Screen Time Duration and Timing: Effects on Obesity, Physical Activity, Dry Eyes, and Learning Ability in Elementary School Children

Yui Mineshita
Waseda Daigaku Riko Gakubu: Waseda Daigaku Riko Gakujutsuin
Hyeon-Ki Kim
Waseda University Faculty of Science and Engineering: Waseda Daigaku Riko Gakujutsuin
Hanako Chijiki
Waseda Daigaku Riko Gakubu: Waseda Daigaku Riko Gakujutsuin
Takuya Nanba
Waseda Daigaku Riko Gakubu: Waseda Daigaku Riko Gakujutsuin
Takae Shinto
Waseda Daigaku Riko Gakubu: Waseda Daigaku Riko Gakujutsuin
Shota Furuhashi
Waseda Daigaku Riko Gakubu: Waseda Daigaku Riko Gakujutsuin
Satoshi Oneda
Waseda Daigaku Riko Gakubu: Waseda Daigaku Riko Gakujutsuin
Mai Kuwahara
Waseda Daigaku Riko Gakubu: Waseda Daigaku Riko Gakujutsuin
Anzu Suwama
Waseda Daigaku Riko Gakubu: Waseda Daigaku Riko Gakujutsuin
Shigenobu Shibata (shibatas@waseda.jp)
Waseda University Faculty of Science and Engineering: Waseda Daigaku Riko Gakujutsuin

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Abstract

Background: As internet use becomes more widespread, the screen time (ST) of elementary school students increases yearly. It is known that longer durations of ST can affect obesity, physical activity, dry eye disease, and learning ability. However, the effects of ST just before bedtime have not been clarified. Therefore, we examined ST duration and timing effects on elementary school children.

Methods: We conducted a survey of 7,419 elementary school students in Tokyo, Japan using a questionnaire on food education. ST duration and timing (just before bedtime) served as the explanatory variables, and the relationship between obesity, physical activity, dry eyes, and learning ability was analyzed using logistic regression analysis. Gender, school year, height, and weight were considered confounding factors. First, we examined whether ST duration and timing were related to each objective variable, using a univariate model to examine all variables. Thereafter, we performed multivariate logistic regression analyses for all variables showing a significant difference in the univariate models.

Results: The results showed that the relationship between the ST duration and obesity, physical activity, and learning ability was statistically significant. The relationship between ST timing and obesity, dry eyes, and learning ability was also statistically significant. Therefore, ST timing has a greater effect on dry eyes, and ST duration has a greater effect on academic performance.

Conclusion: Our findings indicate that ST in school children is related to obesity, physical activity, dry eyes, and learning ability, and they suggest that not only the duration but also the timing of ST is important.

Background

The increasing levels of internet access indicates steadily increasing usage time (screen time or ST) of digital devices such as TVs, smartphones, tablets, and gaming consoles increases year after year. According to data from a survey of elementary school students conducted by the Mobile Marketing Data Laboratory, 40.1% of students began using smartphones in 2019 [1]. In addition, data from the Cabinet Office of Japan indicate that in 2018, the internet usage rate exceeded 85% for elementary school students, and the average usage time was 118.2 minutes per day [2]. Moreover, the average internet usage time increased by approximately 21 minutes compared to that in the previous year [2]. These data suggest that children are going online at younger ages and that elementary school students' ST is increasing.

The various effects of longer ST duration on children's health and life events are widely known. The first conceivable effect from the ST increase is an increase in sedentary behavior. Sedentary behaviors are those that require minimal physical movement [3], resulting in metabolic equivalents of energy expenditure levels of 1.0–1.5 [4]. For children, current physical activity guidelines recommend no more than two hours per day of recreational ST to minimize sedentary behavior [5]. The second conceivable effect of the ST increase is a lower level of physical activity, as more ST may equate to less time for physical activity. The World Health Organization (WHO) recommends that children and adolescents aged 5–17 years perform at least 60 minutes of moderate to vigorous physical activity per day [6]. Nevertheless, in Japan, it was found that approximately 60% of children exceeded the two-hour-per-day maximum of sedentary behavior [7], and approximately half of Japanese elementary school students did not achieve the recommended physical activity levels [8]. Lower levels of physical activity and longer sedentary periods from longer ST duration can increase the risk of obesity. It is already known that children with longer STs show greater obesity and adiposity [9]. The third conceivable effect of the ST increase is decreased academic performance, as longer STs may mean that students do not have adequate time for homework. Recent studies have demonstrated the potential effects of sedentary behavior and physical activity on academic performance [5, 10, 11]. For example, spending more than two hours per day in front of the screen was negatively associated with academic achievement of school-age children [5]. The fourth conceivable effect of the ST increase is a growing frequency of dry eye disease, because long periods of focused ST may lead to incomplete eye blinking and therefore, may result in dry eyes [12–14]. It has been shown that using digital devices such as computers and televisions increased the frequency of dry eyes [15, 16]. However, few studies have examined the relationship between ST and dry eye disease in children.

Along with the duration of the ST, the time of ST occurrence (e.g., just before bedtime) is also an important factor in ST-induced decreased physical activity, academic performance, and in the increased frequency of dry eye disease. Visible light affects the central biological clock in the suprachiasmatic nucleus of the hypothalamus in the human brain, with morning light exposure advancing this biological clock and late-night light exposure (including light from LED devices) delaying it [17]. However, light exposure between morning and evening does not affect the phase of the biological clock [17]. In addition, nighttime light exposure suppresses the secretion of melatonin, a sleep-promoting hormone, from the pineal gland [18–20]. This can interfere with sleep onset [18–20]. Thus, ST just

before bedtime can be problematic. Among the visible light wavelengths, short wavelengths perceived as the color blue can strongly affect the phase delay of the circadian rhythm, along with suppressing melatonin [18–20]. Most digital devices emit blue light. Thus, it would be preferable to avoid using digital devices before bedtime, as it could significantly influence the quality of sleep and the circadian rhythm [20]. Many adolescents exhibit an evening chronotype from exposure to nighttime blue light, and their biological and social rhythms become misaligned. This can result in sleep disturbances as well as fatigue, daytime sleepiness, behavioral problems, and poor academic achievement, among other negative outcomes [20]. According to previous studies, late dinners among evening-chronotype adults and adolescents are associated with a higher risk of developing obesity and metabolic diseases [21, 22]. Artificial light at nighttime has been found to be a risk factor for obesity in both humans and rodents [23]. Thus, ST just before bedtime can induce an evening chronotype, and light exposure during sleep can be a risk factor for obesity. ST late at night may also affect dry eye symptoms, because tear secretion follows the circadian rhythm, with low levels at 21:00 [24]. Moreover, late-night ST may increase sympathetic activity, and activation of the sympathetic nervous system is known to decrease tear secretion [25].

This body of evidence suggests that not only the duration of ST but also ST before bedtime may affect obesity, physical activity, academic performance, and dry eyes in children. Therefore, in the current study, we examined the combined effects of ST duration and timing (just before bedtime) on these factors in elementary school children. To our knowledge, no study has examined multiple factors as objective variables for ST duration and timing in the same group of elementary school students. In this study, we aim to determine not only the influence of ST duration but also the novel combined effect from ST duration and timing. Thus, the objective variables used in this study were as follows: “body mass index (BMI) percentiles” and the “Rohrer index” (for obesity), “weekly physical activities,” “dry eyes,” “class,” and “performance.” The explanatory variables were “duration of ST” and “timing of ST.”

Methods

Participants and the Super Diet Education (Shokuiku) Project

The Super Diet Education (Shokuiku) Project was a food education project, supported by the Japanese Ministry of Education, Culture, Science and Technology. In this project, a cross-sectional study was conducted on a cohort of elementary school children using a survey questionnaire. In total, 7,419 children aged 6–12 from 18 elementary schools in Minato City, Japan participated in the survey during 2018–2019. Cases with missing data were excluded from the analysis.

Questionnaire

Teachers at the schools explained the purpose of the study and distributed the questionnaires, and then children and their parents completed the questionnaires and returned them to the schools. Via the questionnaires, information was collected on gender, school year (1 to 6), learning ability, physical activity, ST duration and timing, and anthropometrics. Table 1 presents a summary of the question contents and response options.

Obesity

The obesity variables consisted of the BMI percentiles and Rohrer index scores, which were assessed using self-reported height and weight. In 1997, the WHO and the International Obesity Task Force adopted BMI as a valid criterion for determining childhood obesity [26]. However, growth can affect BMI; therefore, it cannot be used in the same way in children as it can be in adults. As BMI tends to change considerably with age [27], the BMI percentiles were classified into two groups using age- and gender-appropriate charts [28] according to the following guidelines from Japan’s Ministry of Health, Labour and Welfare: “normal “(BMI ≤ 5th but < 85th percentile) and “obese” (BMI ≥ 85th percentile). The Rohrer indexes were also divided into two groups: the “obese” group, with children who had Rohrer indices ≥ 145, and the “normal” group, with those who had Rohrer indices between 115–145. The Rohrer index score was calculated as shown below [29].

$$\text{Rohrer index} = \text{weight (kg)} / \text{height (cm)}^3 \times 10^7$$

Physical activity

Large-scale population surveys, using a self-report questionnaire are the most feasible method for measuring physical activity [30,31]. The WHO Health Behaviour in School-Aged Children (HBSC) survey is one of the most comprehensive sources of data on school-aged students’ physical activity levels [32]. The HBSC has been translated into Japanese (HBSC-J), and it has been shown to be valid [33]. In our questionnaire, we used the following item from the HBSC to assess how often participants engaged in moderate-to-vigorous physical

exercise: “In the last 7 days, how many days have you engaged in physical activities for more than 60 minutes?” The responses to this question were categorized as follows: 1 for 0 days; 2 for 1 day; 3 for 2 days; 4 for 3 days; 5 for 4 days; 6 for 5 days; 7 for 6 days; and 8 for 7 days. The responses for weekly physical activities were divided into two groups: the “high physical activities” group with children who were above the median and the “low physical activities” group, with those who were below it.

Dry eyes

The Dry Eye-Related Quality-of-Life Score (DEQS) questionnaire was created and validated in Japan [34]. We created the questionnaire items to assess dry eye symptoms based on the DEQS questionnaire. We asked the participants, “Do you have dry eyes?” The responses were on a scale from 1 to 4: 1, often; 2, sometimes; 3, rarely; and 4, never. “Dry eyes” responses were also divided into two groups: the “dry” group, with children who answered 1 or 2, and the “not dry” group, with those who answered 3 or 4.

Learning ability

The study group consisted of “class,” and “performance,” which were divided into two groups. We asked the participants, “Do you understand the material presented in your classes at school?” The answers for “class” were categorized from 1 to 4: 1, understand; 2, mostly understand; 3, slightly understand; and 4, never understand. “Class” answers were then divided into two groups: the “understand” group, with children who answered 1 or 2, and the “do not understand” group, with those who answered 3 or 4. The questions used in this item were also used in a previous study [35]. In addition, we asked the participants, “Please describe your performance at school (in classes, on tests, etc.).” The answers for “performance” were categorized from 1 to 4: 1, perform very well; 2, perform in a satisfactory manner; 3, do not perform well; and 4, cannot perform at all. “Performance” answers were then divided into two groups: the “good” group, with children who answered 1 or 2, and the “poor” group, with those who answered 3 or 4. In Japan, where researchers’ access to children’s actual academic data is restricted, subjective learning ability is used as a feasible surrogate variable [36,37]. Self-reported grades and actual grades have previously been reported to be generally accurate [38].

ST duration and timing

Two items, the duration and timing of ST, were used as indicators of ST. We asked the participants, “How much time do you spend per day playing on smartphones or computers, using communication applications, playing video games, or watching TV or videos?” The responses for “duration of ST” were on a scale from 1 to 4: 1 to indicate $\geq$ 5 h; 2 to indicate 3 h to < 5 h; 3 to indicate 1 h to < 3 h; and 4 to indicate < 1 h. The “duration of ST” responses were then divided into three groups: the “above 3 hours” group, with children who answered 1 or 2; the “1–3 hours” group, with those who answered 3; and the “less than 1 hour” group, with those who answered 4. The current American Academy of Pediatrics guidelines recommend that children under 2 years of age should not spend any time using electronic media, while the ST of children over 2 years of age should be kept to less than 2 hours per day [39,40]. Therefore, 2 hours is often used as a reference for ST. However, Minato City is implementing the “Minato-ku School Informatization Action Plan” and has been introducing electronic teaching materials in classes [41]. As a result, ST among Minato City elementary school students is increasing. Considering that headaches and sleep difficulties have been reported as after more than 3 hours of ST [42], we used 3 hours as the ST reference, which is 1 hour more than the American Academy of Pediatrics guidelines. We asked the participants, “Just before you sleep, do you play on smartphones or computers, use communication applications, play video games, or watch TV or videos?” The responses for “timing of ST” were on a scale from 1 to 4: 1, often; 2, sometimes; 3, rarely; and 4, never. The “timing of ST” responses were then divided into two groups: the “yes” group, with children who answered 1 or 2, and the “no” group, with those who answered 3 or 4. Next, in order to examine differences in the influences of ST duration and timing, we used a combination of ST duration and timing as the explanatory variable (Table 2). For each objective variable, a logistic regression analysis comparing G1 and G2, G3 and G4, and G5 and G6 was performed.

Statistical analyses

A chi-square test was performed to compare the sex, school year, height, and weight used as confounding factors by groups. The ST in each group was examined using logistic regression analysis. First, we examined whether ST duration and timing were related to each objective variable. All variables were examined using a univariate model. Afterward, we performed multivariate logistic regression analyses for all variables that showed a significant difference in the univariate models. The odds ratios (ORs) and 95% confidence intervals (CIs) were calculated. All data were analyzed using predictive analytics software for Windows (Statistical Package for the Social Sciences; IBM Corp., Chicago, IL, USA); a p value of < 0.05 indicated statistical significance.

Results

Obesity

The characteristics of the “obese” group are presented in Table 3. In all, 6,334 school children (85.38%) answered all questionnaire items related to “BMI percentiles,” and an analysis was conducted. The mean age (Standard Error, SE) of the participants in the “normal” group was 9.04 (0.023) years, while for the “obese” group, it was 9.21 (0.063) years. There were significant differences in gender, school year, height, and weight between the “normal” and “obese” groups. In all, 4,683 school children (63,12%) answered all questionnaire items related to the “Rohrer index,” and an analysis was conducted. The mean age (SE) of the participants in the “normal” group was 8.76 (0.023) years, while for the “obese” group it was 8.99 (0.069) years. There were significant differences in gender, school year, height, and weight between the “normal” and “obese” groups. The results of the multivariate analysis for obesity are presented in Table 4. The duration (1 h to < 3 h: OR = 0.61, 95% CI = 0.50–0.74; <1 h: OR = 0.42, 95% CI = 0.33–0.54) and timing of ST (OR = 0.78, 95% CI 0.65–0.93) were passively correlated with the “BMI percentiles.” These results show that the participants with shorter ST durations per day were more likely to be in the “normal” group. In addition, the results show that those who did not have ST before bedtime were more likely than those who did to be in the “normal” group. The duration (1 h to < 3 h: OR = 0.65, 95% CI = 0.52–0.81; <1 h: OR = 0.43, 95% CI = 0.32–0.57) and timing of ST (OR = 0.73, 95% CI 0.60–0.90) were passively correlated with the “Rohrer index” item. These results show that the participants with shorter ST durations per day were more likely to be in the “normal” group. In addition, these results show that compared to those with ST, those who did not have ST before bedtime were more likely to be in the “normal” group.

Physical activity

The characteristics of the “physical activity” group are presented in Table 5. For “weekly physical activities” items, 7,048 elementary school children (95.00%) answered all questionnaire items, and an analysis was conducted. The mean age (SE) of the participants in the “high physical activities” group was 8.95 (0.027) years, whereas in the “low physical activities” group it was 9.20 (0.031) years. There were significant differences in gender, school year, height, and weight between the “high physical activities” and “low physical activities” groups. The results of the multivariate analysis for physical activity are presented in Table 4. The duration of ST (1 h to < 3 h: OR = 1.19, 95% CI = 1.03–1.37; <1 h: OR = 1.27, 95% CI = 1.08–1.48) was negatively correlated with the “weekly physical activities” item, while ST timing was not associated. These results show that the participants with shorter durations of ST per day participated in more physical activities.

Dry eyes

The characteristics of children with “dry eyes” are presented in Table 6. In total, 7,041 elementary school children (74.90%) answered all questionnaire items related to this subject, and an analysis was conducted. The mean age (SE) of the participants in the “not dry” group was 8.98 (0.023) years, whereas in the “dry” group, it was 9.44 (0.048) years. Between the “not dry” and “dry” group, there were significant differences in school year, height, and weight, and there was no significant difference in gender. The results of the multivariate analysis for dry eyes are presented in Table 4. The ST timing (OR = 1.31, 95% CI = 1.15–1.50) was negatively correlated with the “dry eyes” item, while ST duration was not associated. These results show that students who did not have ST just before bedtime were less likely to have dry eyes compared to those who did.

Learning ability

The characteristics of children in the “learning ability” group are presented in Table 7. For the “class” item, 7,026 elementary school children (94.70%) answered all questionnaire items related to this subject, and an analysis was performed. The mean age (SE) of the participants in the “understand” group was 9.08 (0.021) years, whereas in the “do not understand” group it was 8.71 (0.103) years. Between the “understand” and “do not understand” groups, there were significant differences in gender, school year, and height, while no significant difference in weight was noted. For the “performance” item, 7,071 elementary school children (95.31%) answered all related questionnaire items, and an analysis was conducted. The mean age (SE) of the participants in the “good” group was 9.03 (0.022) years, whereas in the “poor” group it was 9.26 (0.053) years. Between the “good” and “poor” groups, there were significant differences in gender, school year, and weight; however, no significant difference in height was observed. The results of the multivariate analysis for learning ability are presented in Table 4. The duration (1 h to < 3 h: OR = 2.24, 95% CI = 1.71–2.94; <1 h: OR = 3.93, 95% CI = 2.70–5.71) and timing of ST (OR = 1.43, 95% CI = 1.10–1.86) were associated with the “class” item. These results show that the participants with shorter ST durations per day had a better understanding of the material presented in their classes. In addition, results show that those who did not have ST before bedtime were more likely than those who did to understand the material presented in their classes. For the

“performance” item, the duration (1 h to < 3 h: OR = 1.67, 95% CI = 1.41–1.98; <1 h: OR = 2.40, 95% CI = 1.95–2.96) and timing of ST (OR = 1.55, 95% CI = 1.33–1.79) were negatively correlated with the academic performance of the participants. These results show that the participants with shorter durations of ST per day had good performance. In addition, it shows that children who had no ST just before bedtime were more likely to have good performance than those who did.

Combination of the duration and timing of ST

In this study, we had six combination groups (G1, G2, G3, G4, G5, and G6) (Table 2). We performed logistic regression analysis to compare G1 and G2, G3 and G4, and G5 and G6 regarding each item. The results are presented in Table 8. For the “BMI percentiles” item, the differences between G4 and G3 (OR = 0.72; 95% CI = 0.57–0.90) was associated with being in the “normal” group. In the “Rohrer index” item, the differences between G4 and G3 (OR = 0.76; 95% CI = 0.60–0.97) was associated with being in the “normal” group. In the “weekly physical activities” item, no predominant association in any combination group was observed. Furthermore, the differences between G4 and G3 (OR = 1.36; 95% CI = 1.14–1.63) and G6 and G5 (OR = 1.38; 95% CI = 1.08–1.77) were associated with “not dry eyes.” Regarding the “class” item, no predominant association in any combination group was noted. The differences between G2 and G1 (OR = 1.85; 95% CI = 1.26–2.72), G4 and G3 (OR = 1.53; 95% CI = 1.26–1.85) and G6 and G5 (OR = 1.42; 95% CI = 1.05–1.91) were associated with good grades. These results show that the timing of ST had a greater impact on dry eye symptoms, while the duration of ST had a greater effect on academic performance.

Discussion

Main results

This study surveyed elementary school children from Minato City to examine the effects of ST duration and timing on obesity, physical activity, dry eyes, and learning ability. The relationships between ST duration and BMI percentile, Rohrer index, weekly physical activity, class, and performance were statistically significant. Furthermore, the relationships between ST timing and BMI percentile, Rohrer index, dry eyes, class, and performance were also statistically significant. In addition, ST timing greatly affected dry eye symptoms, whereas ST duration greatly affected academic performance.

Relationship between ST and each item

First, our results show that participants with shorter ST durations were more likely to have a normal body weight. The relationship between screen media exposure and obesity has been extensively studied. For example, many studies have reported a relationship between TV viewing and obesity [43-45]. A possible cause of the obesity that is associated with TV viewing is increased caloric intake during TV viewing. Watching TV while eating a meal may increase caloric intake by delaying satiety during the meal or by reducing satiety signals from previously consumed food; it may also divert attention from the habitual control of food intake [46]. Note that the ST used in our study included TV viewing, but our results show that ST other than watching TV was also associated with obesity. In addition, our results show that compared to those who did, those who did not have ST just before bedtime were more likely to have normal body weight. This may because late-night ST contributes to evening chronotype behavior [17], and late-night snack consumption is associated with a higher risk of developing obesity and metabolic diseases [21,22].

Second, our results show that participants with shorter ST durations participated in more weekly physical activities. Longer ST durations are associated with increased sedentary behavior and decreased physical activity, and this may relate to obesity. Studies have reported that longer durations of ST, especially from watching TV, are associated with decreased physical fitness [5,47] and decreased muscle strength, regardless of physical activity level [48]. Those with longer TV-viewing time spend less time doing club sports, which may indicate less involvement in physical activity, overall [47]. The results of these studies are consistent with our findings that those with shorter ST durations spent more time participating in physical activities.

Third, our results show that the participants who did not have ST just before bedtime were less likely than those who did to have dry eyes. Digital device use has been correlated with dry eye symptoms [15] and tear film instability [49]. The interblink interval and tear film instability increase during highly focused work [12-14]. Thus, in the current study, ST just before bedtime may be associated with focused ST exposure. Other studies reported that blue light emitted from smart mobile device screens causes eye fatigue [50,51] and that dry eyes are associated with sleep quality [52]. Hence, ST before bedtime can detract from sleep quality and lead to dry eyes.

Finally, our results show that the participants with shorter ST durations could better understand material presented in their classes, and they had better academic performance. Studies have shown that longer ST durations detract from time spent on academic activities,

such as studying and doing homework [53], and this can cause learning and attention deficits and negative attitudes toward school [54]. Another study reported that Japanese children with shorter ST durations were more likely to have high academic performance, regardless of physical activity level [55]. Taken together, these studies suggest that longer ST durations can influence individual behavioral styles that impinge on academic understanding and performance and contribute to poor grades. Our results are consistent with this idea. In addition, our results show that compared to those with ST before bedtime, those who did not have ST just before bedtime were more likely to understand material presented in their classes, and they had better academic performance. As mentioned above, it is believed that ST just before bedtime leads to sleep deprivation in children, and studies have reported that sleep deprivation is associated with poor grades [56]. Our results confirm this idea. Sleep deprivation affects memory retention, increases erroneous memory formation [57], and is associated with a lack of judgment and attention [58]. Therefore, sleep deprivation from ST just before bedtime could affect attitudes toward learning, learning comprehension, and ultimately, overall academic achievement.

Interaction between ST duration and timing

Jointly investigating ST duration and timing showed that ST timing had a greater effect than ST duration on dry eye symptoms. Thus, the timing of ST has a significant impact on dry eyes. Currently, we do not know the mechanism behind this, but several possibilities exist. Late-night ST may lead to dry eye symptoms as tear secretion follows the circadian rhythm, with low levels at 21:00 [24]. Further, late-night ST may promote sympathetic activity, and activation of the sympathetic nervous system is known to decrease tear secretion [25]. Another possibility is related to focused nighttime ST exposure, considering that children may be using digital devices without parental supervision at night. Focused ST exposure causes incomplete blinks and tear film instability [12-14], and these factors contribute to the risk of dry eyes [59-61]. Regarding academic performance, our study has shown that the ST duration has a greater effect than ST timing, and longer ST durations detract more from academic performance. However, the mechanism of the ST duration and timing effect is not yet clear. Spending more than 2 hours per day in front of the screen was negatively associated with academic achievement among school-age children [5]. Thus, having sufficient study time in the afternoon, early evening, and late evening may be a very important factor in academic achievement. Our results call attention to the different effects of ST dependency (duration and/or timing) on individual areas. Blue light exposure before bedtime causes disturbances of the circadian clock, sleep length, energy metabolism, and academic performance [20]. Therefore, parents, school teachers, and leading social media firms should strive to reduce children's late-night ST.

Study strengths and limitations

In this study, we investigated ST effects on multiple objective variables using the same group of elementary school children. To our knowledge, no studies have examined the effect of the duration and timing of ST on obesity, physical activity, dry eyes, and learning ability in the same group of elementary school children. In addition, by combining the duration and timing of ST, we were able to show not only the effect of ST duration, which has already been discussed in the literature, but also that of ST timing (just before bedtime). The combined analysis of ST duration and timing is a strength of this study.

However, our study has several limitations. First, the surveys failed to reflect the actual lifestyles and anthropometric data of the participants. Children may have exaggerated or downplayed aspects of their lifestyles based on social expectations. Second, the study relies on children's answers, which may introduce errors due to their varying interpretations of the questions. Third, because the study focused only on elementary school students, the results may not be applicable to middle school, high school, and college students along with working adults and hence, may not be generalizable. Therefore, it may be necessary to expand the range of participants in future studies. Fourth, the area covered by this study was Minato City, Tokyo, Japan, and it is unclear whether the same results would be obtained in other areas. Therefore, it may be necessary to expand the target area in future studies.

Conclusion

The combined effects of ST duration and timing (at bedtime) on obesity, physical activity, dry eyes, and learning ability were examined in elementary school children. ST timing had a greater impact on dry eyes, while ST duration had a greater effect on academic performance. Our findings indicate that not only the duration but also the timing of ST has important ramifications.

Abbreviations

ST: screen time; BMI: body mass index; WHO: world health organization; HBSC: Behaviour in School-Aged Children: DEQS: Dry Eye-Related Quality-of-Life Score; ORs: odds ratios; Cis; confidence intervals; SE: Standard Error

Declarations

Author Contributions

Y.M., H-K.K., and S.S. designed the research, analyzed the data, and wrote the manuscript. H.C., T.N., T.S., S.F., and S.O. analyzed the data and reviewed the manuscript. M.K. and A.S. reviewed the manuscript. All authors have read and approved the final manuscript.

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Ethics Approval and Consent to Participate

Prior to the study, informed consent from a parent or guardian for participants under 16 years old was obtained after a detailed description of the study (i.e. purpose, methods) were delivered. This study protocol conforms to the Helsinki Declaration and was approved by the ethics committee for humans at Waseda University (application no. 2019-195), Tokyo, Japan.

Competing interests

We declare that there are no conflicts of interest related to this study.

Consent for publication

Not applicable.

Availability of data and materials

The datasets for the current study are available from the corresponding author on reasonable request.

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References

1. Survey of parents' awareness of children with smartphones for the first time this year. Available online: https://mmdlabo.jp/investigation/detail_1838.html (accessed on 4 July 2020).
2. Survey on Internet usage environment of young people in 2018. Available online: https://www8.cao.go.jp/youth/youth-harm/chousa/h30/net-jittai/pdf/sokuhou.pdf (accessed on 4 July 2020).
3. Lynch BM, Healy GN, Dunstan DW, Owen N. Sedentary versus inactive: Distinctions for disease prevention. Nat Rev Cardiol. 2010; 7(11). doi:10.1038/nrcardio.2010.68-c1.
4. Pate RR, Stevens J, Webber LS, Webber LS, Dowda M, Murray DM, Young DR, Going S. Age-related change in physical activity in adolescent girls. J Adolesc Health 2009; 44(3): 275-282. doi:10.1016/j.jadohealth.2008.07.003.
5. Tremblay MS, LeBlanc AG, Janssen I, Kho ME, Hicks A, Murumets K, Colley RC, Duggan M. Canadian sedentary behaviour guidelines for children and youth. Appl Physiol Nutr Metab. 2011; 36: 59-64. doi:10.1139/H11-012.
6. World Health Organization. Global Recommendations on Physical Activity for Health. 2010. Available online: http://whqlibdoc.who.int/publications/2010/9789241599979_eng.pdf (accessed on 4 July 2020).
7. Ishii K, Shibata A, Adachi M, Mano Y, Oka K. School grade and sex differences in domain-specific sedentary behaviors among Japanese elementary school children: A cross-sectional study. BMC Public Health. 2017; 17: 318. doi:10.1186/s12889-017-4221-z.
8. Ishii K, Shibata A, Adachi M, Nonoue K, Oka K. Gender and grade differences in objectively measured physical activity and sedentary behavior patterns among Japanese children and adolescents: Across-sectional study. BMC Public Health. 2015; 15: 1254. doi:10.1186/s12889-015-2607-3.
9. Stiglic N, Viner RM. Effects of screentime on the health and well-being of children and adolescents: a systematic review of reviews. BMJ Open. 2019; 9(1): e023191. doi:10.1136/bmjopen-2018-023191.

10. Marques A, Santos DA, Hillman CH, Sardinha LB. How does academic achievement relate to cardiorespiratory fitness.; self-reported physical activity and objectively reported physical activity: A systematic review in children and adolescents aged 6-18 years. Br J Sports Med. 2018; 52(16): 1039. doi:10.1136/bjsports-2016-097361.
11. Adelantado-Renau M, Moliner-Urdiales D, Cavero-Redondo I, Beltran-Valls MR, Martínez-Vizcaíno V, Álvarez-Bueno C. Association between screen media use and academic performance among children and adolescents: A systematic review and meta-analysis. JAMA Pediatr. 2019; 173(11): 1058-1076, doi:10.1001/jamapediatrics.2019.3176.
12. Bron AJ, Tomlinson A, Foulks GN, Pepose JS, Baudouin C, Geerling G, Nichols KK, Lemp MA. Rethinking dry eye disease: a perspective on clinical implications. Ocul Surf. 2014; 12(2 Suppl): S1-31. doi: 10.1016/j.jtos.2014.02.002.
13. Cardona G, Garcia C, Seres C, Vilaseca M, Gispets J. Blink Rate, Blink Amplitude, and Tear Film Integrity during Dynamic Visual Display Terminal Tasks. Curr Eye Res. 2011; 36 (3): 190-197. doi:10.3109/02713683.2010.544442.
14. Himebaugh NL, Begley CG, Bradley A, Wilkinson JA, Blinking and tear breakup during four visual tasks. Optom Vis Sci. 2009; 86 (2): E106–E114. doi:10.1097/OPX.0b013e318194e962.
15. Uchino M, Schaumberg DA, Dogru M, Uchino Y, Fukagawa K, Shimmura S, Satoh T, Takebayashi T, Tsubota K. Prevalence of dry eye disease among Japanese visual display terminal users. Ophthalmology. 2008; 115(11): 1982-1988. doi:10.1016/j.ophtha.2008.06.022.
16. Alves M, Dias AC, Rocha EM. Dry eye in childhood: epidemiological and clinical aspects, Ocul Surf. 2008; 6(1): 44-51. doi: 10.1016/s1542-0124(12)70104-0.
17. Shibata S, Tahara Y, Hirao A. The adjustment and manipulation of biological rhythms by light, nutrition, and abused drugs. Advanced Drug Delivery Reviews. 2010; 62(9-10): 918-927. doi:10.1016/j.addr.2010.06.003.
18. Wahl S, Engelhardt M, Schaupp P, Lappe C, Ivanov IV. The inner clock-Blue light sets the human rhythm. J Biophotonics. 2019; 12(12): e201900102. doi:10.1002/jbio.201900102.
19. Tähkämö L, Partonen T, Pesonen AK. Systematic review of light exposure impact on human circadian rhythm. Chronobiol Int. 2019; 36(2): 151-170. doi:10.1080/07420528.2018.1527773.
20. Touitou Y, Touitou D, Reinberg A. Disruption of adolescents' circadian clock: The vicious circle of media use, exposure to light at night, sleep loss and risk behaviors. J Physiol Paris. 2016; 110(4 Pt B): 467-479. doi:10.1016/j.jphysparis.2017.05.001.
21. Lopez-Minguez J, Gómez-Abellán P, Garaulet M. Timing of Breakfast, Lunch, and Dinner. Effects on Obesity and Metabolic Risk. Nutrients. 2019; 11(11): 2624. doi:10.3390/nu11112624
22. Rešetar J, Pfeifer D, Mišigoj-Duraković M, Sorić M, Kljusurić JG, Šatalić Z. Eveningness in Energy Intake among Adolescents with Implication on Anthropometric Indicators of Nutritional Status: The CRO-PALS Longitudinal Study. Nutrients. 2020; 12(6): 1710. doi:10.3390/nu12061710
23. Fleury G, Masís-Vargas A, Kalsbeek A. Metabolic Implications of Exposure to Light at Night: Lessons from Animal and Human Studies. Obesity (Silver Spring). 2020; 28(Suppl1): S18-S28. doi:10.1002/oby.22807.
24. Srinivasan S, Chan C, Jones L. Apparent time-dependent differences in inferior tear meniscus height in human subjects with mild dry eye symptoms. Clin Exp Optom. 2007; 90(5): 345-350. doi:10.1111/j.1444-0938.2007.00174.x.
25. Nakamura S, Kinoshita S, Yokoi N, Ogawa Y, Shibuya M, Nakashima H, Hisamura R, Imada T, Imagawa T, Uehara M, Shibuya I, Dogru M, Ward S, Tsubota K. Lacrimal hypofunction as a new mechanism of dry eye in visual display terminal users. PLoS One. 2010; 5(6): e11119. doi:10.1371/journal.pone.0011119.
26. Dietz WH, Robinson TN. Use of the body mass index (BMI) as a measure of overweight in children and adolescents. J Pediatr. 1998; 132(2): 191-193. doi:10.1016/s0022-3476(98)70426-3.
27. Rolland-Cachera MF, Sempé M, Guilloud-Bataille M, Patois E, Péquignot-Guggenbuhl F, Fautrad V. Adiposity indices in children. Am J Clin Nutr. 1982; 36(1): 178-184. doi:10.1093/ajcn/36.1.178.
28. Ministry of Health, Labor and Welfare. About the present condition of height and weight of infants. Available online: https://www.mhlw.go.jp/seisakunitsuite/bunya/kodomo/kodomo_kosodate/boshi-hoken/kenkou-02.html (accessed on 8 September 2020).
29. Ohnishi M, Leshabari S, Ambikile JS, Oishi K, Nakao Y, Nishihara M. Associations among anthropometric measures, food consumption, and quality of life in school-age children in Tanzania. J Rural Med. 2017; 12(1): 38-45. doi:10.2185/jrm.2924.
30. Hallal PC, Andersen LB, Bull FC, Guthold R, Haskell W, Ekelund U. Lancet Physical Activity Series Working Group. Global physical activity levels: surveillance progress, pitfalls, and prospects. Lancet. 2012; 380(9838): 247-257. doi:10.1016/S0140-6736(12)60646-1.

31. Kohl HW, Fulton JE, Casperson CJ. Assessment of physical activity among children and adolescents: a review and synthesis. Prev Med. 2000; 31(Suppl): S54 76.
32. World Health Organization Available online: https://www.euro.who.int/en/health-topics/Life-stages/child-and-adolescent-health/health-behaviour-in-school-aged-children-hbsc/about-hbsc (accessed 8 September 2020)
33. Tanaka C, Kyan A, Takakura M, Olds T. The Validity of the Japanese Version of Physical Activity Questions in the WHO Health Behaviour in School-aged Children (HBSC) Survey. Res Exerc Epidemiol 2017; 19(2): 93-101.
34. Sakane Y, Yamaguchi M, Yokoi N, Uchino M, Dogru M, Oishi T, Ohashi Y, Ohashi Y. Development and validation of the Dry Eye-Related Quality-of-Life Score questionnaire. JAMA Ophthalmol. 2013; 131(10): 1331-1338. doi:10.1001/jamaophthalmol.2013.4503.
35. Yamada M, Sekine M, Tatsuse T, Asaka Y. Association between lifestyle, parental smoke, socioeconomic status, and academic performance in Japanese elementary school children: the Super Diet Education Project. Environ Health Prev Med. 2019; 24(1): 22. doi:10.1186/s12199-019-0776-x.
36. Kohyama J. Self-reported academic performance and lifestyle habits of school children in Japan. Int J Child Health Nutr. 2017; 6: 90–7.
37. Stroebele N, McNally J, Plog A, Siegfried S, Hill JO. The association of self-reported sleep, weight status, and academic performance in fifth-grade students. J Sch Health. 2013; 83(2): 77-84. https://doi.org/10.1111/josh.12001.
38. Kuncel NR, Crede M, Thomas LL. The validity of self-reported grade point average, class ranks, and test score: a meta-analysis and review of the literature. Rev Educ Res. 2005; 75: 62-82.
39. COUNCIL ON COMMUNICATIONS AND MEDIA. Children, Adolescents, and the Media. Pediatrics. 2013; 132(5): 958-961. doi:10.1542/peds.2013-2656.
40. Council on Communications and Media, Brown A. Media use by children younger than 2 years. Pediatrics. 2011; 128(5): 1040-1045. doi:10.1542/peds.2011-1753.
41. Minato-ku Board of Education. Minato-ku School Informatization Action Plan Available online:https://www.city.minato.tokyo.jp/kyouikushomu/kodomo/gakko/documents/actionplan30-32.pdf (accessed 8 September 2020)
42. Domingues-Montanari S. Clinical and psychological effects of excessive screen time on children. J Paediatr Child Health. 2017; 53(4): 333-338. doi:10.1111/jpc.13462.
43. Viner RM, Tim J. Television viewing in early childhood predicts adult body mass index. Pediatrics. 2005; 147(4): 429-435. doi:10.1016/j.jpeds.2005.05.005.
44. Hancox RJ, Milne BJ, Poulton R. Association between child and adolescent television viewing and adult health: a longitudinal birth cohort study. The Lancet 2004; 364(9430): 257-262. doi:10.1016/S0140-6736(04)16675-0.
45. Carson V, Hunter S, Kuzik N, Gray CE, Poitras VJ, Chaput J-P, Saunders, TJ, Katzmarzyk PT, Okely AD, Gorber SC, Kjo ME, Sampson M, Lee H, Tremblay MS. Systematic review of sedentary behaviour and health indicators in school-aged children and youth: an update. Appl Physiol Nutr Metab. 2016; 41(6): 240–65. doi:10.1139/apnm-2015-0630
46. Bellissimo N, Pencharz PB, Thomas SG, Anderson GH. Effect of television viewing at mealtime on food intake after a glucose preload in boys. Pediatric Research 2007; 61: 745-749. doi:10.1203/pdr.0b013e3180536591.
47. Greier K, Drenowatz C, Ruedl G, Riechelmann H. Association between daily TV time and physical fitness in 6- to 14-year-old Austrian youth. Transl Pediatr. 2019; 8(5): 371-377. doi:10.21037%2Ftp.2019.03.03.
48. Paalanne NP, Korpelainen RI, Taimela SP, Auvinen JP, Tammelin TH, Hietikko TM, Kaikkonen HS, Kaikkonen KM, Karppinen JI. Muscular fitness in relation to physical activity and television viewing among young adults. Med Sci Sports Exerc. 2009; 41(11): 1997-2002. doi:10.1249/MSS.0b013e3181a7f3a6
49. Uchino M, Yokoi N, Uchino Y, Dogru M, Kawashima M, Komuro A, Sonomura Y, Kato H, Kinoshita S, Schaumberg DA, Tsubota K. Prevalence of dry eye disease and its risk factors in visual display terminal users: the Osaka study. Am J Ophthalmol. 2013; 156 (4); 759-766. doi:10.1016/j.ajo.2013.05.040.
50. Kim DJ, Lim CY, Gu N, Park CY. Visual Fatigue Induced by Viewing a Tablet Computer with a High-resolution Display. Korean J Ophthalmol. 2017; 31(5): 388-393. doi:10.3341/kjo.2016.0095
51. Tosini G, Ferguson I, Tsubota K. Effects of blue light on the circadian system and eye physiology. Mol Vis. 2016; 22: 61-72.

52. Oh JH, Yoo H, Park HK, Do YR. Analysis of circadian properties and healthy levels of blue light from smartphones at night. Scientific Reports. 2015; 5: 11325. doi:10.1038/srep11325
53. Vandewater EA, Bickham DS, Lee JH. Time well spent? Relating television use to children's free-time activities. Pediatrics. 2006; 117(2): 181-191. doi:10.1542/peds.2005-0812.
54. Johnson JG, Cohen P, Kasen S, Brook JS. Extensive television viewing and the development of attention and learning difficulties during adolescence. Arch Pediatr Adolesc Med. 2007; 161(5): 480-486. doi:10.1001/archpedi.161.5.480.
55. Ishii K, Aoyagi K, Shibata A, Koohsari MJ, Carver A, Oka K. Joint Associations of Leisure Screen Time and Physical Activity with Academic Performance in a Sample of Japanese Children. Int J Environ Res Public Health. 2020; 17(3): 757. doi:10.3390/ijerph17030757.
56. Schmidt RE, Van der Linden M. The Relations Between Sleep, Personality, Behavioral Problems, and School Performance in Adolescents. Sleep Medicine Clinics. 2015; 10(2): 117-123. doi:10.1016/j.jsmc.2015.02.007.
57. Lo JC, Chong PL, Ganesan S, Leong RL, Chee MW. Sleep deprivation increases formation of false memory. J Sleep Research. 2016; 25(6): 673-682. doi:10.1111/jsr.12436.
58. Harrison Y, Horne JA. The impact of sleep deprivation on decision making: a review. J Exp Psychol Appl. 2000; 6(3): 236-249. doi:10.1037//1076-898x.6.3.236
59. Pult H, Riede-Pult BH, Murphy PJ. The relation between blinking and conjunctival folds and dry eye symptoms. Optom Vis Sci. 2013; 90(10): 1034-1039. doi:10.1097/OPX.0000000000000029.
60. Craig JP, Nichols KK, Akpek EK, Caffery B, Dua HS, Joo C-K, Liu Z, Nelson JD, Nichols JJ, Tsubota K, Stapleton F. TFOS DEWS II definition and classification report. Ocul Surf. 2017; 15(3): 276-283. doi:10.1016/j.jtos.2017.05.008.
61. Wolkoff P, Nojgaard JK, Troiano P, Piccoli B. Eye complaints in the office environment: precorneal tear film integrity influenced by eye blinking efficiency. Occup Environ Med. 2005; 62(1): 4-12. doi:10.1136/oem.2004.016030.

Tables

Table 1
Question contents and response options for the explanatory variables and objective variables

	Explanatory variable	Content of question
Screen time	Duration	How much time do you spend per day playing on smartphones or computers, using communication applications, playing video games, or watching TV or videos?
		1. > 5 h; 2. 3 h to < 5 h; 3. 1 h to < 3 h; 4. < 1 h
	Timing	Just before you sleep, do you play on smartphones or computers, use communication applications, play video games, or watch TV or videos?
		1. often; 2. sometimes; 3. rarely; 4. never
	Objective variable	
Obesity	BMI percentiles	Calculated using height and weight
	Rohrer index	Calculated using height and weight
Physical activity	Weekly physical activity	In the last 7 days, how many days have you engaged in physical activities for more than 60 minutes?
		1. 0 days; 2. 1 day; 3. 2 days; 4. 3 days; 5. 4 days; 6. 5 days; 7. 6 days; 8. 7 days
Dry eyes	Dry eyes	Do you have dry eyes?
		1. often; 2. sometimes; 3. rarely; 4. never
Learning ability	Class	Do you understand the material presented in your classes at school?
		1. understand; 2. mostly understand; 3. slightly understand; 4. never understand
	Performance	Please describe your performance at school (in classes, on tests, etc.)
		1. perform very well; 2. perform in a satisfactory manner; 3. do not perform well; 4. cannot perform at all

Table 2
The combination of ST duration and timing

	ST duration			ST timing		Students belonging to each group
Group	Above 3 hours	1–3 hours	Less than 1 hour	Yes	No	% range among 6 items[a]
G1	□			□		12.6–13.2
G2	□				□	3.01–3.14
G3		□		□		28.6–29.8
G4		□			□	20.8–21.2
G5			□	□		7.69–7.84
G6			□		□	25.0–27.0

[a] 6 items are BMI percentile, Rohrer index, physical activity in a week, dry eyes, class, and performance.

Table 3
Characteristics of the children in the obese group

		BMI percentiles						Rohrer index					
Item			Normal		Obese				Normal		Obese		
Age, mean (SE)			9.04	(0.023)	9.21	(0.063)			8.76	(0.023)	8.99	(0.069)	
		N	n	%	N	%	P-value	N	N	%	n	%	P-value
Gender	Boys	3346	2882	86.1	464	13.9	< 0.001	2582	2160	83.7	422	16.3	< 0.001
	Girls	2988	2744	91.8	244	8.2		2101	1886	89.8	215	10.2	
School year	1	1235	1126	91.2	109	8.8	0.021	1136	996	87.7	140	12.3	0.021
	2	1161	1039	89.5	122	10.5		945	833	88.1	112	11.9	
	3	1106	978	88.4	128	11.6		813	708	87.1	105	12.9	
	4	1080	949	87.9	131	12.1		730	626	85.8	104	14.2	
	5	989	857	86.7	132	13.3		617	511	82.8	106	17.2	
	6	763	677	88.7	86	11.3		442	372	84.2	70	15.8	
Height[b]	higher than median	3195	2739	85.7	456	14.3	< 0.001	2662	2253	84.6	409	15.4	< 0.001
	lower than median	3139	2887	92.0	252	8.0		2021	1793	88.7	228	11.3	
Weight[c]	higher than median	3205	2576	80.4	629	19.6	< 0.001	2448	1948	79.6	500	20.4	< 0.001
	lower than median	3129	3050	97.5	79	2.5		2235	2098	93.9	137	6.1	

[a] Chi-square test.

[b] The median height was divided into tall and short.

[c] The median weight was divided into heavy and light.

Table 4
Results of logistic regression analysis of ST duration and timing

		Obesity		Physical activity	Dry eyes	Learning ability	
		BMI percentiles	Rohrer index	Weekly physical activity[bb]	Dry eyes	Class	Performance
		OR[a]	OR[a]	OR[a]	OR[a]	OR[a]	OR[a]
		95%CI	95%CI	95%CI	95%CI	95%CI	95%CI
Duration of ST	Above 3 hours	1	1	1	1	1	1
	1-3hours	0.61***	0.65***	1.19*	1.15	2.24***	1.67***
		0.50–0.74	0.52–0.81	1.03–1.37	0.97–1.36	1.71–2.94	1.41–1.98
	Less than 1 hour	0.42***	0.43***	1.27**	1.19	3.93***	2.4***
		0.33–0.54	0.32–0.57	1.08–1.48	0.98–1.45	2.70–5.71	1.95–2.96
Timing of ST[c]	No/(Yes)	0.78**	0.73**	1.06	1.31***	1.43**	1.55***
		0.65–0.93	0.60–0.90	0.95–1.17	1.15–1.50	1.10–1.86	1.33–1.79

***p < 0.001,**p < 0.01 *p < 0.05

[a] OR: odds ratio, 95% CI: 95% confidence interval

[b] The median number of physical activities per week was divided into two.

[c] Whether there was ST just before bedtime.

Table 5
Characteristics of the children in the physical activity group

		Weekly physical activities[d]					
Item			High		Low		
Age, mean (SE)			8.95	(0.027)	9.2	(0.031)	
		N	n	%	n	%	P-value[a]
Gender	Boys	3619	2161	59.7	1458	40.3	< 0.001
	Girls	3429	1605	46.8	1824	53.2	
School year	1	1393	756	54.3	637	45.7	< 0.001
	2	1283	723	56.4	560	43.6	
	3	1218	705	57.9	513	42.1	
	4	1180	670	56.8	510	43.2	
	5	1111	560	50.4	551	49.6	
	6	863	352	40.8	511	59.2	
Height[b]	higher than median	3538	1844	52.1	1694	47.9	0.026
	lower than median	3510	1922	54.8	1588	45.2	
Weight[c]	higher than median	3608	1853	51.4	1755	48.6	< 0.001
	lower than median	3440	1913	55.6	1527	44.4	

[a] Chi-square test. [b] The median height was divided into tall and short.

[c] The median weight was divided into heavy and light.

[d] The median number of physical activities per week was divided into two.

Table 6
Characteristics of children with dry eyes

Dry eyes							
Item			Not dry		Dry		
Age, mean(SE)			8.98	(0.023)	9.44	(0.048)	
		N	n	%	N	%	P-value[a]
Gender	Boys	3611	2921	80.9	690	19.1	0.25
	Girls	3430	2811	82.0	619	18.0	
School year	1	1385	1208	87.2	177	12.8	< 0.001
	2	1280	1073	83.8	207	16.2	
	3	1219	1007	82.6	212	17.4	
	4	1179	934	79.2	245	20.8	
	5	1114	870	78.1	244	21.9	
	6	864	640	74.1	224	25.9	
Height[b]	higher than median	3537	2758	78.0	779	22.0	< 0.001
	lower than median	3504	2974	84.9	530	15.1	
Weight[c]	higher than median	3609	2837	78.6	772	21.4	< 0.001
	lower than median	3432	2895	84.4	537	15.6	

[a] Chi-square test. [b] The median height was divided into tall and short.

[c] The median weight was divided into heavy and light.

Table 7
Characteristics of the children in learning ability group

		Class						Performance					
Item			Understand		Do not understand				Good		Poor		
Age, mean(SE)			9.08	(0.021)	8.71	(0.103)			9.03	(0.022)	9.26	(0.053)	
		N	n	%	N	%	P-value[a]	N	n	%	N	%	P-value[a]
Gender	Boys	3594	3414	95.0	180	5.0	0.009	3623	2962	81.8	601	16.6	0.001
	Girls	3432	3304	96.3	128	3.7		3438	3022	87.9	476	13.8	
School year	1	1389	1305	94.0	84	6.0	0.017	1394	1226	87.9	168	12.1	< 0.001
	2	1273	1213	95.3	60	4.7		1288	1109	86.1	179	13.9	
	3	1218	1171	96.1	48	3.9		1223	1052	86.0	171	14.0	
	4	1174	1132	96.4	42	3.6		1182	976	82.6	206	17.4	
	5	1114	1070	96.1	44	3.9		1113	909	81.7	204	18.3	
	6	858	827	96.4	31	3.6		861	712	82.7	149	17.3	
Height[b]	higher than median	3523	3394	96.3	129	3.7	0.003	3539	2972	84.0	567	16.0	0.072
	lower than median	3505	3324	94.8	179	5.1		3522	3012	85.5	510	14.5	
Weight[c]	higher than median	3597	3456	96.1	141	3.9	0.052	3614	3018	83.5	596	16.5	0.003
	lower than median	3429	3262	95.1	167	4.9		3447	2966	86.0	481	14.0	

[a] Chi-square test.

[b] The median height was divided into tall and short.

[c] The median weight was divided into heavy and light.

Table 8
Results of the combination of ST duration and timing

	BMI percentiles	Rohrer index	Weekly physical activities[b]	Dry eyes	Class	Performance
	OR[a]	OR[a]	OR[a]	OR[a]	OR[a]	OR[a]
	95%CI	95%CI	95%CI	95%CI	95%CI	95%CI
G1[c] × G2[c]	0.73	0.64	1.09	1.04	1.59	1.85**
	0.47–1.12	0.40–1.05	0.81–1.48	0.72–1.49	0.88–2.87	1.26–2.72
G3[C] × G4[C]	0.72**	0.76*	1.09	1.36***	1.37	1.53***
	0.57–0.90	0.60–0.97	0.95–1.25	1.14–1.63	0.97–1.93	1.26–1.85
G5[C] × G6[C]	1.05	0.73	0.99	1.38*	1.41	1.42*
	0.71–1.56	0.49–1.09	0.81–1.20	1.08–1.77	0.78–2.56	1.05–1.91

***p < 0.001,**p < 0.01□*p < 0.05

[a]OR: odds ratio, 95% CI: 95% confidence interval

[d]The median number of physical activities per week was divided into two.

[c]Divided into G1 to G6 based on the combination of ST duration and timing (Please refer to Table 2).