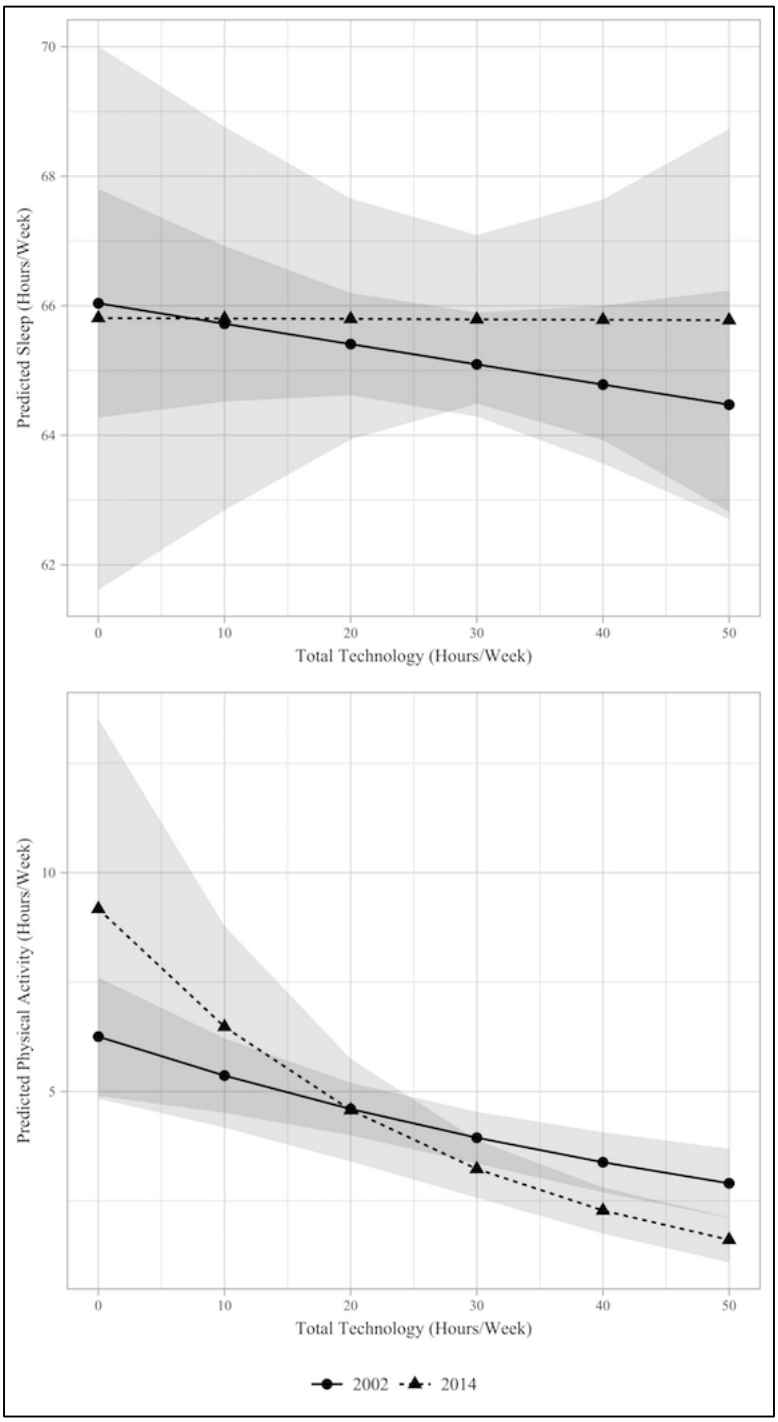

Figure 2. Predicted Weekly Values of Sleep and Physical Activity by Total Tech Time, 2002-03 and 2014-16

Source: Panel Study of Income Dynamics Child Development Supplement Time Diaries. *N* = 1,866. *Note:* Predicted values from multiple regression models with all covariates held at mean values.

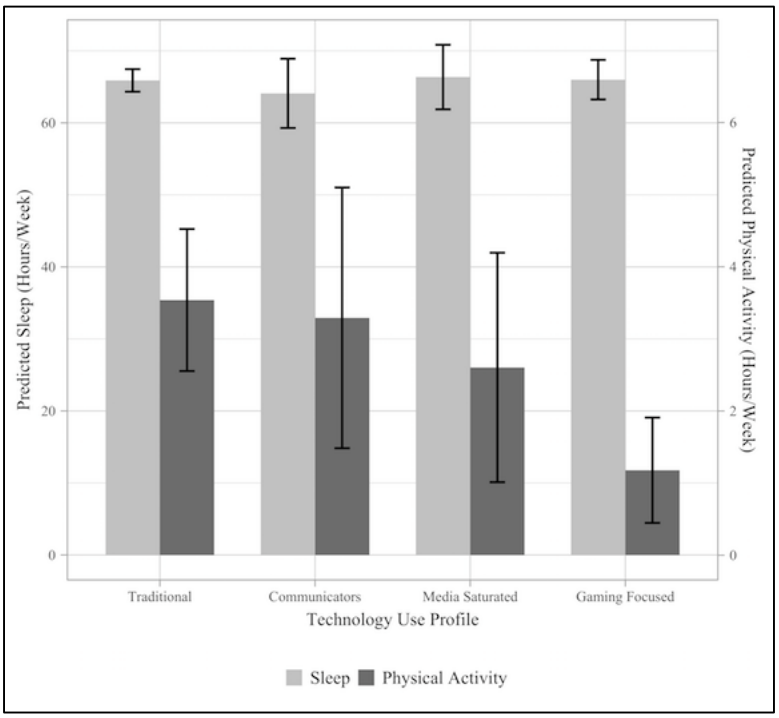

Figure 3. Predicted Weekly Values of Sleep and Physical Activity by Technology Use Profile, 2014-16
Source: Panel Study of Income Dynamics Child Development Supplement Time Diaries. $N = 527$. *Note:* Predicted values from multiple regression models with all covariates held at mean values.

Table A1. Item-Response Probabilities and Descriptive Means for Technology Use Profiles, 2014-16
Source: Panel Study of Income Dynamics Child Development Supplement Time Diaries. *Notes*. All data are weighted.

	Traditional	Comm.	Media Saturated	Gaming Focused	95% CI	
Item-Response Probabilities						
Listening to Music						
None	0.14	0.00	0.00	0.37	0.10	0.19
Bottom 25%	0.20	0.00	0.18	0.01	0.11	0.19
Middle 50%	0.46	0.51	0.66	0.18	0.38	0.51
Highest 25%	0.20	0.49	0.15	0.44	0.20	0.32
Television						
None	0.01	0.07	0.05	0.25	0.03	0.08
Bottom 25%	0.26	0.49	0.00	0.05	0.18	0.29
Middle 50%	0.57	0.44	0.27	0.19	0.41	0.54
Highest 25%	0.16	0.00	0.69	0.52	0.19	0.30
Video Games						
None	0.36	0.79	0.61	0.41	0.37	0.50
Bottom 25%	0.23	0.00	0.01	0.00	0.10	0.20
Middle 50%	0.28	0.15	0.36	0.32	0.22	0.34
Highest 25%	0.14	0.05	0.02	0.27	0.09	0.18
Communication						
None	0.68	0.02	0.02	0.96	0.53	0.65
Bottom 25%	0.15	0.06	0.04	0.01	0.07	0.15
Middle 50%	0.15	0.42	0.42	0.00	0.13	0.23
Highest 25%	0.02	0.50	0.52	0.04	0.08	0.17
Social Media						
None	0.75	0.58	0.04	0.87	0.62	0.74
Bottom 25%	0.07	0.37	0.01	0.13	0.06	0.15
Middle 50%	0.14	0.05	0.45	0.00	0.09	0.19
Highest 25%	0.04	0.00	0.50	0.00	0.04	0.10
Any Web/Other	0.28	0.56	0.26	0.17	0.23	0.35
Descriptive Means						
Age	14.20	15.74	15.57	14.39	14.24	14.79
Male	0.51	0.30	0.43	0.65	0.42	0.57
Race/Ethnicity						
Non-Hispanic White	0.67	0.65	0.48	0.70	0.58	0.73
Non-Hispanic Black	0.16	0.14	0.19	0.09	0.09	0.21
Hispanic	0.12	0.11	0.27	0.15	0.08	0.19
Other	0.04	0.09	0.06	0.06	0.02	0.08
Primary Caregiver Education						
Less than High School	0.09	0.05	0.16	0.09	0.05	0.14
High School Grad	0.26	0.32	0.39	0.25	0.19	0.36
Some College	0.34	0.17	0.27	0.42	0.24	0.41
4-Year College Grad	0.31	0.46	0.18	0.24	0.23	0.38
2 Parents in Home	0.61	0.64	0.52	0.45	0.48	0.69
Kids in Home	2.29	2.36	1.98	2.24	2.07	2.46
Total Technology Time	29.91	33.38	47.31	39.44	30.73	35.24
Total Technology Time (No TV)	16.96	27.98	30.02	23.55	18.03	22.22
Devices in Home						
Smartphone	0.93	0.97	0.94	0.73	0.87	0.96
Computer	0.90	0.96	0.84	0.89	0.86	0.94
Tablet	0.73	0.82	0.79	0.61	0.67	0.80
N	388	40	34	65	527	

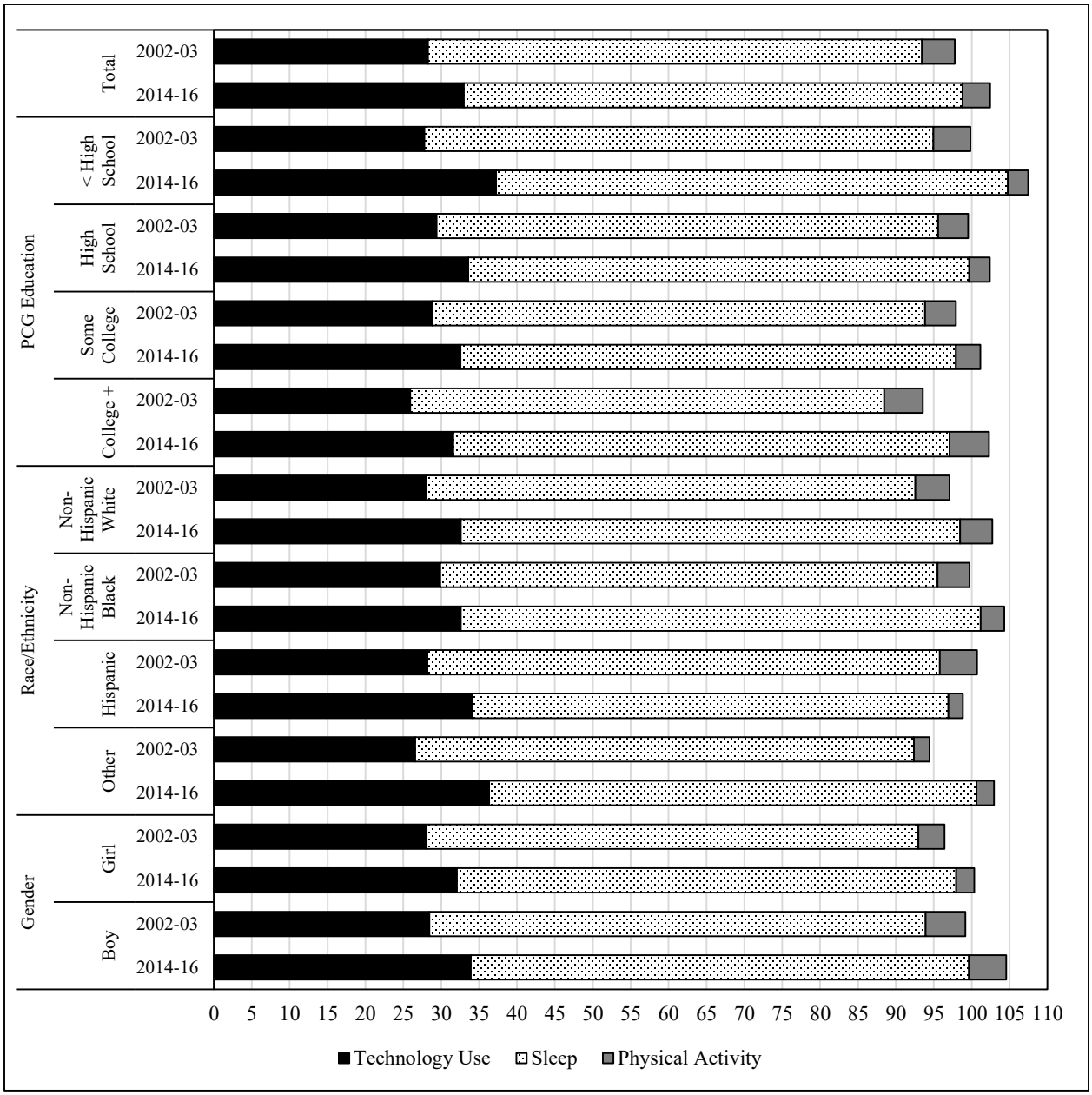

Figure A1. Total Time in Technology Use, Sleep, and Physical Activity by Primary Caregiver Education, Race/Ethnicity, and Gender, 2002-03 and 2014-16

Source: Panel Study of Income Dynamics Child Development Supplement Time Diaries. $N = 1{,}866$.