Psychiatry Research 273 (2019) 456–460

Contents lists available at ScienceDirect

Psychiatry Research

journal homepage: www.elsevier.com/locate/psychres

Interactive effect of sleep duration and physical activity on anxiety/depression in adolescents

Sayoko Ogawa[a], Yuko Kitagawa[a,b,c], Masako Fukushima[d], Hiromi Yonehara[d], Atsushi Nishida[e], Fumiharu Togo[a], Tsukasa Sasaki[a,*]

[a] The University of Tokyo, Graduate School of Education, Department of Physical and Health Education, 7-3-1 Hongo, Bunkyo, Tokyo 113-0033, Japan
[b] Department of Neuropsychiatry, Teikyo University School of Medicine, 2-11-1 Kaga, Itabashi, Tokyo 173-0003, Japan
[c] Japan Society for the Promotion of Science, 5-3-1, Koujimachi, Chiyoda-ku, Tokyo 102-0083, Japan
[d] The University of Tokyo Secondary School attached to the Faculty of Education, Nakano-ku, 1-15-1 Minamidai, Tokyo 1648654, Japan
[e] Tokyo Metropolitan Institute of Medical Science, Department of Psychiatry and Behavioral Science, Setagaya-ku, 2-1-6 Kamikitawaza, Tokyo 1568506, Japan

ARTICLE INFO

Keywords:
Adolescents
Sleep duration
Physical activity
Anxiety/depression
Interactive effect

ABSTRACT

Although effects of sleep duration and physical activity (PA) have been demonstrated on mental health in adolescents, their interactive effect has not been studied. This cross-sectional study first examines this interactive effect on anxiety/depression in adolescents. A total of 983 Japanese students aged 12—17 were studied, using a self-report questionnaire. The interaction of sleep duration and amount of PA and their main effects on anxiety/depression, assessed using the 12-item General Health Questionnaire (GHQ-12), were investigated employing multiple regression, adjusting for grade and sex. Sleep duration and amount of PA were classified as being adequate or not, according to the duration and amount recommended by the National Sleep Foundation and World Health Organization, respectively. As a result, the interaction between sleep duration and amount of PA and their main effects were statistically significant. GHQ-12 score was significantly better in adolescents with either adequate sleep or adequate PA, not both, than those with neither adequate sleep nor adequate PA. The score, however, seemed no further improved in those with both adequate sleep and PA. The present study suggests that effects of sleep and PA on mental health need to be studied with consideration to their interaction.

1. Introduction

A number of studies have shown that sleep may be associated with mental health in adolescents (Bauducco et al., 2016; Raniti et al., 2017; Roberts and Duong, 2014; Sivertsen et al., 2014; Stheneur et al., 2017; Winsler et al., 2015; Yen et al., 2010). In these studies, it was observed that adolescents who sleep less than the recommended hours are at an elevated risk of suffering from mental disorders (Bauducco et al., 2016; Roberts and Duong, 2014; Winsler et al., 2015; Yen et al., 2010). For example, studies showed that adolescents who were sleeping less than 8.5 h/day in boys and less than 7.5 h/day in girls had elevated scores for depression/anxiety symptoms (Ojio et al., 2016). A study in monozygotic twins also showed that bedtime and sleep duration may be significantly related to the score of GHQ after adjusting for genetic factors (Matamura et al., 2014). However, sleep duration might have become shorter than required in a substantial portion of adolescents (Matricciani et al., 2012), which could have elevated their risk of poor mental health. For example, a survey in the USA showed that average weekday sleep duration was less than the recommended duration (8–10 h) (National Sleep Foundation, 2018) in 68% of adolescents aged 14–17 (Wheaton et al., 2016).

Effects of physical activity (PA) on mental health have also been observed in adolescents. Several studies have observed a significant association between PA (or sport participation) and lower anxiety/depression in adolescents (Kantomaa et al., 2008; Kremer et al., 2014; McDowell et al., 2017; McMahon et al., 2017; Norris et al., 1992; Sabiston et al., 2013; Sigfusdottir et al., 2011; Sund et al., 2011; Wiles et al., 2012). Meta-analysis also found a significant effect of PA on the improvement of depressive symptoms in normal adolescents (Ahn and Fedewa, 2011; Bailey et al., 2018; Carter et al., 2016; Larun et al., 2006; Radovic et al., 2017) . Another study observed an association between sport participation at age 12 and positive mental health outcomes in adulthood (Appelqvist-Schmidlechner et al., 2017).

As described above, sleep and PA were considered major factors

* Corresponding author.
E-mail addresses: s-ogawa@p.u-tokyo.ac.jp (S. Ogawa), yk@p.u-tokyo.ac.jp (Y. Kitagawa), masako@hs.p.u-tokyo.ac.jp (M. Fukushima), hiromi@hs.p.u-tokyo.ac.jp (H. Yonehara), nishida-at@igakuken.or.jp (A. Nishida), tougou@p.u-tokyo.ac.jp (F. Togo), sasaki@p.u-tokyo.ac.jp (T. Sasaki).

https://doi.org/10.1016/j.psychres.2018.12.085
Received 27 April 2018; Received in revised form 27 November 2018; Accepted 16 December 2018
Available online 18 December 2018
0165-1781/

affecting mental health in adolescence. However, although several studies have shown the main effects of sleep duration and amount of PA, their interactive effect remains to be studied; whether the effect of PA is at a similar level when sleep duration is adequate or not, and vice versa, seems not to have been studied. While a study has examined the interactive effect of amounts of sleep and PA on mortality risk in elderly people (Bellavia et al., 2014), to our knowledge, no study has investigated the interactive effect on mental health. The present study therefore first examines the interactive effect of daily sleep duration and amount of PA on anxiety/depression in adolescents. School-based cross-sectional data is analyzed. In addition to the interaction, the main effects of sleep duration and PA are also examined, controlling for each, in a simultaneous analysis, which might also require further study.

2. Methods

2.1. Participants

The subjects were grade 7–11 students (aged 12–17 y) of a unified junior (grades 7–9) and senior (grades 10–12) high school in Tokyo. A school–based longitudinal survey has been conducted annually in this school since 2009. The number of the students was around 120 (60 boys and 60 girls) per grade or approximately 720 in grades 7–12 in this school. All of them were invited to take part in the survey. In the present study, we used data from the 2011 and 2016 surveys. Although the school has six grades (grades 7–12), the 12th grade students were excluded from the present study, because at the beginning of the final grade, they would normally retire from their extracurricular activities and start preparation for entrance exams for universities and other schools in Japan. None of the students in grades 7–11 overlapped in the two surveys (2011 and 2016). The number of grade 7–11 students was 599 at the time of both surveys in 2011 and 2016, with a total of 1198 students. In 2011, 593 of the 599 participated in the survey (participation rate = 98.9%). In the 2016 survey, 592 of the 599 participated (participation rate = 98.8%). Thus, 1185 students out of 1198 participated in the surveys (participation rate = 98.9%). In the analysis, we excluded students who stated that they slept <2 h ($n = 5$) because the reliability of this response was considered questionable. We also excluded students whose answer was >10 h (or longer than the sleep duration recommended by the National Sleep Foundation, $n = 31$), because the present study was to compare adolescents with adequate (or recommended) sleep duration and those with less sleep duration. Excluding subjects with missing data ($n = 166$), in total 983 adolescents were statistically analyzed.

2.2. Procedure

The surveys were conducted using a self-report questionnaire. The questionnaires and envelopes were handed to the students by their teachers at school. The students were asked to seal the completed questionnaires in the envelopes provided. Research staff collected the sealed questionnaires. Before the survey, the teachers explained to the students and their parents that: (1) participation was anonymous and voluntary; (2) strict confidentiality would be maintained. A written document was used for the explanation to the parents. Ethical approval was given by the Life Science Committee of the University of Tokyo (#15–128) and the ethics committee of the Research Department of the school.

2.3. Measurement

2.3.1. Sleep duration

To estimate sleep duration, we used the following question: “How long on average do you sleep at night before school days?” Participants stated the sleep duration in hours and minutes. In the analyses, students who indicated that they slept 8—10 h/day on school nights were defined as being “with adequate sleep duration”, and those who slept <8 h were defined as being “without adequate sleep duration”, in accordance with the recommended sleep duration for this age (8—10 h/night) of the National Sleep Foundation (NSF, 2018). Students who stated that they slept <2 h ($n = 5$) or >10 h ($n = 31$) were excluded from the analysis, as mentioned in Section 2.1 *Participants*.

2.3.2. Physical activity

In Japanese junior and senior high schools, most students participate in extracurricular activities in their schools, as is the case in the school under consideration. Few students participate in regional, community or church/religion-related club activities, compared with school club activities in Japan. The rate of students who participate in club activities, including sports clubs, out-of-school was 1—2% in the school in question. The club activities in schools are generally divided into two categories: sports clubs and culture clubs. As examples, in sports clubs, students engage in football, basketball, tennis, baseball, athletics, swimming et cetera, and in cultural clubs they practice music, fine art, drama, science, biology, photography, cooking et cetera. Sports club activities were on 3—4 weekdays/week and almost 1 day/week on the weekend in the school in question. The length of the activity was 2—2.5 h on weekdays and 3—4 h on weekends. In addition to the club activities, 50 min of physical education is given to all students 3 times a week at the school in question. Therefore, when the students participated in a sports club fully or half of the time, they experienced moderate to vigorous physical activity for more than 1 h almost every day on average. The amount of PA was considered to be generally equal to the recommended PA for adolescents by the World Health Organization (WHO, 2018). In contrast, when the students did not belong to or rarely participated in sports club activities at school, the amount of PA was considered to be less than the amount recommended for this age (WHO, 2018). Japanese adolescents/children rarely undertake chores requiring moderate to high PA at home, according to the Japanese government statistics (Cabinet office, Government of Japan, 2018). Therefore, we estimated PA in the students by using the level of participation in sports club activities at school. The participants were asked how often they took part in the sports club activities at school and selected one of five possible responses: “always”, “often”, “about half the time”, “rarely” or “never”. Students who answered “always” “often” or “about half the time” were categorized as being "with adequate PA", and those who answered “rarely” or “never” were categorized as being "without adequate PA".

2.3.3. Anxiety and depressive symptoms

The General Health Questionnaire-12 (GHQ-12) consists of 12 items evaluating anxiety and depressive symptoms in the previous 1 month, evaluating the extent of anxiety and depression in not only clinical but normal subjects. The validity and reliability of the Japanese version of the GHQ-12 have been confirmed (Doi and Minowa, 2003). Each item is rated on a four-point scale (“often”, “sometimes”, “seldom”, “never”). This study used bi-modal scoring, according to Goldberg's original scoring method (Goldberg and Williams, 1988). In this scoring method, “often” and “sometimes” were scored 1, and “seldom” and “never” were scored 0. The total score ranged from 0 to 12. A higher score represents more symptoms of anxiety/depression. This scoring may be less vulnerable to biases (Goldberg and Williams, 1988) and better in validity testing for GHQ-12 (Goldberg et al., 1997) than Likert scoring.

2.3.4. Statistical analysis

We used the data of grade 7–11 students from the 2011 and 2016 surveys. No students were overlapping, and variances of sleep duration, GHQ-12 score and physical activity were not significantly different between the two data sets (sleep duration; $t = -0.497$, $df = 1164$, $p = 0.62$, GHQ-12 score; $t = 0.975$, $df = 1165$, $p = 0.33$; physical activity; $t = -0.526$, $df = 1049$, $p = 0.59$, respectively). Therefore, we pooled the two data sets and analyzed them together. The effects of

Table 1
Amount of physical activity (PA), sleep duration and GHQ-12 score in junior and senior high school students (n = 983).

School grade	Number (%) of students					Sleep duration (min)		GHQ-12 score	
	Total	With adequate PA		With adequate sleep[a]		Mean	SD	Mean	SD
7	214	111	51.9%	105	49.1%	459.5	53.4	1.68	2.2
8	205	126	61.5%	66	32.2%	432.6	71.5	2.39	2.5
9	208	121	58.2%	44	21.2%	416.4	61.5	1.97	2.4
10	173	79	45.7%	18	10.4%	397.2	57.8	3.42	3.3
11	183	97	53.0%	16	8.7%	391.2	64.0	3.10	2.9
Sex									
boys	488	331	67.8%	152	31.1%	429.6	67.2	2.01	2.5
girls	495	203	41.0%	97	19.6%	412.7	65.0	2.90	2.9

[a] 8—10 h.

sleep duration, PA and their interactive effect on GHQ-12 score were examined using multiple regression, controlling for grade and sex. In the analyses, sleep duration and amount of PA were dichotomized according to the sleep duration and amount of PA for this age recommended by the NSF (2018) and WHO (2018), respectively, as described in 2.3.1. and 2.3.2. Being without adequate sleep duration and without adequate PA were set as the reference (or = 0). All analyses were conducted using SPSS (ver.25, IBM, New York). The level of significance (alpha) was set at 0.05 (two-sided).

3. Results

Table 1 summarizes sleep duration, GHQ-12 score and PA level by grade and sex. Duration of sleep was significantly longer in boys (mean = 430 min) than girls (mean = 413 min, $p < 0.001$). GHQ-12 score was significantly higher in girls (mean = 2.90) than in boys (mean = 2.01, $p < 0.001$).

Table 2 summarizes average sleep durations and GHQ-12 scores in adolescents with/without adequate sleep duration and with/without adequate PA. Sleep duration was not significantly different between adolescents with and without adequate PA, either in adolescents with or without adequate sleep duration. GHQ-12 score in adolescents without adequate sleep duration and PA was significantly higher, compared with those without adequate sleep duration and with adequate PA ($p < 0.001$), those with adequate sleep duration and without adequate PA ($p < 0.001$) and those with adequate sleep duration and adequate PA ($p < 0.001$). Meanwhile, GHQ score was not significantly different between adolescents without adequate sleep duration and with adequate PA, those with adequate sleep duration and without adequate PA, and those with adequate sleep duration and adequate PA.

Multiple regression was conducted to test main effects of sleep duration and PA, and their interactive effect on anxiety/depression, controlling for sex and grade (summarized in Table 3). No multicollinearity among independent variables was observed according to the variance inflation factor (VIF < 5) and the tolerance score (tolerance > 0.20). Partial regression coefficients were statistically significant for main effects of PA ($B = -0.841$, $p < 0.001$) and sleep duration ($B = -0.889$, $p < 0.01$), and their interaction ($B = 1.022$, $p < 0.01$). The intercept was 1.669 ($p < 0.001$). These estimations of the partial regression coefficients suggest that among adolescents with neither adequate sleep nor PA, the mean GHQ-12 score, excluding the effect of sex and grade, was point estimated at 1.67 (=intercept), since being without adequate sleep (<8 h) and without adequate PA were set as the reference (or = 0). When one, not both, of them was adequate, the score was point estimated at 0.83 (=1.669 − 0.841) in those without adequate sleep/with adequate PA and 0.78 (=1.669 − 0.889) in those with adequate sleep/without adequate PA, respectively. The GHQ-12 score was estimated at 0.96 (=1.669 − 0.889 − 0.841 + 1.022) in those with both adequate sleep and PA.

Table 3
Effects of sleep duration and physical activity and their interaction on anxiety/depressive symptoms: analyses using multiple regression.

	B	(SE)	p value
Intercept	1.669	(0.28)	0.000
Sex	0.672	(0.17)	0.000
Grade	0.336	(0.06)	0.000
Sleep duration	−0.889	(0.31)	0.004
Physical activity	−0.841	(0.20)	0.000
Interaction PA × sleep duration	1.022	(0.39)	0.009

B: Partial regression coefficient, SE: Standard error.

Fig. 1 shows lines of simple-regression between sleep duration and GHQ-12 score, stratified by sex and PA. Regression coefficients (standard errors) were −0.24/h (0.12) and −0.60/h (0.18) for boys with and without adequate PA, and −0.48/h (0.18) and −0.66/h (0.18) for girls with and without adequate PA, respectively. A statistical trend was observed for a difference in the regression coefficients between boys with and without adequate PA ($p < 0.1$). However, no trend for this difference was observed in girls.

4. Discussion

This study first examined the interaction of daily sleep duration and amount of PA on anxiety/depression in adolescents, aged 12–17. Main effects of sleep duration and PA, after controlling for each, were also studied in the same analysis. The main effects were statistically significant with positive impacts on anxiety/depression, which may be consistent with a number of previous studies, most of which investigated the two main effects separately (Bauducco et al., 2016;

Table 2
Mean and standard deviation (SD) of sleep duration and GHQ-12 score in groups with or without adequate PA and sleep duration.

		Without adequate PA		With adequate PA	
Without adequate sleep duration (≥2 h and <8 h)	Sleep duration (min)	391.2	(54.8)	396.8	(50.1)
	GHQ-12 score	3.21	(3.0)***	2.16	(2.5)
With adequate sleep duration (≥8 h and ≤10 h)	Sleep duration (min)	500.8	(31.7)	500.5	(30.7)
	GHQ-12 score	1.83	(2.4)	1.87	(2.4)

*** $p < 0.001$, compared with adolescents without adequate sleep and with adequate PA, those with adequate sleep and without adequate PA, and those with adequate sleep and adequate PA.

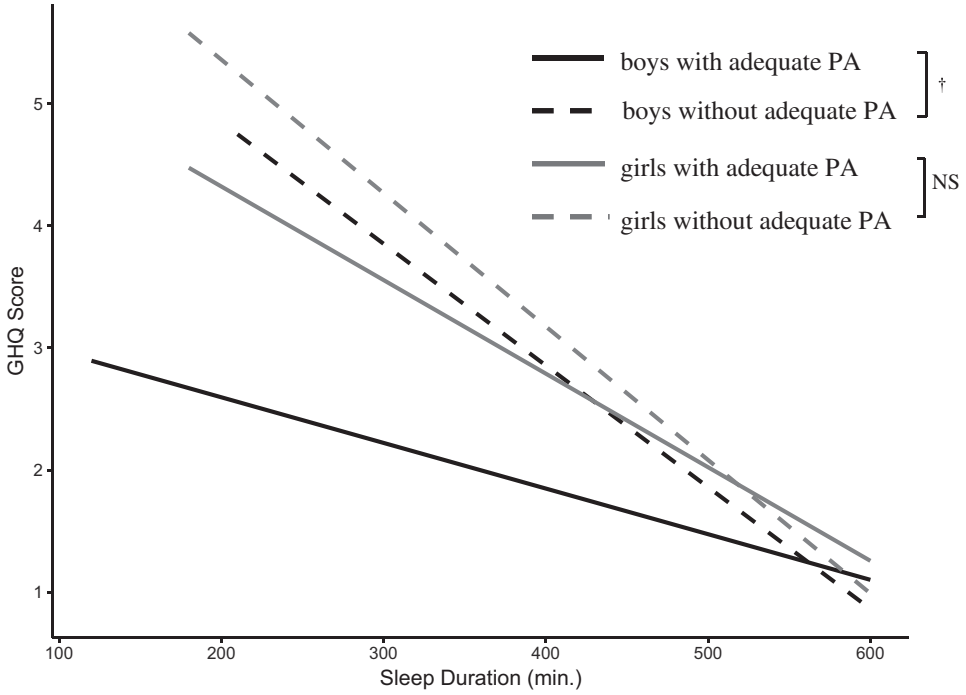

Fig. 1. Relationship between sleep duration and GHQ-12 score by sex and the amount of physical activity
Students with sleep durations <2 h or >10 h are not included.
NS: Non-significant, $^{\dagger}p < 0.1$; comparison of regression coefficients between subjects with and without adequate PA.

Kantomaa et al., 2008; Kremer et al., 2014; Matamura et al., 2014; McDowell et al., 2017; McMahon et al., 2017; Norris et al., 1992; Ojio et al., 2016; Raniti et al., 2017; Roberts and Duong, 2014; Sabiston et al., 2013; Sigfusdottir et al., 2011; Sivertsen et al., 2014; Stheneur et al., 2017; Sund et al., 2011; Wheaton et al., 2016; Wiles et al., 2012; Winsler et al., 2015; Yen et al., 2010). The effect of interaction was also statistically significant, with a similar size but in the opposite (or negative) direction to the main effects of sleep duration and PA. This means that anxiety/depression in adolescents with both adequate sleep and adequate PA may be at a similar level to that of adolescents with only one of these.

The reason for the negative impact of the interaction is not clear, with few previous studies on the interaction of sleep and PA. It might, however, be speculated as follows: one of the two conditions, "adequate PA" or "adequate sleep duration", in the present study might be sufficient to maintain mental health at a substantially positive level, with little room for improvement. This may in turn result in few effects of adding the other condition. "Adequate sleep duration" was defined as 8–10 h/night in the present study, according to the recommendation for this age by the NSF (Bauducco et al., 2016; NFS 2018). "Adequate PA" was defined as equivalent to 1 h/day or more of moderate to vigorous physical activity, which is recommended by the WHO (2018) for this age. It should also be noted that the present subjects were adolescents who regularly attend an ordinary school, and a very small portion of them, if any at all, might be expected to be clinical samples. For such normal adolescents, adequate sleep duration or adequate PA defined in the present study, not both, might be sufficient to maintain good mental health by itself. Regarding the effect of PA, another explanation could be that adequate PA improves objective quality of sleep, including increased deep sleep and decreased light sleep (Brand et al., 2010; Kalak et al., 2012; Lang et al., 2013), which might cover any negative effect of a shorter bedtime. The effect of adequate PA also seems to improve subjective sleep quality (Brand et al., 2017).

Another possibility is that the limited range of the GHQ-12 score is related to the result. GHQ-12 has its range of 0–12 (lower score for less anxiety/depression, with the cut-off at 3/4), where the mean score of GHQ-12, excluding the effect of sex and school grade, was estimated to be 1.67 in adolescents without adequate sleep duration and PA. Little room for improvement in the score may have affected the result. Use of scales with greater room for improvement, including scales for well-being, might lead to different results with the interaction.

The following limitations should be acknowledged. First, we evaluated PA according to participation in sports club activities. However, this measurement may well correspond, in the Japanese grade 7–11 students, to whether the amount of PA reaches the level recommended by WHO (2018). A previous Japanese study in adolescents observed the positive effect of fully participating in school sports club activities on mental health (Hyakutake et al., 2016). However, use of established objective measurements such as metabolic equivalents (METs) may be recommended in studies to confirm the present results. Second, sleep duration was self-reported, not using objective measures. Third, quality of sleep, such as efficiency, latency of onset and regularity of sleep, was not evaluated. Fourth, use of scales other than the GHQ-12, including scales for well-being, might have led to different results with the interaction. Finally, the present study raised the possibility of a sex difference in the interactive effect between sleep duration and PA, but this remains open to future study in larger samples. A statistical trend was observed for a difference in univariate regression coefficients between sleep duration and anxiety/depression in boys, while no such trend was observed in girls. However, further analyses by sex, including multiple regression, was not conducted, due to the limited sample size.

In conclusion, the present study first examined and observed a significant interaction between sleep duration and PA in their effect on anxiety/depression (or mental health). Future studies are required to examine the effects of sleep and PA on mental health, not in separate but simultaneous analyses, with consideration of their interaction.

Declaration of interest

None.

Acknowledgment

We would like to give special thanks to all the junior and senior high school students who participated in the survey, and to all the teachers who supported the data collection. We would also like to express appreciation to Asuka Nishida for advice on the manuscript.

Funding

This work was supported by the Japan Society for Promotion of Science, [grant number 15H03083]. All the authors declare that they have no conflicts of interest with regards to the present report.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.psychres.2018.12.085.

References

Ahn, S., Fedewa, A.L., 2011. A meta-analysis of the relationship between children's physical activity and mental health. J. Pediatr. Psychol. 36, 385–397. https://doi.org/10.1093/jpepsy/jsq107.

Appelqvist-Schmidlechner, K., Vaara, J., Häkkinen, A., Vasankari, T., Mäkinen, J., Mäntysaari, M., et al., 2017. Relationships between youth sports participation and mental health in young adulthood among Finnish males. Am. J. Health Promot AJHP 890117117746336. https://doi.org/10.1177/0890117117746336.

Bailey, A.P., Hetrick, S.E., Rosenbaum, S., Purcell, R., Parker, A.G., 2018. Treating depression with physical activity in adolescents and young adults: a systematic review and meta-analysis of randomised controlled trials. Psychol. Med. 48 (7), 1068–1083. https://doi.org/10.1017/S0033291717002653.

Bauducco, S.V., Flink, I.K., Jansson-Fröjmark, M., Linton, S.J., 2016. Sleep duration and patterns in adolescents: correlates and the role of daily stressors. Sleep Health 2, 211–218. https://doi.org/10.1016/j.sleh.2016.05.006.

Bellavia, A., Åkerstedt, T., Bottai, M., Wolk, A., Orsini, N., 2014. Sleep duration and survival percentiles across categories of physical activity. Am. J. Epidemiol. 179, 484–491. https://doi.org/10.1093/aje/kwt280.

Brand, S., Gerber, M., Beck, J., Hatzinger, M., Pühse, U., Holsboer-Trachsler, E., 2010. Exercising, sleep-EEG patterns, and psychological functioning are related among adolescents. World J. Biol. Psychiatry 11, 129–140. https://doi.org/10.3109/15622970903522501.

Brand, S., Kalak, N., Gerber, M., Clough, P.J., Lemola, S., Sadeghi Bahmani, D., et al., 2017. During early to mid adolescence, moderate to vigorous physical activity is associated with restoring sleep, psychological functioning, mental toughness and male gender. J. Sports Sci. 35, 426–434. https://doi.org/10.1080/02640414.2016.1167936.

Cabinet office, Government of Japan, 2018. Kodomo to kazoku ni kansuru kokusaihikakucho-sa (gaiyo)-figure 3 [WWW Document]. URL. http://www8.cao.go.jp/youth/kenkyu/kodomo/images/zu03.html (accessed 2.6.18).

Carter, T., Morres, I.D., Meade, O., Callaghan, P., 2016. The effect of exercise on depressive symptoms in adolescents: a systematic review and meta-analysis. J. Am. Acad. Child Adolesc. Psychiatry 55, 580–590. https://doi.org/10.1016/j.jaac.2016.04.016.

Doi, Y., Minowa, M., 2003. Factor structure of the 12-item General Health Questionnaire in the Japanese general adult population. Psychiatry Clin. Neurosci. 57, 379–383. https://doi.org/10.1046/j.1440-1819.2003.01135.x.

Goldberg, D.P., Gater, R., Sartorius, N., Ustun, T.B., Piccinelli, M., Gureje, O., et al., 1997. The validity of two versions of the GHQ in the WHO study of mental illness in general health care. Psychol. Med. 27, 191–197. https://doi.org/10.1017/S0033291796004242.

Goldberg, D.P., Williams, P., 1988. A User's Guide to the General Health Questionnaire. NFER-Nelson, Windsor, Berks 1988.

Hyakutake, A., Kamijo, T., Misawa, Y., Washizuka, S., Inaba, Y., Tsukahara, T., et al., 2016. Cross-sectional observation of the relationship of depressive symptoms with lifestyles and parents' status among Japanese junior high school students. Environ. Health Prev. Med. 21, 265–273. https://doi.org/10.1007/s12199-016-0522-6.

Kalak, N., Gerber, M., Kirov, R., Mikoteit, T., Yordanova, J., Pühse, U., et al., 2012. Daily morning running for 3 weeks improved sleep and psychological functioning in healthy adolescents compared with controls. J. Adolesc. Health Off. Publ. Soc. Adolesc. Med. 51, 615–622. https://doi.org/10.1016/j.jadohealth.2012.02.020.

Kantomaa, M.T., Tammelin, T.H., Ebeling, H.E., Taanila, A.M., 2008. Emotional and behavioral problems in relation to physical activity in youth. Med. Sci. Sports Exerc. 40, 1749–1756. https://doi.org/10.1249/MSS.0b013e31817b8e82.

Kremer, P., Elshaug, C., Leslie, E., Toumbourou, J.W., Patton, G.C., Williams, J., 2014. Physical activity, leisure-time screen use and depression among children and young adolescents. J. Sci. Med. Sport 17, 183–187. https://doi.org/10.1016/j.jsams.2013.03.012.

Lang, C., Brand, S., Feldmeth, A.K., Holsboer-Trachsler, E., Pühse, U., Gerber, M., 2013. Increased self-reported and objectively assessed physical activity predict sleep quality among adolescents. Physiol. Behav. 120, 46–53. https://doi.org/10.1016/j.physbeh.2013.07.001.

Larun, L., Nordheim, L.V., Ekeland, E., Hagen, K.B., Heian, F., 2006. Exercise in prevention and treatment of anxiety and depression among children and young people. Cochrane Database Syst. Rev. 3, 2006, CD004691, 10.1002/14651858.CD004691.pub2.

Matamura, M., Tochigi, M., Usami, S., Yonehara, H., Fukushima, M., Nishida, A., et al., 2014. Associations between sleep habits and mental health status and suicidality in a longitudinal survey of monozygotic twin adolescents. J. Sleep Res. 23, 290–294. https://doi.org/10.1111/jsr.12127.

Matricciani, L., Olds, T., Petkov, J., 2012. In search of lost sleep: secular trends in the sleep time of school-aged children and adolescents. Sleep Med. Rev. 16, 203–211. https://doi.org/10.1016/j.smrv.2011.03.005.

McDowell, C.P., MacDonncha, C., Herring, M.P., 2017. Brief report: associations of physical activity with anxiety and depression symptoms and status among adolescents. J. Adolesc. 55, 1–4. https://doi.org/10.1016/j.adolescence.2016.12.004.

McMahon, E.M., Corcoran, P., O'Regan, G., Keeley, H., Cannon, M., Carli, V., et al., 2017. Physical activity in European adolescents and associations with anxiety, depression and well-being. Eur. Child Adolesc. Psychiatry 26, 111–122. https://doi.org/10.1007/s00787-016-0875-9.

National Sleep Foundation, 2018. Teens and sleep [WWW Document]. URL. https://sleepfoundation.org/sleep-topics/teens-and-sleep (accessed 2.6.18).

Norris, R., Carroll, D., Cochrane, R., 1992. The effects of physical activity and exercise training on psychological stress and well-being in an adolescent population. J. Psychosom. Res. 36, 55–65. https://doi.org/10.1016/0022-3999(92)90114-H.

Ojio, Y., Nishida, A., Shimodera, S., Togo, F., Sasaki, T., 2016. Sleep duration associated with the lowest risk of depression/anxiety in adolescents. Sleep 39, 1555–1562. https://doi.org/10.5665/sleep.6020.

Radovic, S., Gordon, M.S., Melvin, G.A., 2017. Should we recommend exercise to adolescents with depressive symptoms? A meta-analysis. J. Paediatr. Child Health 53, 214–220. https://doi.org/10.1111/jpc.13426.

Raniti, M.B., Allen, N.B., Schwartz, O., Waloszek, J.M., Byrne, M.L., Woods, M.J., et al., 2017. Sleep duration and sleep quality: associations with depressive symptoms across adolescence. Behav. Sleep. Med. 15, 198–215. https://doi.org/10.1080/15402002.2015.1120198.

Roberts, R.E., Duong, H.T., 2014. The prospective association between sleep deprivation and depression among adolescents. Sleep 37, 239–244. https://doi.org/10.5665/sleep.3388.

Sabiston, C.M., O'Loughlin, E., Brunet, J., Chaiton, M., Low, N.C., Barnett, T., et al., 2013. Linking depression symptom trajectories in adolescence to physical activity and team sports participation in young adults. Prev. Med. 56, 95–98. https://doi.org/10.1016/j.ypmed.2012.11.013.

Sigfusdottir, I.D., Asgeirsdottir, B.B., Sigurdsson, J.F., Gudjonsson, G.H., 2011. Physical activity buffers the effects of family conflict on depressed mood: a study on adolescent girls and boys. J. Adolesc. 34, 895–902. https://doi.org/10.1016/j.adolescence.2011.01.003.

Sivertsen, B., Harvey, A.G., Lundervold, A.J., Hysing, M., 2014. Sleep problems and depression in adolescence: results from a large population-based study of Norwegian adolescents aged 16-18 years. Eur. Child Adolesc. Psychiatry 23, 681–689. https://doi.org/10.1007/s00787-013-0502-y.

Stheneur, C., Sznajder, M., Spiry, C., Marcu Marin, M., Ghout, I., Samb, P., et al., 2017. Sleep duration, quality of life and depression in adolescents: a school-based survey. Minerva Pediatr. https://doi.org/10.23736/S0026-4946.17.04818-6.

Sund, A.M., Larsson, B., Wichstrøm, L., 2011. Role of physical and sedentary activities in the development of depressive symptoms in early adolescence. Soc. Psychiatry Psychiatr. Epidemiol. 46, 431–441. https://doi.org/10.1007/s00127-010-0208-0.

Wheaton, A.G., Olsen, E.O., Miller, G.F., Croft, J.B., 2016. Sleep duration and injury-related risk behaviors among high school students–United States, 2007-2013. Morb. Mortal. Wkly. Rep. 65, 337–341. https://doi.org/10.15585/mmwr.mm6513a1.

WHO, 2018. Physical activity and young people [WWW Document]. WHO. URL. http://www.who.int/dietphysicalactivity/factsheet_young_people/en/ (accessed 2.6.18).

Wiles, N.J., Haase, A.M., Lawlor, D.A., Ness, A., Lewis, G., 2012. Physical activity and depression in adolescents: cross-sectional findings from the ALSPAC cohort. Soc. Psychiatry Psychiatr. Epidemiol. 47, 1023–1033. https://doi.org/10.1007/s00127-011-0422-4.

Winsler, A., Deutsch, A., Vorona, R.D., Payne, P.A., Szklo-Coxe, M., 2015. Sleepless in Fairfax: the difference one more hour of sleep can make for teen hopelessness, suicidal ideation, and substance use. J. Youth Adolesc. 44, 362–378. https://doi.org/10.1007/s10964-014-0170-3.

Yen, C.-F., King, B.H., Tang, T.-C., 2010. The association between short and long nocturnal sleep durations and risky behaviours and the moderating factors in Taiwanese adolescents. Psychiatry Res 179, 69–74. https://doi.org/10.1016/j.psychres.2009.02.016.