Mobile touch screen device use and associations with musculoskeletal symptoms and visual health in a nationally representative sample of Singaporean adolescents

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Practitioner summary:

1884 adolescents in Singapore completed an in-depth questionnaire regarding their use of technology. The smartphone was the device with the highest usage, and greater smartphone use was associated with increased odds of musculoskeletal and visual symptoms. High use of smartphones has physical health implications for adolescents.

Mobile touch screen device use and associations with musculoskeletal symptoms and visual health in a nationally representative sample of Singaporean adolescents

This study aimed to describe contemporary technology use, especially smartphones and tablets (mobile touch screen devices), and examine associations with musculoskeletal symptoms and visual health among adolescents in Singapore. A representative sample of 1884 adolescents (50.4% girls) from grades primary 5 to post-secondary (10-18 years old), recruited from 13 schools, completed an online questionnaire in class. Total technology use was high, with smartphone duration being highest (mean=264 (SD=243) minutes/day). Patterns of use, including multitasking and bout length, were influenced by gender, school level, type of device and activities. Musculoskeletal discomfort and visual symptoms were commonly reported. After adjusting for potential confounders, more hours/day of smartphone use was associated with increased risk of neck/shoulders, upper back, arms and wrist/hand discomfort (OR=1.04(95%CI=1.01-1.07) to 1.07(1.03-1.10)) and visual symptoms (OR=1.05(1.02-1.08)), but was associated with decreased odds of myopia (OR=0.97(0.94-0.99)). No significant associations were found for tablet use.

Keywords: mobile touch screen devices; smartphone; tablet; musculoskeletal symptoms; visual symptoms

Introduction

Technology use by children has exponentially increased in recent years, especially following the introduction of mobile touch screen devices (MTSDs), primarily smartphones and tablet computers. Recent large-scale surveys have shown high and increasing use of MTSDs amongst adolescents (Ofcom 2017; Rideout 2015; Australian Communications and Media Authority 2016), and there is concern about its potential negative impact on adolescents' musculoskeletal and visual health (Lissak 2018; Straker and Howie 2016). However, there is a dearth of evidence to support this hypothesis. Whilst extensive research has been conducted on associations between musculoskeletal

symptoms and computer use, studies on MTSD use have been limited and mostly conducted in adult populations (Toh et al. 2017; Xie, Szeto, and Dai 2017).

Musculoskeletal symptoms can adversely affect adolescents' health, leading to school absenteeism, reduced physical activity (Bejia et al. 2005; O'Sullivan et al. 2012), and an increased risk of musculoskeletal problems during adulthood (Brattberg 2004). Similarly, existing research has shown associations between computer use/video gaming (Bao et al. 2015) and impaired vision or symptoms such as eye strain (Gowrisankaran, Sheedy, and Albin 2015; Lissak 2018). MTSD use from a young age raises the concern of eye-related developmental problems (Akinbinu and Mashalla 2014). In addition, blue light emitted from screens has been proposed to increase the risk for age-related macular degeneration (Tosini, Ferguson, and Tsubota 2016). Given the current ubiquity of MTSD use by adolescents, it is important to examine associations between MTSD use and musculoskeletal and visual symptoms among adolescents.

The quality of available evidence on MTSD use and musculoskeletal and visual outcomes in adolescents is limited by convenience sampling, a focus on Western populations and simple exposure measures of MTSD use. Even with a large sample size, convenience sampling can introduce a selection bias and recruited participants may not be representative of the population (Tyrer and Heyman 2016). Moreover, to date, the majority of epidemiological studies on technology use, including MTSDs, have been conducted in Western countries, such as the USA, Australia and Europe (Rideout 2015; Torsheim et al. 2010; Houghton et al. 2015), while studies in Asian countries have recently gained interest amongst researchers (Shan et al. 2013; Kwok, Lee, and Lee 2017; Woo, White, and Lai 2016). Compared to the Western countries, adolescents in Asian countries may exhibit different patterns of technology use due to cultural differences (Recabarren, Nussbaum,

and Leiva 2008; Jackson et al. 2008) or even more widespread internet availability than in some Western countries (We Are Social 2017).

Research to date investigating MTSD use has mostly reported simple measures of use and duration of use, with a lack of comprehensive reporting on patterns of use, including weekday weekend use, types of activities, bout length of use or extent of multitasking. Patterns of computer use, such as the types of activities (Straker et al. 2013; Torsheim et al. 2010) and bout use duration (Menéndez et al. 2008) have been found to be related to musculoskeletal symptoms. A recent review has also found gaming and texting on mobile handheld devices (inclusive of physical keypad phones) as risk factors for musculoskeletal symptoms (Xie, Szeto, and Dai 2017). These findings suggest that patterns, and not just duration, of MTSD use may influence the risk for musculoskeletal symptoms. However, these studies on use of other digital devices may not be applicable to MTSDs as patterns of use and risks for symptoms may be different for MTSDs due to their greater portability, multifunctionality and different biomechanical demands (Straker et al. 2008; Gustafsson et al. 2018; Xie et al. 2018). There is, therefore, a need to examine the contemporary patterns of technology use, especially MTSD use among adolescents, which can inform public health recommendations for use and interventions. This study aimed to examine among a nationally representative group of adolescents in Singapore the:

- amount and patterns of contemporary technology use, particularly MTSDs
- associations of MTSD use with musculoskeletal symptoms and visual health.

Methods

Study design and sample

This cross-sectional study involved administering an online survey to 2009 adolescents recruited from schools in Singapore, using a sampling matrix stratified on socioeconomic and academic indicators (see Figure 1). Four school year levels were selected to capture adolescents from 10 to 18 years of age: primary 5, secondary 1, secondary 3, and post-secondary year 1 (equivalent to grades 6, 8, 10 and 12, respectively, of the US education system), using a list of all the schools that was obtained from the Ministry of Education Singapore (2015). Primary schools were selected from different types of school (government or government-aided) and location (higher and lower socioeconomic status based on the top and bottom 50th percentile of median monthly household income of each planning area, according to the last census report from the Department of Statistics Singapore (2010). Secondary schools were also selected from different types of school (government or government-aided) and educational stream (Express [higher academic] or Normal [lower academic] stream, based on students' primary school leaving examination performance). Post-secondary schools were selected from different types of schools (junior college, polytechnic or vocational [Institute of Technical Education]). Using G*Power software, a sample size of 2000 was estimated to enable the detection of an odds ratio (OR) of 1.17 with 80% power and an alpha probability of 0.05. This expected effect size was based on the OR reported by a survey study on risk of neck/shoulder and back pain with computer and tablet use in adolescents (Shan et al. 2013). Within each sampling cell, schools were invited in random order until ~2000 adolescents had agreed to participate.

Ethics approval was obtained from Curtin University Human Research Ethics Committee (RDHS-100-15), and approval for data collection in schools was obtained from

the Singapore Ministry of Education and a polytechnic institution, as well as the school principal of each participating school. Assent from adolescents and written informed consent from parents/guardians were obtained for participants less than 18 years old, while adolescents who were at least 18 years old provided written consent. The primary and secondary school participants completed an online questionnaire in a school classroom or computer laboratory using a laptop or tablet computer, while the junior college students did so on a smartphone (due to facility constraints). A research team member was present to answer any questions during administration of the questionnaire. Due to ethical and logistics constraints at the polytechnic institution, it was not possible to administer the questionnaire during the students' curriculum time or to recruit students from a wide variety of courses. Instead, a short information session regarding the study was given to the polytechnic students from one course. Brochures containing the survey link were distributed to them and they were asked to complete the online survey on their own time within a stipulated timeframe. There were no participants from the vocational school (Institute of Education) as none of the principals provided approval.

Measures

The Technology Use Questionnaire (TechU-Q) was administered online through Qualtrics. It has been developed based on prior studies and pilot testing by the investigators (Harris, Straker, and Pollock 2017). Test-retest reliability of TechU-Q for total technology use was high, with an intraclass correlation for total technology use of 0.90 (Straker et al. 2017). It had also been shown to be acceptable and understandable by a sample of grade 5 children in an Australian school (Straker et al. 2017). To ensure feasibility and comprehensibility by adolescents in Singapore, the questionnaire was pilot-tested with 15 adolescents in Singapore from different school levels and across ages of 10

to 17 years. After obtaining feedback, the text and formatting of the questionnaire were slightly amended to make the questions clearer and ensure cultural applicability.

Questions covered duration (for a typical weekday and weekend day) and frequency (number of weekdays and weekend days) of technology use for multiple devices, including MTSDs and other devices, i.e. TV, desktop, laptop, handheld electronic games (e.g. PSP, Nintendo DS), active (playing actively and moving about, e.g. XBOX Kinect, Wii Remote, PS3 MOVE) and non-active game consoles (playing in sitting position, not actively moving, e.g. game-pad operated XBOX, PS3). Usage for weekdays and weekend days was assessed separately. The TechU-Q also included questions on use in the last 12 months, ownership, bedroom usage, types of activities on weekdays and weekend (i.e. homework, social, watching videos, games or other general use), extent of multitasking with other devices (i.e. never, a little of the time, some of the time or most of the time) and bout length of use (typical duration of usage before stopping). Answer options for duration of device use, types of activities and bout length of use range from five, 15 or 30 minutes, to one hour, two hours, three hours and so forth with an increment of one hour up to a maximum of 12 hours or more. Device use across the whole week and duration for the types of activities were tabulated by multiplying duration and frequency for weekdays and weekend days.

In addition, demographic information, i.e. date of birth, gender, age, housing type, father's and mother's education level, and typical school marks (Short et al. 2013) were also collected from the participants. Musculoskeletal symptoms for neck/shoulders, upper back, low back, wrist/hand were reported using a modified Nordic Musculoskeletal Questionnaire (Kuorinka et al. 1987), which included questions on prevalence in the last month, frequency (i.e. almost never [<1 time/month], occasionally [1-3 times/month], often [1-3 times/week], always [>3 times/week]), intensity and interference with normal

activities (scale 0 to 10). Questions on visual health included visual symptoms (i.e. eye strain (irritation, heaviness), tiredness, watering, redness, itching of eyes, blurring of vision, dry eye, double vision or headache as adapted from symptoms of computer vision syndrome) (Seguí et al. 2015) experienced during or after use of MTSDs, use of glasses or contact lenses, trouble seeing far (myopia) and trouble seeing near (hyperopia) (Ojaimi et al. 2005). Mental health (using the Depression Anxiety Stress Scale 21 (DASS-21) (Szabo 2010)) and physical activity (using the Physical Activity Questionnaire for Adolescents (PAQ-A) (Kowalski, Crocker, and Donen 2004)) were also reported as covariates. To ensure cultural applicability and comprehensibility, certain physical activities for question one in PAQ-A, i.e. "football, soccer, floor hockey, street hockey, bicycling, tag, in-line skating, ice skating, cross-country skiing, ice hockey/ringette" were amended to "rugby/touch rugby, soccer/football, hockey (outdoors/indoors), netball, bicycling/cycling, tag/catching chasing game, in-line skating/roller skating, tennis, captain's ball" respectively, according to the top 15 sports by teens (13-19 years old) (Singapore Sports Council 2011).

In order to obtain an overview of technology use in schools, a short questionnaire on the types and amount of technology use by adolescents in school was completed by a teacher from each participating school.

Data analysis

Descriptive statistics were calculated for technology use for each device and total technology use, by weekdays and weekend days, gender and school levels. Both mean (SD) and median (IQR) of daily use duration were estimated. As usage data were not normally distributed, comparisons between weekdays and weekend days, genders and among school levels were conducted using chi-square, Mann-Whitney U, Wilcoxon

signed rank or Fisher's exact tests. Musculoskeletal and visual symptoms were also reported by gender and school levels. Associations between MTSD use (mean daily use across the whole week (hrs/day)) and musculoskeletal symptoms (prevalence of discomfort in the last month) were examined using binary logistic regression, while those between MTSD use and visual symptoms were examined using ordered logistic regression. These associations were adjusted for gender, school level, mental health, physical activity and total technology use duration of the other devices (excluding smartphone or tablet use) (see Table 4) using STATA 14. Adjustment for total technology use of the other devices was conducted in view of potential co-linearity between MTSD use and use of the other devices. ORs with 95% confidence interval were estimated and a p-value lower than 0.05 was adopted to be statistically significant.

Results

Sample

A total of 2009 adolescents from 14 schools provided responses to at least one question in the survey that was conducted from January 2016 to June 2016. Four primary schools, eight secondary schools, two post-secondary schools (one junior college and one polytechnic institution) participated. All responses from polytechnic students (n=125) were excluded from further analysis in this paper due to: different method of administration of questionnaire (participants did the questionnaire online at their own time as the polytechnic did not agree to in-class completion); poor response rate; and difficulties recruiting an unbiased sample of polytechnic students (participants were all from a single course and had many more girls (n=105) than boys (n=20)). Therefore, data from 1884 respondents (74.1% response rate) were included for further analysis (see Figure 2).

There was a similar percentage of girls and boys in the total sample of 1884 adolescents (50.4% girls) and across each school level of primary 5, secondary 1 and 3, and junior college 1 (Figure 1). Mean age (SD) of participants was 13.3 (2.0) years, ranging from 10 to 18 years. The majority of participants were of Chinese race (73.1%), followed by Malay (14.3%), Indian (6.0%) and others (6.6%); these races were all represented across each school level. Gender and race demographics of the sample were comparable to that for the adolescent population in Singapore, according to data from the Department of Statistics Singapore (2016).

The number of participants for each stratum of the stratified sampling matrix is presented in Figure 1. Different socioeconomic strata (SES) and academic levels were well represented in the matrix, with generally higher percentages of students with higher SES for housing types and parents' education in government-aided than government schools, and higher percentages of students with higher typical school marks in the Express compared to the Normal course (Appendix A).

Overall mean DASS-21 score (SD) was 13.6 (11.4), with poorer mental health scores for girls (14.9(11.2)) than boys (12.4(11.4), $p<.001$). Mental health also decreased with increasing school levels ($p<.001$; e.g. 11.0(9.8) in primary 5 to 19.3(11.4) in junior college 1). Mean PAQ-A score (SD) was 2.4 (0.7), with higher level of physical activity for boys (2.6(0.7)) than girls (2.3(0.7), $p<.001$). Physical activity level also decreased with increasing school levels ($p<.001$; e.g. 2.6(0.7) in primary 5 to 2.1(0.5) in junior college 1).

Technology use

Across the included sample of 1884 adolescents, the smartphone was the most widely used device (95.1%), followed by TV, laptop, tablet (71.1%), desktop, non-active game consoles, active game consoles and handheld games (Table 1). Ownership and bedroom

usage of devices was highest for the smartphone at 88.9% and 83.1% respectively, followed by laptop (61.2% and 48.8%, respectively) (Appendix B and C). Although responses from polytechnic students were excluded from analysis, descriptives of their technology use including MTSDs are provided in supplementary information (Appendix D and E).

There were no significant gender differences in the last 12 months' usage for smartphone and tablet (Table 1). Girls had significantly higher smartphone ownership and bedroom usage than boys, while boys had higher ownership as well as bedroom usage of desktop and all the gaming devices (handheld games, non-active and active game consoles) (Appendix B and C). With increasing school levels, smartphone and laptop usage in the last 12 months increased while that for tablet generally decreased (Table 1). Smartphone use for the younger adolescents (in primary 5) was high at 88.2%; it then increased rapidly to 96.2% for secondary 1 and continued to increase for secondary 3 and junior college 1. Similar increasing ownership and bedroom usage for both smartphone and laptop were observed with increasing school levels (Appendix B and C). Smartphone ownership was already high at 70.2% for primary 5 and increased to 99.3% by junior college 1. On the other hand, tablet ownership and bedroom usage were similar among the school levels.

Total technology use, obtained by summing mean daily use across the whole week for each of the devices, was 537 (471) minutes. None of the participants reported total technology use greater than 3600 minutes/~~ per~~ day (five or more devices with max use of 12hours/~~ per~~ day) as implausible data. Among all the devices, the adolescents used smartphone the most throughout the entire week, with mean usage (SD) of 264 (243) minutes, or 4 (4) hours per day (Appendix F). TV was the next most used device (106 (138) minutes), followed by laptop (63 (114) minutes), then tablet (53 (124) minutes).

Mean technology use on weekends was significantly higher than on weekdays for all the devices (Appendix F). Median (IQR) daily use for smartphone was 180 (51-429) minutes while that for tablet was much lower at 2 (0-39) minutes (see Appendix F for the other devices).

Some gender and school level differences were also noted in technology use. Mean smartphone use was higher for girls than boys ($p<.001$), while desktop, laptop, as well as handheld, non-active and active game consoles were higher for boys ($p<.05$) (Appendix F). Total technology use and mean daily use of the smartphone, tablet, TV, laptop and non-active game consoles were different among the school levels (Figure 3) ($p<.03$). Total technology use increased from primary 5 to secondary 3, and dropped in junior college 1 to lower than that for secondary 1. Daily smartphone use was fairly similar to daily TV use in primary 5 students, but smartphone use increased steeply while TV use remained similar in secondary 1 and 3, and both dropped slightly in junior college 1. Among secondary 1 and 3 and junior college 1 students, smartphone use dominated, and was much higher than all the other devices, as presented in Figure 3. Tablet use was similar among primary 5, secondary 1 and 3, and lowest for junior college 1. Laptop use increased with increasing school level.

Regarding technology use in school, questionnaire responses from the teachers indicated that MTSDs were being used in school, sometimes during lessons, but not formally incorporated into the school curriculum. Smartphones (students' own), and tablets (provided by the school) were used at times during lessons (ranging from few times per week to few times throughout the semester), when allowed by teachers for browsing information, gathering survey responses from students, or used to aid in teaching. Laptops (provided by the school) were generally used more frequently than MTSDs, usually once a week or more in school computer laboratory for computer lessons. Online checking and/or

submission of homework were sometimes given during the school semester or holidays. Some teachers also reported that students commonly used messaging on smartphones to communicate with each other regarding homework and other school-related matters.

Types of activities

Smartphone use dominated for each type of activity: homework, social, videos, games and general use among the devices (see Figure 4). Social activity, e.g. messaging and social media, had the highest amount of use among the activities on smartphone, while watching videos had the highest usage for tablet, desktop and laptop. However, there were different patterns of use as a result of gender, school level, device and types of activities. Figure 5 shows the greater use of smartphones for homework (panel A), watching videos (panel C) and social activities (panel E) by girls compared to boys across all the school levels, although the gender differences in primary 5 were much smaller than at other school levels. On the other hand, panel F highlights the greater use of smartphones for games by boys compared to girls across all the school levels, and this greater game use by boys was also consistent across tablet, desktop and laptop computers. Boys and girls had similar use of devices, other than smartphone, for all activities except games: e.g. homework on a laptop (which increased fairly equally with increasing school levels, panel B), or watching videos on a tablet (panel D).

Multitasking

The percentage of adolescents reporting frequent multitasking (some or most of the time) with other devices was highest for smartphone use (69.4%), followed by TV (57.3%), then laptop (41.8%), tablet (30.8%), desktop (23.1%) and game consoles (<11.4%) (Appendix G). A higher proportion of girls (71.9%) reported frequent multitasking during smartphone use compared to boys (66.8%), while multitasking was fairly similar between boys and

girls during tablet use (31.5% and 30.1%, respectively). Percentages of frequent multitasking for smartphone increased from primary 5 (53.2%) to secondary 1 (70.4%) and remained high thereafter; whilst for tablet it remained stable and reduced at junior college 1.

Bout length of use

Mean bout length of use, was the highest for smartphone with bout lengths of 191 (221) minutes, followed by TV (101 (133 mins), laptop (100 (148) mins) and tablet (69 (127) mins) (Appendix H). There were no gender differences for smartphone and tablet bout length. Smartphone bout length increased from primary 5 (118 (176) mins) to secondary 3 (239 (239) mins), and then decreased fairly steeply in junior college 1 (128 (173) mins). Tablet bout length was the highest at primary 5 (81 (138) mins) and it then similarly reduced at junior college 1 (28 (59) mins). Median (IQR) bout length for each device was also estimated (see Appendix H).

Musculoskeletal symptoms

Musculoskeletal symptoms in the previous month were most commonly reported in the neck/shoulder region (42.4%), followed by arms (33.3%), upper back (29.1%), wrist/hand (26.8%) and low back (22.7%) (Table 2). In those adolescents with symptoms in the past one month, at least 26.1% reported having symptoms 'often or always' for all the body regions. Moreover, in those with symptoms, the intensity of discomfort and interference to daily activities were fairly similar among the different body regions, ranging from mean scores of 4.0 to 4.4 (out of 10), and 3.4 to 3.6 (out of 10), respectively. Girls had a significantly higher prevalence of symptoms at neck/shoulder in the previous month compared to boys. Prevalence of having symptoms increased with increasing school levels for all the body regions.

Visual symptoms

The number of visual symptoms reported during or after using MTSDs was 2.2 (2.0) (out of a list of nine symptoms), with tiredness of eyes being most commonly reported (56.2%) (Appendix I). The number of symptoms reported by girls was slightly higher compared to boys, with number of symptoms increasing after secondary 1 school level. 63.6% of adolescents reported wearing glasses or contact lenses. Among those who wore glasses or contact lenses, 83.0% reported having trouble seeing far (myopia) (Table 3). The percentage of adolescents wearing glasses or contact lenses and having trouble seeing far (myopia) was higher for girls than boys and increased with increasing school levels.

Associations of MTSD use with musculoskeletal and visual symptoms

A greater amount of hours/day smartphone use was associated with a higher last month prevalence of neck/shoulder, upper back, arms and wrist/hand symptoms (OR=1.04 (1.01-1.07) to 1.07 (1.03-1.10); $p<.05$) (Table 4), as well as with a greater number of visual symptoms (OR=1.05 (1.02-1.08), $p<.001$) and with decreased odds of trouble seeing far (myopia) (Table 4). Using regression models consisting of MTSD use (yes/no) and MTSD use duration (mean daily hours across whole week) resulted in the same findings. Greater tablet use was not significantly associated with musculoskeletal symptoms at any location/site, or visual symptoms or wearing glasses or having trouble seeing far.

Discussion

To the best of our knowledge, this is the first study to examine associations between MTSD use and musculoskeletal symptoms and visual health, in a nationally representative population of adolescents. There was a remarkably high prevalence of technology use, with smartphone use having the highest usage (total use and longest bout length) across all the school levels among the devices. Adolescents used technology for both school and

leisure purposes including homework, social activities (e.g. social media or messaging), games, watching videos and other general use. Multitasking was also common during technology use, with the highest prevalence of frequent multitasking during smartphone use. A higher prevalence of musculoskeletal symptoms and a greater number of visual symptoms, but a lower prevalence of myopia, were significantly associated with a greater amount of smartphone use, but not with tablet use.

Dominance of smartphone use

This study has revealed substantial total technology use of 8.9 hours/day (537 (471) mins/day across the whole week) by adolescents and dominance of smartphone use among all the devices. Smartphone had the highest prevalence of use, ownership, amount of use (twice as much as the second most highly used device – TV), and also the highest amount of use for each type of activity. Differences between the means and medians of smartphone and tablet daily use (Appendix F) shows that use duration was not normally distributed, and also further highlighted the much higher usage of smartphone compared to tablet. Likely reasons for the high smartphone use included portability, convenience and the multiple functions offered, such as ease of accessing internet, social media and messaging, and use for daily functions.

Similar to recent large studies conducted in the USA (Rideout 2015) and UK (Ofcom 2017), the smartphone was the most used device among the older adolescents; however, daily smartphone use among adolescents was higher (4h 23mins) in the current study than in USA (2h 42mins) and UK (2h 24mins on school day, 3h 12mins on weekend day). The higher smartphone use might be due to higher smartphone ownership among adolescents in this study (88.9% among 10-17 years old) compared to in the USA (67% among 13-18 years old) (Rideout 2015) and UK (83% among 12-15 years old) (Ofcom

2017). Another reason might be the greater proliferation of mobile technology use in Singapore than in USA and UK, as revealed by a survey of multiple nations (We Are Social 2017).

School policies appear to influence technology use

The prevalence and amount of tablet use among adolescents in this study were lower than that of smartphone. This may be due to the much lower tablet ownership and, from anecdotal evidence, tablets being mostly shared among the family. This lower tablet use is in contrast to high tablet use reported by adolescents in a recent study in Australia, who used tablets and/or laptops frequently as part of their school curriculum (Straker et al. 2017). To date, only a few schools in Singapore have incorporated tablet use as part of their regular school curriculum under the "Future ~~s~~Schools" program (Yang 2016). Schools that participated in this study only had tablet used sometimes during lessons to aid in learning, hence possibly the lower tablet use in this study. The amount of laptop use was also lower than that reported in the Australian study (Straker et al. 2017), which again might be likely due to lesser laptop use in Singapore schools. Nonetheless, despite not being used frequently during lessons, a considerable amount of MTSD use was reported for homework or school-related purposes by adolescents in this study. MTSD use may also increase further among adolescents in Singapore, with ongoing plans to integrate more technology use in schools (Infocomm Media Development Authority 2018). School policies for technology use in education can thus drive changes in MTSD use and play an important role in patterns of technology use among adolescents.

Differences in technology use among school levels were also noted in this study. For adolescents in primary 5, unlike the other school levels, tablet users ~~was~~ were higher than smartphone users. This might be due to the lower ownership of and accessibility to

smartphones in younger than older adolescents. In addition, smartphone and laptop prevalence, ownership and bedroom usage increased with increasing school levels, which is consistent with other studies showing greater technology use among older adolescents (Harris, Straker, and Pollock 2013; Babey, Hastert, and Wolstein 2013). However, interestingly, although there was a steep increase in use from secondary 1 to secondary 3, it dropped in junior college 1. This drop also occurred for use of tablet and other devices except laptop. Anecdotally, adolescents in junior college 1 might be more occupied with schoolwork or other activities and hence use technology less often than those in secondary 3, except for laptop which they likely use more for schoolwork. Also, bout length of smartphone use by adolescents in junior college 1 was much lower than in secondary 3. These findings suggest that secondary 3 adolescents or certain school levels might be at higher risk for increased technology use, hence guidelines or strategies for appropriate use may need to be tailored to each school level.

Technology use is substantial on weekdays but even higher on weekends

This study has also shown that greater use of all devices on weekend days than weekdays, possibly due to more discretionary time being available on weekends. Nevertheless, the amount of technology use, especially smartphone and TV, was substantial even on weekdays when there was school. These findings further highlight the high and ubiquitous use of technology by adolescents and the importance of targeting strategies for wise use for all days of the week.

Girls socialise and boys play games on technology

Gender differences were observed regarding the types of activities on MTSDs, desktop and laptop in this study. Similar to other survey studies (Straker et al. 2017; Lenhart 2015), girls used the smartphone for social activities more than boys, which might account

for their greater smartphone use. On the other hand, boys participated in gaming across all the devices more than girls, consistent with existing research (Straker et al. 2017; Ofcom 2017). Hence, the types and purposes of activities that adolescents engage in and potential gender differences should be considered when developing guidelines for wise use of technology.

Smartphones frequently used in multitasking

This study has also highlighted the prevalence of multitasking during technology use, especially with smartphones which had the highest prevalence of frequent multitasking among all the devices. Recent surveys have also indicated increasing prevalence of multitasking with other tasks or devices, e.g. use of smartphone for messaging or schoolwork at the same time as doing homework (Rideout 2015; Australian Communications and Media Authority 2016). This may be due to the portability of MTSDs, incoming messages or notifications, or poor self-regulation or habits of use with adolescents finding it hard to resist the urge to check their devices (Rosen, Carrier, and Cheever 2013; Rideout 2015; Robb, Bay, and Vennegaard 2017). Moreover, this study has found an increasing prevalence of frequent multitasking with increasing school levels during use of smartphone, TV, desktop and laptop, suggesting that multitasking may increase with age over adolescence. Given that multitasking with multiple devices has been shown to be associated with negative outcomes such as poorer academic performance, cognitive and socioemotional functioning (Cain et al. 2016; van der Schuur et al. 2015), there is a need for further research on the nature of, and strategies for self-regulation on, the extent of multitasking by adolescents.

High bout length of use for smartphones may increase health risks

Typical bout length of use was the highest for smartphone, almost twice as high as for TV which had the second highest duration. This suggests that adolescents tend to use smartphone for the longest uninterrupted duration among the devices, further highlighting the importance of smartphone use. Studies on computer use have shown that continuous use, or the lack of or reduced breaks, were related to greater musculoskeletal symptoms, possibly due to muscle overloading and sustained postures (Galinsky et al. 2007; Brewer et al. 2006). Hence, this suggests that smartphone use, with its longest bout length of use, may pose a risk for negative musculoskeletal outcomes. However, it is unclear whether a bout of smartphone use results in sustained muscle activation and postures, as noted for computer use, due to multitasking with other tasks or devices. More detailed usage patterns for smartphones, including bout lengths, should be examined to determine if there are any risks posed for adverse outcomes.

Smartphone use associated with musculoskeletal symptoms

The increasing musculoskeletal symptom prevalence with increasing school levels (and thus age) is consistent with other studies on musculoskeletal complaints in adolescents (Jeffries, Milanese, and Grimmer-Somers 2007). Neck/shoulder region had the highest prevalence rates of musculoskeletal symptoms reported, which is similar to that reported in other studies conducted with adults and adolescents (Xie, Szeto, and Dai 2017). The ~~G~~greater amount of smartphone use was associated with a higher prevalence of musculoskeletal symptoms in neck/shoulders, upper back, arms and wrist/hand, even after adjustment for gender, grade, mental health, physical activity and total technology use of the other devices. Potential mechanisms for this link include altered muscle activity or awkward postures from MTSD use, as suggested by recent laboratory studies with adults (Gustafsson et al. 2018; Kietrys et al. 2015). The current study thus showed smartphone

use may pose a risk for musculoskeletal symptoms, with an increase in odds of having pain or discomfort in the past month of 4% to 7% for every hour increase in smartphone usage per day. The amount of increase in risk can be considered as clinically meaningful in view of adolescents spending up to several hours daily on their smartphone. This finding is also consistent with other studies on smartphone use conducted with college students and adults (Toh et al. 2017), and had relatively similar odds ratio as the few recent studies with adolescents in an Australian school (Straker et al. 2017), and in primary and secondary schools in Hong Kong (Kwok, Lee, and Lee 2017). However, the temporal association between MTSD use and musculoskeletal symptoms is not known and there is a need for longitudinal studies to provide more information on the nature of the relationship.

Low tablet use may explain lack of association with musculoskeletal symptoms

In contrast to smartphone use, a greater amount of tablet use was not significantly associated with musculoskeletal symptoms. This is in contrast to the few existing other studies, which showed tablet use was related to musculoskeletal symptoms in adolescents (Sommerich et al. 2007; Shan et al. 2013; Straker et al. 2017). One of these studies (Shan et al. 2013) only examined association between musculoskeletal symptoms and prevalence of tablet use (instead of amount of use as in the current study). For the other two studies in the USA (Sommerich et al. 2007) and Australia (Straker et al. 2017), the amount of reported tablet use was substantially higher than in the current study, likely due to tablet use being incorporated into their school curriculum (Straker et al. 2017; Sommerich et al. 2007). The low tablet use in the current study, potentially due to low ownership and no school requirement, may account for the lack of associations between tablet use and musculoskeletal symptoms.

Smartphone, but not tablet, use associated with visual symptoms

Similar to musculoskeletal symptoms, a greater amount of smartphone use was significantly associated with visual symptoms experienced during or after use of MTSDs and showed a clinically meaningful increase in risk of having visual symptoms. Visual symptoms reported included eye strain, tiredness of eyes and dry eyes. Prior research has shown that continuous computer use increased the risk of having visual symptoms, thought to be due to prolonged near vision work, impaired blink reflex and blue light emitted from screens (Gowrisankaran, Sheedy, and Albin 2015; Lurati 2018). Use of smartphone also involves near vision of the screen, which might thus explain its association with visual symptoms, especially when smartphone use was substantial and of longest bout length of use among all the devices. However, no association was found between tablet use and visual symptoms, which might again be due to the low tablet exposures in this sample.

Lower smartphone use associated with myopia

In contrast to the generally held belief that greater technology use can lead to vision problems, a higher amount of smartphone use was related to *decreased* risk of having myopia in this study. However, the causality in this association is not known due to the cross-sectional design of this study. It might be that adolescents who had myopia used smartphones less to prevent worsening of their eyesight. In Singapore, concern about myopia and awareness of eye care have been promoted with health campaigns and promotions held by schools and the government, in attempts to tackle the high prevalence of myopia (Seet et al. 2001). Moreover, several studies have shown~~ed~~ that technology use or screen time alone are of minimal risk to myopia, whilst more time spent outdoors is related to reduced risk of myopia and myopic progression (Ramamurthy, Lin Chua, and Saw 2015; Sherwin et al. 2012). Possible mechanisms for this association include

increased light intensity outdoors, low accommodative demand for distance vision, and increased time spent outdoors reducing time spent on near-work activities such as using technology. Further research is required on the possible interplay of technology use and outdoor time as risk factors for myopia, and longitudinal studies are needed to determine the direction of association.

Strengths and limitations

Major strengths of this study include the representative sample of a substantial number of participants obtained through~~via~~ stratified sampling (which included socioeconomic status and educational achievement levels), high response rate of participation and adjustment for important confounders (i.e. gender, grade, mental health and physical activity). One of the limitations for this study was that the sample size was less than the proposed 2000 participants, mainly due to recruitment of only junior college students from post-secondary schools. There were difficulties with obtaining approval from polytechnic and vocational schools (there are fewer of these institutions compared to primary and secondary schools). Results presented for post-secondary students may thus not be representative of the population for this school level. Nonetheless, the results were statistically significant. This study also captured details on device specific exposure frequency and duration, and other patterns of use including types of activities, multitasking and bout length of use, using a reliable questionnaire adjusted for local cultural applicability. However, the self-report method used to obtain technology exposure might present recall bias from participants. Total technology use obtained by summing use of all the devices might have also overestimated the total daily technology use, as it had not accounted for possible multitasking among the devices. Lastly, the cross-sectional study design adopted in this study is not able to determine the direction of the associations examined.

Conclusion

There was high technology use, especially smartphones, among Singaporean adolescents. This study also showed that technology was used for various types of school-related and leisure activities, and prevalent multitasking during technology use. Smartphone use was the most prevalent and its usage dominated among all the devices. Moreover, greater amount of smartphone use was associated with more musculoskeletal and visual symptoms. The high MTSD exposures are therefore a cause for concern, and further research on the implications of its use among adolescents are warranted.

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Table 1. Percentage of adolescents using technology in the last 12 months by gender and school level.

Table 2. Number (percentage) of adolescents reporting musculoskeletal symptoms in the last month by body regions, gender and school levels, and in those with symptoms the number (percentage) reporting high frequency symptoms in the last month of "Often or always", mean (standard deviation) of discomfort intensity (out of 10) and interference with daily activities (out of 10).

Table 3. Mean (standard deviation) number of visual symptoms, number (percentage) of students reporting wearing glasses/ contact lenses and in those wearing glasses/contact lenses reporting trouble seeing far (myopia) or near (hyperopia) or both, across gender and school levels.

Table 4. Association between hours per day of MTSD use and prevalence of discomfort in the last month in various body regions, number of visual symptoms, wearing glasses or contact lenses, and trouble seeing far (myopia).

Figure 1. Stratified sampling matrix and sample number for each school.

Figure 2. Flowchart of number of participants.

Figure 3. Mean daily minutes of technology use for each school level.

Figure 4. Daily technology use for various activities (across whole week).

Figure 5. Mean (standard deviation) daily minutes of technology use across school levels for boys and girls for panel (a) homework on smartphone, (b) homework on laptop, (c) watching videos on smartphone, (d) watching videos on tablet, (e) social activities on smartphone and (f) playing games on smartphone.

Supplemental material

Appendix A. Percentage of higher socioeconomic status (SES) for housing type, parents' education and academic level for each category of schools in stratified sampling matrix

Appendix B. Percentage of adolescents with technology ownership by gender and school level

Appendix C. Percentage of adolescents using technology in bedroom by gender and school level

Appendix D. Percentage of polytechnic students using technology in the last 12 months, mean (standard deviation) daily minutes of technology use across whole week, on weekdays and weekend days

Appendix E. Number (percentage) of polytechnic students reporting musculoskeletal symptoms in the last month by body regions, gender and school levels, and in those with symptoms the number (percentage) reporting high frequency symptoms in the last month of "Often or always", mean (standard deviation) of discomfort intensity (out of 10) and interference with daily activities (out of 10), as well as mean (standard deviation) for number of visual symptoms, number (percentage) of polytechnic students reporting wearing glasses/ contact lenses and in those wearing glasses/contact lenses reporting trouble seeing far (myopia) or near (hyperopia) or both, across school levels

Appendix F. Mean (standard deviation) daily minutes of technology use across whole week, on weekdays and weekend days, and for boys and girls (for across whole week usage)

Appendix G. Number (percentage) of students reporting multitasking some or most of the time during technology use, by gender and school level

Appendix H. Mean (standard deviation) minutes of typical bout length of technology use

Appendix I. Number (percentage) of adolescents reporting each visual symptom