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A novel mixed methods approach to assess children's sedentary behaviours

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Abstract

Purpose: Accurately measuring sedentary behaviour (SB) in children is challenging by virtue of its complex nature. Whilst self-report questionnaires are susceptible to recall errors, accelerometer data lacks contextual information. This study aimed to explore the efficacy of using accelerometry combined with the Digitising Children's Data Collection (DCDC) for Health application (app), to capture SB comprehensively. **Methods:** 74 children (9-10 years old) wore ActiGraph GT9X accelerometers for 7 days. Each received a SAMSUNG Galaxy Tab4 (SM-T230) tablet, with the DCDC app installed and a specially designed sedentary behaviour study downloaded. The app uses four data collection tools: 1) Questionnaire, 2) Take a photograph, 3) Draw a picture 4) Record my voice. Children self-reported their SB daily. Accelerometer data were analysed using R-package GGIR. App data were downloaded and individual participant profiles created. SBs reported were grouped into categories and reported as frequencies. **Results:** Participants spent on average 629min, i.e. 73% of their waking time sedentary. App data revealed most of their out-of-school SB consisted of screen time (112 photos, 114 drawings and screen time mentioned 135 times during voice recordings). Playing with toys, reading, arts and crafts, and homework were also reported across all four data capturing tools on the app. On an individual level, data from the app often explained irregular patterns in physical activity and sedentary behaviour observed in accelerometer data. **Conclusion:** This mixed methods approach to assessing SB adds context to accelerometer data, providing researchers with information needed for intervention design.

Key words: accelerometers, activity classification, context, adolescents

Introduction

Evidence suggests that sedentary behaviour (SB) in children is a risk factor for adverse health outcomes (Martinez-Gomez et al., 2010; Saunders, Chaput, & Tremblay, 2014; Tremblay et al., 2011). Despite this, children spend the majority of their waking time engaged in sedentary activities (Carson, Tremblay, Chaput, & Chastin, 2016; Talarico & Janssen, 2018). Defined as any waking behaviour characterised by low energy expenditure while in a seated, reclining or lying posture (Tremblay et al., 2017), SB encompasses a diverse group of behaviours, and different types of SB have different associations with health indicators (Carson, Hunter, et al., 2016). Not only do researchers need an understanding of the amount of time spent sedentary, but also the types of behaviours and the context in which these behaviours occur, in order to design future interventions effectively. Accurate assessment of SB in children is notoriously difficult to achieve (Hardy et al., 2013; Lubans et al., 2011), due mainly to the complexity of the behaviour itself.

Traditionally, self-report questionnaires (or in the case of young children, proxy-report by a parent/carer) have been used to measure SB (Atkin et al., 2012; Lubans et al., 2011). However, self- and proxy-report tools are known to be susceptible to recall errors, misrepresentations and social desirability (Atkin et al., 2012; Hardy et al., 2013; Loprinzi & Cardinal, 2011). More recently, accelerometry has become a widely accepted device-based method of measuring SB (Atkin et al., 2012; Cain, Sallis, Conway, Van Dyck, & Calhoon, 2013). Researchers are now able to use population-specific raw acceleration cut-points to classify SB (Hildebrand, Hansen, van Hees, & Ekelund, 2016; Hurter et al., 2018) and/or the sedentary sphere method to predict the most likely posture from wrist-worn devices (Hurter et al., 2019). One of the limitations of accelerometry however, is its inability to provide any *context* about the type of behaviour or

settings in which the behaviours occur. Rich, contextual data would include type of activity (e.g. screen time, reading, homework etc.), whether children are alone or interacting with other people (e.g. friends, siblings or parents/guardians) and the settings where the behaviours occur (e.g. home, car, school). Currently, direct observation is the only tool that can provide researchers with this type of information, and has successfully been used to report behaviours in restricted areas during short time periods (e.g. school playgrounds during break time (Roberts, Fairclough, Ridgers, & Porteous, 2013)). However, direct observation is labour intensive, expensive and not feasible in a free-living context. In adult studies, (e.g. Kim & Kang, 2019) wearable cameras have successfully been used as a criterion measure of a direct observation proxy, however, due to limited battery life, added participant burden and various ethical considerations (Kelly et al., 2013) this was not feasible for this study conducted involving children. Indeed, Lubans and colleagues (Lubans et al., 2011) recommend that a mix of methods be used to estimate SB in children. More recently, researchers investigating associations between SB and academic performance also called for studies to use both accelerometry and self-report tools in order to differentiate between academic-based- (e.g. reading, homework) and screen-based SB (Lima, Pfeiffer, Moller, Andersen, & Bugge, 2019; Syväoja et al., 2013). According to Lima et al. (2019), a lack of contextual information has prevented researchers from evaluating the association between SB and academic performance. Moreover, researchers need to differentiate between different forms of screen time, as evidence suggests that television viewing for example is related to obesity (Stiglic & Viner, 2019), but there is currently insufficient evidence to conclude the same relationship exists with other forms of screen time (e.g. computers, video games, mobile phone use).

The present study aimed to explore the efficacy of using accelerometry in combination with a digitalised data capture tool called the Digitising Children's Data Collection (DCDC) for

Health (Cooper & Dugdill, 2014), in order to capture SB more comprehensively. The DCDC application (app) was developed at the [redacted] to allow flexible data collection with primary school aged children via tablets across multiple settings, using a mixed-methods approach. DCDC may therefore enable the capture of contextual data that is lacking when using accelerometry alone.

The app can be used within diverse settings and be used to collect data over a longer period of time than is currently possible with traditional self-report questionnaires which would require repeat administration by a researcher. Whilst paper based methods that ask children to recall their behaviour over the previous week are typically used in a school setting, giving children a tablet enables them to report their behaviour through photos, drawings and voice recordings at home or wherever they go. Asking children to self-report their SB on a daily basis, as opposed to trying to remember what they did the previous week could reduce recall errors. Combining the DCDC app with accelerometry, this study aimed to explore whether the app can capture the rich, contextual data about children's SB that has been absent in the literature until now. Knowing *what* types of SB children engage in and the settings in which these behaviours occur, together with time spent sedentary (according to accelerometry) would help researchers identify specific behaviours to influence intervention design.

Methods

After gaining institutional research ethics approval (reference number: [redacted]), 74 Year 5 children (9-11 years old, n = 45 girls) were recruited from four primary schools. School administration consent was obtained from the schools (e.g. school head teacher or year tutor), while parents/guardians and children signed informed consent and child assent forms

respectively, prior to data collection. Parents/guardians completed demographic information forms, reporting participants' dates of birth, home postcodes and ethnicity. The National Statistics Postcode Directory Database was used to generate UK Government 2015 Indices of Multiple deprivation (IMD) rank scores, an indication of neighbourhood-level socio-economic status. IMD rank scores are reported as IMD deciles, where 1 represents the highest level of deprivation. Rolling recruitment and data collection took place between November 2017 and June 2018. The researcher had one contact session with participants in each school prior to the start of data collection, which was used for anthropometric measurements, explanation and fitting of accelerometers and familiarisation with the DCDC application on the tablet.

Anthropometrics

Body mass was measured in light clothing without shoes, to the nearest 0.1 kg using an electronic scale (Seca, Birmingham, UK). Stature and sitting height were measured to the nearest 0.1 cm using a stadiometer (Leicester Height measure; Seca, Birmingham, UK). Waist circumference was measured at the midpoint between the bottom rib and the iliac crest, to the nearest 0.1 cm using a plastic non-elastic measuring tape (Seca, Birmingham, UK). Participants self-reported their dominant hand to establish accelerometer wear site, by answering the question "Which hand do you usually write with?" Maturation were calculated using anthropometric data, participant date of birth, date of testing and validated regression equations (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002).

Sedentary behaviour

Participants wore an ActiGraph GT9X (ActiGraph LLC, Pensacola, FL) accelerometer on their non-dominant wrist, and were asked to wear it 24hr.d^{-1} for 7 consecutive days. They were instructed to remove the monitor only for water-based activities (e.g. swimming, bathing) or

151 contact sports (e.g. rugby). Participants were given a log sheet (paper based) to record any
152 times and reasons they removed the monitors.
153
154 Each participant also received a Samsung Galaxy Tab4 (SM-T230) tablet, with the Digitising
155 Children's Data Collection (DCDC) for Health application installed (Cooper & Dugdill, 2014).
156 Each tablet had a unique asset number, enabling the researcher to link the data captured by
157 each tablet to the relevant participant. The DCDC for Health consists of two applications, a
158 Supporting Server Application (SSA) and a Tablet application (TA). The SSA (a remotely
159 installed web application) allows researchers to design and build their own studies, using a
160 mixed-methods approach. Further, the SSA manages and stores data flowing to and from the
161 TAs. Prior to data collection, the first author designed and built a SB study using the SSA, and
162 downloaded the study onto the TA on each Samsung tablet. In order to prevent children from
163 using the tablets for longer than necessary, only the DCDC app was accessible, with all other
164 applications password protected. Internet access was also blocked, preventing children from
165 accessing unsuitable content online.
166
167 The app uses four types of data collection tools: 1) Answer some questions (a questionnaire
168 tool), 2) Take and explain a photograph, 3) Draw and explain a picture and 4) Record my voice.
169 Participants were asked to open the app once per day (suggested as towards the end of the day)
170 and report their SB, by answering the questions in each tool. Once one of the tools were opened
171 and answered, that tool was greyed out and the child could only access it again the next day.
172 The first tool, "Answer some questions", consisted of six multiple-choice questions regarding
173 behaviours outside of school time. The questions were adapted from the SB section of the
174 Youth Activity Profile (Saint-Maurice & Welk, 2015). The second tool, "Take a photograph",
175 asked the child "Can you take a photograph of any activities you did while sitting or lying down

today?", and allowed a photo to be taken with the tablet's built-in camera. Children were instructed not to take any photographs of people, but rather of places/settings they spent time in. After taking a photo, children were given the option to save their photo and either to write something about their photo or describe their photo with a voice recording. The "Draw a picture" tool asked children the question: "Can you draw a picture of any activity you did while sitting or lying down today?" Children used their fingers to draw on the screen, and could choose between different brush sizes and colours. Once saved, they were given the opportunity to write or talk (record their voice) about their drawing. Finally, the "Record your voice" tool asked participants to answer two questions: "Can you tell us what you did this morning?" and "Can you tell us what you did this afternoon?" During the familiarisation session, children were instructed to answer these questions by reflecting on their out-of-school time, i.e. in the mornings before school, and afternoons after school. A short video with a more detailed explanation of how the app works can be viewed *here.*

After 7 days of data collection, all tablets, accelerometers and log sheets were returned to school for collection. The results synchronised automatically with the SSA when connected to WiFi. Once synchronised, the study could be downloaded again for the next round of participants, using the same tablets but with new participant numbers. Audio files from voice recordings were transcribed verbatim. Participant profiles were created for each participant using a template, with their photos, drawings, voice recordings and multiple-choice answers, all of which were time and date stamped. For each tool, activities photographed, drawn or mentioned by the participants in voice recordings were grouped into different categories for analysis (e.g. television, computer/laptop, reading, playing with toys) and reported as frequencies. Whenever a photo, drawing or recording was unclear, researchers referred to the

data from the other tools on that particular day and for most of the time, this triangulation of data clarified the uncertainty.

Accelerometer data processing and analysis

The ActiGraph accelerometers were initialised to collect data at 100Hz. After each data collection session, the 7-day files were downloaded using ActiLife (version 6.13.3) software, saved in raw format as .gtx3 files and converted to time-stamped .csv files and analysed using R package GGIR (version 1.6-7). GGIR is an open source R package developed to generate physical activity outcomes from raw accelerometer data (Migueles, Rowlands, Huber, Sabia, & Van Hees, 2019) and was used as described by Rowlands, Edwardson, et al. (2018). As the participants kept the monitors on while sleeping, researchers used GGIR to report the full 24 hour activity behaviour profiles, which include the following: time in bed (sleep), time spent sedentary per day (threshold defined as waking time accumulated below 50 mg (Hurter et al., 2018)), moderate to vigorous intensity physical activity (MVPA) per day (defined as time accumulated above 200 mg (Hildebrand, Van Hees, Hansen, & Ekelund, 2014)), average acceleration across the day (ENMO, mg) and intensity gradient. The intensity gradient is a recently published (Rowlands, Edwardson, et al., 2018) accelerometer metric describing the intensity distribution of physical activity over the 24-hour day. All outcomes were broken down into weekdays, weekend days and whole week data. Inclusion criteria for raw data analysis were at least 16 hours of wear time per day (Rowlands, Mirkes, et al., 2018) for at least 4 days (including at least 1 weekend day) (Trost, Pate, Freedson, Sallis, & Taylor, 2000).

Differences between boys and girls, weekday and weekend data were examined using paired t-tests and effect sizes calculated as Cohen's *d* (Cohen, 1988) with 0.2, 0.5 and 0.8 defined as small, medium and large effects. Analysis was completed using IBM SPSS Statistics v.24

(IBM, Armonk, NY) with level of statistical significance set at $p < 0.05$ and Microsoft Excel 2016 (Microsoft, Redmond, WA).

Results

Descriptive characteristics of all participants are presented in Table 1, while Figure 1 is a flow diagram showing participants included and excluded from each step of the analysis. Compliance from the 65 participants included in the raw acceleration data analysis was high with 52 (80%) full datasets (i.e. 7 valid days), 9 consisting of 6 valid days, 3 with 5 valid days each and 1 dataset of 4 valid days. Children mostly removed the monitors when taking a bath or shower, swimming or for sports like rugby, gymnastics or martial arts.

Table 2 shows results from the accelerometer data analysis, separated into weekdays and weekend days, while Table 3 shows differences between boys and girls. Participants spent on average 629 min (almost 10.5 hours) of their waking time per day sedentary. Time spent sedentary on weekend days was significantly higher than weekdays (652 min ± 78.27 vs 619.88 min ± 57.11; $p<0.001$; Cohen's $d = 0.47$). There were no significant differences found between boys' and girls' sedentary times (weekdays: $p = 0.58$, weekends: $p = 0.78$). Results from the intensity gradient metric showed a significantly lower (steeper) gradient over weekends compared to weekdays ($p < 0.001$, $d = 0.96$). On average, girls had significantly lower (steeper) intensity gradients than boys (whole week: $p = 0.001$, $d = 0.9$; weekdays: $p = 0.001$, $d = 0.88$; weekend days: $p = 0.009$, $d = 0.7$).

Contextual data provided by 72 participants via the app were included in the analysis. Only 9 children had full datasets, i.e. their results included 7 photos, 7 drawings, 14 voice recordings

and the multiple choice questionnaire answered on all 7 days. One of the full datasets, however, had 10 blank audio files (from the "Record my voice" tool).

The first data capturing tool, "Answer some questions", was the preferred option of the four methods, with participants answering at least some of the questions on average 5.3 (SD=1.7) days during the 7-day period of data collection. The different questions were answered between 377 and 383 times by the participants (out of a possible 504). The app allows participants to go to the next question without answering the one on their screen, therefore not all questions were answered the same number of times.

Results from this tool are displayed in Supplementary tables S1-S3. Table S1 shows the number of days each answer was given, broken down into weekdays and weekend days, while Table S2 shows the differences between boys' and girls' answers (in number of days). Table S3 shows only the answers from screen-based behaviours, specifically how many participants chose each answer, and its weekly average. Results indicated an increased amount of television viewing on weekend days compared to weekdays (Table S1), with a 10% reduction in the number of children reporting not watching any TV during weekend days (25%) as opposed weekdays (35%). The same trend was observed for playing video games, with all answers indicating an increased amount of time playing video games during weekend days. Children reported not using a computer at all on 244 days (63.9%) and not using a mobile phone at all on 242 (63.4%) of days (Table S3). There was limited active travel on school days with the majority of participants in this study traveling to school by car (59.9% of days reported). The biggest difference between boys and girls was observed in playing video games (Table S2). Boys reported on 12.2% of days (17/139) to have spent more than three hours playing video games, as opposed to girls reporting the same behaviour on only 2.5% of days (6/243).

Participants took 300 photos during the study. 142 of the photos had written text attached, while 37 had voice recordings, explaining what the photo was about. Despite being instructed not to take photos of people, 29 photos had to be subsequently "blurred", as faces were recognisable. However, 10 of these were useable within the analysis as their comments explained the context of the photo, resulting in 281 photos used in the analysis. On average, participants took photos on 4 of the 7 data collection days. Even though the question clearly asked to take a photo of an activity they did while *sitting* or *lying down*, participants often chose to take photos of any activity they did during the day, not only sedentary activities. However, the majority of photos (68%) were taken of various sedentary activities, with screen time the most frequently photographed behaviour. A total of 110 photos (39%) were taken of different screens including televisions (35 photos by 14 girls and 8 boys), video game consoles like an Xbox or PlayStation (27 photos by 6 girls and 9 boys), tablets (21 photos by 7 girls and 3 boys), computers / laptops (13 photos by 6 girls and 1 boy) and mobile phones (12 photos by 11 girls). Often the voice recordings or written text attached to the photos provided more detail, like a photo of a TV screen with the following attached: "While eating my breakfast I watched YouTube" (P28).

Other types of SBs photographed include playing with toys (24 photos by 11 girls and 4 boys), reading books (17 photos by 7 girls and 8 boys), followed by 13 photos from 8 girls and 2 boys of a bed/couch, arts and crafts (13 photos by 9 girls and 1 boy) and homework (9 photos from 6 girls). As stated earlier, sometimes children reported other, non-sedentary types of behaviours. Most notably were 19 photos (by 5 girls and 5 boys) related to physical activities they participated in during that day, e.g. swimwear, a bicycle, a park or a garden with a football.

From the "Draw a picture" tool, 333 drawings were downloaded, with written text attached to 174 and voice recordings attached to 24 drawings. Twenty-five of the drawing files were blank, leaving 308 drawings for analysis. As with the photos, participants often chose to ignore the question and drew any activity they took part in, including 40 drawings (by 7 girls and 6 boys) related to physical activity. Again, screen time was the most reported sedentary activity, with 114 (37%) drawings depicting screen-based behaviours. These included 43 drawings of television viewing (by 17 girls and 7 boys), 27 drawings of playing video games (by 3 girls and 9 boys), 17 drawings of spending time on a mobile phone (by 7 girls and 2 boys), 14 drawings of playing with a tablet (by 6 girls and 2 boys) and 13 drawings of a computer/laptop (by 7 girls and 1 boy). Other after-school sedentary activities included reading (10 by 8 girls and 1 boy), playing with toys (11 by 6 girls and 2 boys), arts & crafts (11 by 8 girls and 1 boy), spending time on the bed/couch (6 by 6 girls), playing a musical instrument (4 by 4 girls), sitting in the car (3 by 2 girls and 1 boy) or church (3 by 2 girls and 1 boy) and homework (3 by 2 girls and 1 boy). Figure 2 shows some examples from the "Take a photo" and "Draw a picture" tools.

The "Record your voice" tool yielded 550 recordings, made over a total of 278 days. Thirteen files were blank and one corrupted, leaving 536 recordings used in the analysis. This was the least preferred method for the participants to use, recording their voices on average 3.79 (SD=2.45) days per week. As with the other data collection tools, screen time was the most frequently reported activity, with participants mentioning it 154 times. While these were mainly reported in the afternoon (92 instances), except for one incidence of homework, screen time was also the only sedentary activity mentioned on weekday mornings (66 instances). Children reported watching television a total of 68 times, while other forms of screen time (video games (29), computer / laptop (29), tablet (21) and mobile phone (7)) were mentioned

86 times. As with the photos and drawings, girls reported these activities more often than boys, except for playing video games, which was mentioned 29 times by 12 boys and only 3 girls.

The question "Can you tell us what you did this morning?", as expected, produced little variety during weekdays, with participants talking about their morning routines which included getting up, having breakfast, getting dressed and ready for school, brushing their teeth and going to school. Thirteen participants reported screen time on weekday mornings, with two of them mentioning it on all 5 weekday mornings and one on 4 weekday mornings. For these participants, the screen time seemed part of their morning routines. For example: *"This morning I had breakfast while on my laptop, got changed while on the laptop. Then I got off the laptop to brush my teeth…."* (P59). The "Record your voice" tool often provided the researchers with rich, contextual information. A discrete case study demonstrating this type of data from the app, adding context to sedentary time according to the accelerometer, is presented below.

Case study 1: Participant 7 (girl, P7)

On a Saturday evening at 20:12, P7 answered the question "Can you tell us what you did this afternoon?" with the following voice recording: *"When I came back from ballet, I played Minecraft. Then [Participant 4] came to visit. We played IQ puzzler, Dobble and I showed her my ballet. Then when she went home I played on my computer for a little while, bathed, ate dinner and played Minecraft a little. Then brushed my teeth and went to bed."* In this one recording, there is evidence of physical activity (ballet), video games (Minecraft), games/toys (IQ puzzler and Dobble) and computer time all within one afternoon. Accelerometer data revealed that despite an hour's ballet lesson, P7 only engaged in 50 minutes of MVPA that day,

while 652 min was spent sedentary. Not all children, however, gave such detailed accounts of their day. Participant 4's voice recording from the same afternoon simply stated: *"I went to [P7's] house"*.

The combination of accelerometer data, log sheets as well as the different data capturing tools via the app allowed the researcher to triangulate data, resulting in a clearer picture of the participants' behaviour across the whole week. Following are two case studies, chosen to show how the app sometimes provided clarity around 'irregular' accelerometer data.

Case study 2: Participant 32 (boy, P32)

Accelerometer data showed high levels of sedentary time on most weekdays (around 720 min, or 12 hours per day) and even higher on weekend days (818 min, or 13.6 hours per day). Data from the app showed that he spent almost all of his free time playing video games, with 6 photos of his laptop, accompanied by written descriptions of the games he played as well as one photo of a games console. He also drew 5 pictures of himself sitting in front of his laptop and all 14 voice recordings were about his games, for example *"This afternoon I was also playing games, which means I'm a gamer"* and *"This afternoon I was also playing games, you know, I am always playing games."* Despite this, he still managed to meet the recommended guidelines for physical activity (60 minutes of MVPA per day) on all 4 weekdays included in the analysis (mean of 72.2 minutes per day), but his MVPA levels dropped significantly over the weekend (mean of only 16 minutes per day). On Friday, however, his sedentary time dropped to 467 min (7.7 hours) per day, with 82.75 minutes of MVPA according to the accelerometer. That evening he drew a picture of four stick men and a bicycle lying next to them and wrote: *"I was going with my friends outside and I had a great time!"* As he meets the recommended guidelines for physical activity, without the contextual data from the app,

we would not have understood how much time he spent in screen-based sedentary pursuits. In this case, intervention design should focus on replacing some of his video gaming time with more opportunities to play outside with friends.

Case study 3: Participant 2 (girl, P2)

On most days, P2 exceeded the government guidelines for physical activity with a mean MVPA of 70 minutes/day, except for Wednesday and Thursday when her activity levels dropped to 30 minutes of MVPA per day, together with an increase in sedentary time. On Wednesday she drew a picture of herself in bed and wrote *"I was lying in my bed"*. On Thursday she took a photo of her bed and wrote *"I was in my bed"*. She also drew a picture of herself in front of the television and wrote *"I was watching the TV at my Nanna's house"*. Voice recordings revealed how she started feeling ill on Wednesday morning *("…felt a little bit achy…"*) before going to school. Wednesday evening she reported how she felt worse: *"This afternoon I got home from school and I got my pyjamas on because I was feeling a lot achy…"* On Thursday, she reported that they dropped her siblings off at school after which she went home and watched television. In the afternoon, she went to her Nanna's and watched television until her mum came to pick her up. Without the context from these photos, drawings and recordings, data from the accelerometer alone would have led the researchers to identify P2 as a child not meeting the recommended government guidelines for physical activity (as on two days her MVPA fell well below the recommended 60 minutes per day). When we exclude the two days she was ill, her mean MVPA level was 70 minutes per day and her sedentary time only 542 min per day (i.e. 87 minutes less than the group mean). Thus, contextual data from the app allowed us to classify her as a typically sufficiently active child spending much less time than her peers in sedentary pursuits.

Discussion

The aim of the study was to explore whether a digitalised data capture tool in combination with accelerometry could capture SB more comprehensively, by adding contextual data to sedentary time derived according to accelerometers. Results from this study showed that on average, the participants spent more than 10 hours per day (629 min) in sedentary pursuits. This result, however, is according to an intensity threshold (50mg) unable to distinguish between postures. Therefore, it is likely to overestimate sedentary time by about 5% (Hurter et al., 2019) as it will likely include time spent standing still. It has recently been suggested that the term *stationary time* is more accurate when describing time spent below this threshold (Freedson, 2018). According to data from the app, most of our participants' out of school SB was spent using a variety of screens. The observed increases in television viewing and video gaming over weekends could explain the increased amount of sedentary time observed in the accelerometer data during this period. On weekend days, the participants engaged in these behaviours long enough to exceed the equivalent time spent sitting in school on weekdays.

Participants' increased sedentary time and decreased MVPA observed over weekends is consistent with findings from previous studies (Biddle, Gorely, Marshall, & Cameron, 2009; Brooke, Corder, Atkin, & van Sluijs, 2014). Whilst boys engaged in significantly higher levels of MVPA compared to girls (also consistent with previous literature (Hallal et al., 2012)), there were no significant differences found in their sedentary times. The steeper intensity gradient observed in girls indicates that they have a poorer intensity profile, with less time spent across the intensity range compared with boys. A recent study showed that a higher (shallower) intensity profile, as observed in the boys, is associated with favourable changes in health indicators (Fairclough, Taylor, Rowlands, Boddy, & Noonan, 2019).

Data from the DCDC app added context to the accelerometry results, illustrating various forms of screen time as the main behaviour reported across all four data capturing tools. These include television viewing, video game consoles, tablets, computers/laptops and mobile phones. Results from the multiple choice questionnaire revealed that on 64% of days, the participants reported not using a computer at all, suggesting that for participants within this age group, SB does not comprise of much computer time. From the amount of days children reported not using a mobile phone at all (63%), it can perhaps be assumed that most participants did not yet own their own mobile phones. However, 45 (62.5%) participants reported that on at least one day that they had used a mobile phone. It is unknown whether they used their own, or parent's/carer's/other adult's phone.

Photos, drawings and voice recordings revealed that, for these participants, television viewing was not children's main screen-based activity. Watching YouTube videos, playing online games like Roblox or Fortnite, watching movies (on tablets or laptops) and talking with friends (online via social media) were activities most frequently reported by participants. This trend, showing a decreased amount of TV viewing with increasingly higher usage of other screen-based devices is consistent with results from a recent review of studies (Schaan et al., 2019). Across all photos, drawings and voice recordings, girls reported using these devices more frequently than boys, except for playing video games, suggesting that for boys video gaming was their preferred screen-based activity. A recent study by Perrino and colleagues (Perrino, Brincks, Lee, Quintana, & Prado, 2019) confirms this gender-based difference, with girls engaged in types of screen time more likely to involve social contact and communication. This is an important finding, suggesting that interventions aiming to reduce screen use should be targeted differently for boys and girls. Furthermore, Suchert, Hanewinkel, Isensee, and läuft

Study Group (2015) found that screen-based SBs had different associations with mental health indicators in boys versus girls. For example, higher screen-based SBs were associated with lower self-esteem in girls, but higher self-esteem in boys. This finding is likely the result of boys mainly playing video games (as observed in the present study), during which they master new challenges accompanied by a sense of achievement, while girls spend time on social media, often comparing themselves to unrealistic images of female body ideals (Suchert et al., 2015). Interventions designed to reduce some of the time boys spend playing video games, should aim to replace the behaviour with PAs that might have a similar outcome (e.g. an obstacle course that increases in levels of difficulty). Girls, on the other hand, might benefit from PA interventions that allow them to socialise with their friends, therefore replacing their time spent on social media by spending time with peers in real life, who are less likely to portray unrealistic body ideals.

Playing with toys, reading, arts and crafts and homework were the only other sedentary activities reported across all data capturing tools. However these behaviours would probably not be targeted during interventions aiming to reduce SB, due to their positive association with academic achievement (Carson, Hunter, et al., 2016). While summarising the results from the app on group level proved to be difficult, the main strength of the method lies on the individual level. Despite not having full compliance by way of full datasets, most participants still provided the researchers with contextual data beyond what the accelerometer alone can offer. The app allowed participants to choose their preferred method of reporting their behaviour. While some children mainly took photos, others chose to draw pictures or record their voices. The app often complemented the objective data, by helping to explain the patterns of sedentary behaviour and physical activity observed.

One of the strengths of the app is that children only have to recall their behaviour from that specific day, which should minimise recall errors. Self-report use-of-time tools like MARCA or PDPAR (Foley, Maddison, Olds, & Ridley, 2012) have successfully been used to report *previous* day behaviours of children, however, most focus on PA with limited information gathered regarding SB. Children might be able to choose from a selection of screen time activities (TV, video games, computer use etc.), but with the fast-paced technological advances and children's increased access to screen-based devices, more details are required. For example, data from the app showed the current popularity of watching YouTube videos and playing Fortnite, which provides useful information when attempting to understand children's SBs and when designing interventions targeting reductions in SB.

Another strength of the app was that the four tools complemented each other. For example, sometimes a photo in itself was not clear, but the recordings clarified it or the other way around. Using only one or two of the four tools would not have given the same amount of depth and would most likely have resulted in unclear photos or drawings being discarded. This type of data triangulation, together with the direct measurement of sedentary time using accelerometers is effective in more comprehensively describing individual children's physical behaviour over the seven days of data collection. This, however, is only possible in cases where the child complies with the task. For example, P4's account of her afternoon (*"I went to [P7's] house"*) is far less comprehensive than P7's description of the same period, highlighting the individual variation in reporting.

The method also has other limitations that require consideration. Typically, the researchers were given between 40 and 60 minutes with the participants, to complete anthropometric measurements, fit and explain accelerometers as well as familiarise the participants with the

app. Classrooms were busy, with both participants and non-participants in attendance. This limited the time available for children to be familiarised with the app and to ask questions. While the questions on the app asked about sedentary activities only (except for the "Record your voice" tool), children often chose to ignore the question, giving an unrelated answer. Most often, these answers were related to physical activity and while that was not the main purpose, it still provided the researcher with contextual information about the 24-hour movement profile and highlights the potential of the app to be used in future studies to add context to both physical activity and SB. Some data collection sessions took place close to Christmas, which resulted in a lot of photos, drawings and voice recordings about things like Christmas trees and festive activities. Though participants were engaging with the tool, this generated a considerable amount of irrelevant data. Future studies may wish to develop an online video explaining the tool and study that could also be shown in class detailing the necessary information. We also recommend that in future, software developers consider adding an interactive feature to the app, making it possible for the researcher to communicate with participants (via the app) during the data collection period, specifically in cases where a participant is not complying with the task. However, for the researcher to monitor incoming results from the Tablet Application to the Supporting Server Application, an internet connection would be needed and there are a number of ethical considerations to take into account. While we are confident that this method reduced recall errors, we acknowledge that some degree of recall is required, and that especially the question regarding their time spent in the mornings before school, might have been affected by recall errors. Finally, our aim was not to specifically assess the validity of the app or sections of the app for measuring SB, however, future studies may investigate this.

Conclusions

This study combined accelerometry with a mixed-method digitalised self-report data capturing tool (app), and captured children's sedentary behaviours comprehensively. Various forms of screen time were identified as activities that need to be targeted in future interventions, with a distinct difference observed between boys' and girls' preferences. Gender-specific interventions are needed when aiming to reduce children's SB. On an individual level, the app added context to accelerometer data, often explaining irregular physical activity and SB patterns. It might be used in studies prior to intervention, in order to identify specific behaviours to be targeted or during evaluation to observe any changes in reported behaviours. The app can potentially be used in future studies to add rich, contextual information about the whole 24-hour movement continuum, that has been absent in the literature until now.

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667 Table 1: Descriptive characteristics for all participants (n=74, expressed in Means (SD))

	Boys (n=29)	Girls (n=45)	All (n=74)
Age (years)	9.9 (0.4)	10 (0.4)	10 (0.4)
Height (cm)	140.8 (9.6)	139.8 (6.9)	140.2 (8.1)
Body mass (kg)	37.8 (12.5)	36.6 (8.5)	37.1 (10.2)
BMI (kg/m^2)	18.6 (4.0)	18.6 (3.2)	18.6 (3.5)
Overweight* (n, %)	6 (20.7%)	10 (22.2%)	16 (21.6%)
Obese* (n, %)	4 (13.8%)	3 (6.6%)	7 (9.5%)
Waist circumference (cm)	65.7 (10.2)	65.5 (8.2)	65.6 (8.9)
APHV† (years)	13.5 (0.6)	11.7 (0.4)	12.5 (0.9)
Maturity offset	-3.6 (0.7)	-1.7 (0.5)	-2.5 (1.1)
Ethnicity (n, %)			
White (UK)			53 (71.6)
Mixed			13 (17.6)
White (other)			3 (4.1)
Chinese			4 (5.4)
Asian (Indian)			1 (1.4)
SES¥			3 (2.6)

668 * Age and sex-specific BMI cut points used to classify children as overweight / obese (Cole,
669 Bellizzi, Flegal, & Dietz, 2000)
670 † Age at Peak Height Velocity
671 ¥ SES is measured by the Index of Multiple Deprivation decile score, where 1 is the most
672 deprived and 10 the least deprived

673 Table 2: Sedentary behaviour and Physical Activity outcomes for weekday and weekend data (n=65)

	Weekday data		Weekend data		Whole week (weighted week)	
	Mean minutes (SD)	**95% CI Lower - Upper**	**Mean minutes (SD)**	**95% CI Lower - Upper**	**Mean minutes (SD)**	**95% CI Lower - Upper**
Mean ENMO [mg]	49.73 (15.47)	45.89 – 53.56	36.58 (17.56)	32.23 – 40.94	45.91 (15.23)	42.14 – 49.69
Sleep	563.17 (40.98)	553.02 – 573.33	556.36 (55.26)	542.67 – 570.05	561.19 (37.77)	551.84 – 570.56
Sedentary time*	619.88 (57.11)	605.73 – 634.03	652.0 (78.27)†	632.61 – 671.4	629.19 (51.28)	616.49 – 641.90
LPA	172.64 (29.65)	165.28 – 180.0	155.36 (46.65)	143.8 – 166.92	167.63 (30.01)	160.19 – 175.07
MPA	48.18 (14.63)	44.56 – 51.81	41.74 (22.97)	36.05 – 47.44	46.31 (15.56)	42.46 – 50.17
VPA	13.05 (7.49)	11.19 – 14.90	8.56 (9.33)	6.25 – 10.87	11.74 (7.64)	9.85 – 13.64
MVPA	61.24 (20.74)	56.1 – 66.38	50.29 (30.96)	42.63 – 57.97	58.06 (22.03)	52.61 – 63.52
Intensity regression line Intensity gradient	-1.96 ± 0.14		-2.11 ± 0.17		-2.01 ± 0.13	

674 *threshold = <50mg †significantly higher than weekday data

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ASSESSING CHILDREN'S SEDENTARY BEHAVIOURS

Table 3: Sedentary behaviour and Physical Activity outcomes for boys (27) and girls (38)

	Weekday data (mean (SD))		Weekend data (mean (SD))		Whole week (weighted week)	
	Boys	**Girls**	**Boys**	**Girls**	**Boys**	**Girls**
Mean ENMO [mg]	57.56 (16.86)	43.95 (11.63)	42.4 (22.22)	32.45 (12.0)	53.08 (17.64)	40.62 (10.71)
Sleep	560.5 (35.9)	565.07 (44.62)	548.46 (50.43)	561.97 (58.46)	557.01 (31.35)	564.17 (41.9)
Sedentary time*	614.45 (40.38)	623.03 (66.88)	655.43 (86.24)	649.57 (73.18)	627.04 (43.96)	630.72 (56.44)
LPA	172.52 (33.86)	172.73 (26.83)	155.63 (49.82)	155.18 (44.95)	167.62 (32.82)	167.64 (28.31)
MPA	53.99 (14.59)	44.06 (13.37)	48.28 (27.6)	39.09 (18.0)	52.34 (16.67)	42.04 (13.36)
VPA	17.23 (8.28)	10.08 (5.19)	11.64 (12.51)	6.37 (5.38)	15.61 (9.07)	9.0 (4.94)
MVPA	71.23 (21.02)	54.13 (17.59)	59.91 (38.27)	43.47 (22.66)	67.95 (24.17)	51.04 (17.52)
Intensity regression line						
Intensity gradient	-1.89 (0.11) †	-2.01 (0.14)	-2.05 (0.18) †	-2.16 (0.15)	-1.94 (0.12) †	-2.05 (0.12)

*threshold = <50mg † significantly lower than girls

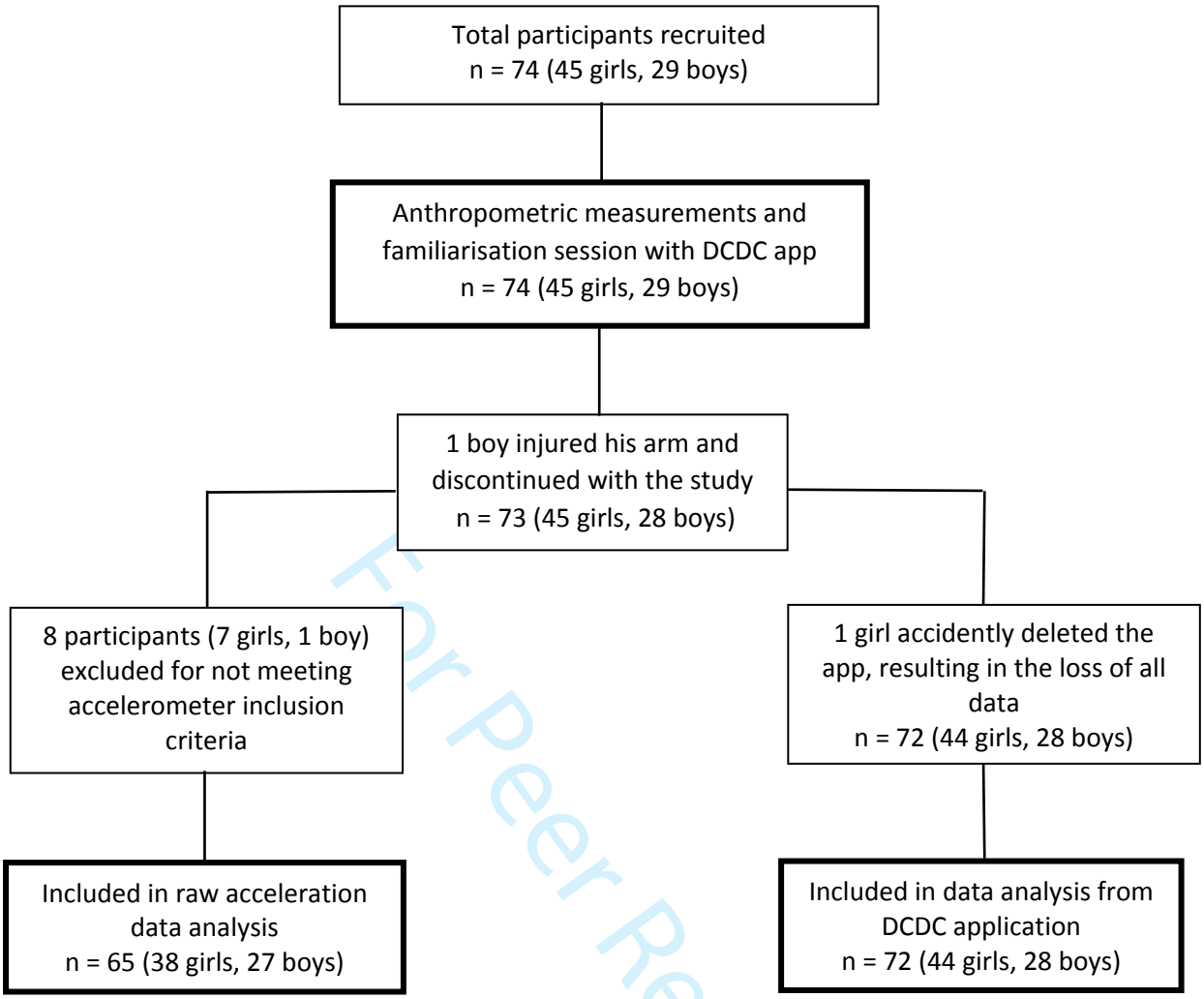

FIGURE 1: Flow diagram of participants

Figure 2: Examples of photos taken and drawings made by participants

338x190mm (96 x 96 DPI)

Supplementary Table S1: Answers from the multiple choice questionnaire ("Answer some questions") of the DCDC application (n = 72)

	Answers to multiple choice questions (Number of days (%))		
	Weekdays N (%)	**Weekend days N (%)**	**Total N (%)**
Question 1: How much time did you spend watching TV outside of school today?			
I didn't watch TV at all	100 (35.2)	25 (25.3)	125 (32.6)
I watched less than one hour today	97 (34.2)	30 (30.3)	127 (33.2)
I watched one to two hours today	53 (18.7)	28 (28.3)	81 (21.1)
I watched two to three hours today	14 (4.9)	4 (4)	18 (4.7)
I watched more than three hours today	20 (7)	12 (12.1)	32 (8.4)
Question 2: How much time did you spend playing video games outside of school today?			
I didn't really play at all	155 (54.8)	41 (41.4)	196 (51.3)
I played less than one hour today	62 (21.9)	27 (27.3)	89 (23.3)
I played one to two hours today	42 (14.8)	17 (17.1)	59 (15.4)
I played two to three hours today	9 (3.1)	6 (6.1)	15 (3.9)
I played more than three hours today	15 (5.3)	8 (8.1)	23 (6)
Question 3: How much time did you spend using a computer outside of school today?			
I didn't really use a computer at all	183 (64.9)	61 (61)	244 (63.9)
I used a computer less than one hour today	57 (20.2)	25 (25)	82 (21.5)
I used a computer one to two hours today	23 (8.2)	8 (8)	31 (8.1)
I used a computer two to three hours today	6 (2.1)	2 (2)	8 (2)
I used a computer more than three hours today	13 (4.6)	4 (4)	17 (4.5)
Question 4: How much time did you spend using a mobile phone today?			
I didn't really use a mobile phone	185 (65.3)	57 (57.5)	242 (63.4)
I used a phone less than one hour today	50 (17.7)	24 (24.2)	74 (19.4)
I used a phone one to two hours today	16 (5.7)	5 (5.1)	21 (5.5)
I used a phone two to three hours today	17 (6)	6 (6.1)	23 (6)
I used a phone more than three hours today	15 (5.3)	7 (7.1)	22 (5.7)
Question 5: Which of the following best describes your typical sedentary habits at home?			
I spent almost none of my free time sitting	47 (16.7)	19 (19.4)	66 (17.4)
I spent a little of my free time sitting	101 (36)	32 (32.7)	133 (35.1)
I spent a moderate amount of my time sitting during my free time	59 (21)	25 (25.5)	84 (22.2)
I spent a lot of time sitting during my free time	31 (11)	9 (9.2)	40 (10.5)
I spent almost all of my free time sitting	43 (15.3)	13 (13.2)	56 (14.8)

Questions 6: How did you travel to school today?			
Bus	4 (1.4)	0 (0)	4 (1.1)
Train	4 (1.4)	1 (1)	5 (1.3)
Bicycle	6 (2.2)	0 (0)	6 (1.6)
Walk	77 (27.6)	5 (5.1)	82 (21.8)
Car	167 (59.9)	13 (13.3)	180 (47.7)
I didn't go to school today	9 (3.2)	77 (78.6)	86 (22.8)
Bus and car	2 (0.7)	0 (0)	2 (0.5)
Car and Walk	9 (3.2)	1 (1)	10 (2.7)
Car and I didn't go to school today	1 (0.4)	0 (0)	1 (0.3)

Notes: Question 1 – 383 days in total: 284 weekdays, 99 weekend days
Question 2 and Question 4 – 382 days in total: 283 weekdays, 99 weekend days
Question 3 – 382 days in total: 282 weekdays, 100 weekend days
Question 5 – 379 days in total: 281 weekdays, 98 weekend days
Question 6 – 377 days in total: 279 weekdays, 98 weekend days

Supplementary Table S2: Boys' (n=28) and girls' (n=44) answers from the multiple-choice questionnaire ("Answer some questions") of the DCDC application

	Answers to multiple-choice questions (Number of days (%))		
	Boys	**Girls**	**Total (%)**
Question 1: How much time did you spend watching TV outside of school today?			
I didn't watch TV at all	51 (36.7)	74 (30.3)	125 (32.6)
I watched less than one hour today	47 (33.8)	80 (32.8)	127 (33.2)
I watched one to two hours today	32 (23)	49 (20.1)	81 (21.1)
I watched two to three hours today	1 (0.7)	17 (7)	18 (4.7)
I watched more than three hours today	8 (5.8)	24 (9.8)	32 (8.4)
Question 2: How much time did you spend playing video games outside of school today?			
I didn't really play at all	61 (43.9)	135 (55.6)	196 (51.3)
I played less than one hour today	32 (23)	57 (23.5)	89 (23.3)
I played one to two hours today	24 (17.3)	35 (14.4)	59 (15.4)
I played two to three hours today	5 (3.6)	10 (4)	15 (3.9)
I played more than three hours today	17 (12.2)	6 (2.5)	23 (6)
Question 3: How much time did you spend using a computer outside of school today?			
I didn't really use a computer at all	84 (60.4)	160 (65.8)	244 (63.9)
I used a computer less than one hour today	23 (16.5)	59 (24.3)	82 (21.5)
I used a computer one to two hours today	14 (10.1)	17 (7)	31 (8.1)
I used a computer two to three hours today	7 (5)	1 (0.4)	8 (2)
I used a computer more than three hours today	11 (8)	6 (2.5)	17 (4.5)
Question 4: How much time did you spend using a mobile phone today?			
I didn't really use a mobile phone	96 (69.1)	146 (60.1)	242 (63.4)
I used a phone less than one hour today	26 (18.7)	48 (19.8)	74 (19.4)
I used a phone one to two hours today	7 (5)	14 (5.7)	21 (5.5)
I used a phone two to three hours today	6 (4.3)	17 (7)	23 (6)
I used a phone more than three hours today	4 (2.9)	18 (7.4)	22 (5.7)
Question 5: Which of the following best describes your typical sedentary habits at home?			
I spent almost none of my free time sitting	29 (20.9)	37 (15.4)	66 (17.4)
I spent a little of my free time sitting	47 (33.8)	86 (35.8)	133 (35.1)
I spent a moderate amount of my time sitting during my free time	33 (23.7)	51 (21.3)	84 (22.2)
I spent a lot of time sitting during my free time	15 (10.8)	25 (10.4)	40 (10.5)
I spent almost all of my free time sitting	15 (10.8)	41 (17.1)	56 (14.8)

Questions 6: How did you travel to school today?			
Bus	1 (0.7)	3 (1.2)	4 (1.1)
Train	1 (0.7)	4 (1.7)	5 (1.3)
Bicycle	4 (2.8)	2 (0.8)	6 (1.6)
Walk	42 (30.9)	40 (16.6)	82 (21.8)
Car	51 (37.5)	129 (53.5)	180 (47.7)
I didn't go to school today	29 (21.3)	57 (23.7)	86 (22.8)
Bus and car	0 (0)	2 (0.8)	2 (0.5)
Car and Walk	7 (5.4)	1 (0.4)	10 (2.7)
Car and I didn't go to school today	1 (0.7)	0 (0)	1 (0.3)

Notes: Question 1 – 383 days in total: boys' answers totalled 139 days, girls' 244 days
Question 2, 3 and 4 – 382 days in total: boys' answers totalled 139, girls' 243
Question 5 – 379 days in total: boys' answers totalled 139, girls' 240
Question 6 – 377 days in total: boys' answers totalled 136, girls' 241

Supplementary Table S3: Screen-based behaviour according to the multiple choice questions 1 to 4.

	Answers to multiple-choice questions		
	Number of children/72 (%)	Average per week (SD)	Total number of days (%)
Question 1: How much time did you spend watching TV outside of school today?			
I didn't watch TV at all	46 (63.8)	2.7 (1.8)	125 (32.6)
I watched less than one hour today	57 (79.1)	2.2 (1.2)	127 (33.2)
I watched one to two hours today	48 (66.6)	1.7 (0.9)	81 (21.1)
I watched two to three hours today	10 (13.8)	1.8 (1.0)	18 (4.7)
I watched more than three hours today	17 (23.6)	1.9 (1.3)	32 (8.4)
Question 2: How much time did you spend playing video games outside of school today?			
I didn't really play at all	59 (81.9)	3.3 (1.9)	196 (51.3)
I played less than one hour today	44 (61.1)	2.0 (1.3)	89 (23.3)
I played one to two hours today	40 (55.5)	1.5 (0.8)	59 (15.4)
I played two to three hours today	10 (13.8)	1.5 (0.7)	15 (3.9)
I played more than three hours today	11 (15.2)	2.1 (1.4)	23 (6)
Question 3: How much time did you spend using a computer outside of school today?			
I didn't really use a computer at all	64 (88.8)	3.8 (1.6)	244 (63.9)
I used a computer less than one hour today	41 (56.9)	2.0 (1.2)	82 (21.5)
I used a computer one to two hours today	23 (31.9)	1.3 (0.6)	31 (8.1)
I used a computer two to three hours today	7 (9.7)	1.1 (0.4)	8 (2)
I used a computer more than three hours today	9 (12.5)	1.8 (1.4)	17 (4.5)
Question 4: How much time did you spend using a mobile phone today?			
I didn't really use a mobile phone	61 (84.7)	3.9 (2.1)	242 (63.4)
I used a phone less than one hour today	34 (47.2)	2.0 (1.4)	74 (19.4)
I used a phone one to two hours today	15 (20.8)	1.4 (0.6)	21 (5.5)
I used a phone two to three hours today	14 (19.4)	1.6 (1.3)	23 (6)
I used a phone more than three hours today	10 (13.8)	2.2 (1.9)	22 (5.7)