Preventive Medicine Reports 35 (2023) 102316

Contents lists available at ScienceDirect

Preventive Medicine Reports

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

Associations between sedentary behavior and health and the moderating role of physical activity in young people within a cross-sectional investigation

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ARTICLE INFO

Keywords:
Sedentary behavior
Physical activity
Health complaints
Self-rated health
Body mass index
Epidemiology
Youth
Moderating effect

ABSTRACT

The purpose of this study was to determine the influence of sedentary behavior (SB) on the frequency of health complaints (fHC) as well as on self-rated health (SRH) and body mass index (BMI), and to determine whether physical activity (PA) moderated this influence. Data were obtained from the Youth Survey Luxembourg 2019 (N = 2,802), a nationally representative stratified random sample of all youths aged 16 to 29 years who were living in Luxembourg. fHC is a composite measure of eight common psychosomatic health complaints, SRH was measured on a five-point scale, and BMI was calculated by dividing participants' body weight by the square of their body height (kg/m^2). PA and SB values were obtained from factor analyses of the relevant questionnaire items. SB was evaluated as both leisure-time SB and gaming-associated SB. Multiple regression analyses adjusted for age, sex, socioeconomic status, and migration status were used to determine the association between SB, fHC, BMI, and SRH. We found that leisure-time SB was positively associated with fHC, but not with SRH or BMI. Gaming-associated SB was positively associated with fHC and BMI but was negatively associated with SRH. PA was negatively associated with fHC, BMI and SRH. No statistically significant moderating effects were observed. We found that both leisure-time and gaming-associated SB showed statistically significant impacts on health. Although PA is known to be beneficial to health, we conclude that its potential to mitigate the negative effects of SB is limited in young people.

1. Introduction

Physical activity (PA) is known to have strongly positive effects on health. For example, increased PA has been found to decrease the risk of premature mortality and diabetes as well as the incidence of some cancer entities (Warburton and Bredin, 2017). However, there is a lack of knowledge regarding whether PA can mitigate the negative health impacts of sedentary behavior (SB) in young people (Chaput et al., 2020; Owen et al., 2010).

According to the definition from the World Health Organization (2020a) SB is to be understood as any waking behavior with an energy expenditure of <1.5 metabolic equivalents (MET), such as sitting in school or at work, leisure time, and various screen-based activities (e.g., playing videogames, watching TV, surfing the Internet, listening to music, or reading) (Chaput et al., 2020; Prince et al., 2020; Tremblay et al., 2017). Based on a review conducted by Pearson et al. (2014), SB shows only a weak inverse correlation with PA in children below the age of 11 years and adolescents aged 12 to 18 years. The literature to date emphasizes the importance of considering SB as an independent risk factor with regard to health and should not be equated to the health impacts of insufficient PA (van der Ploeg and Hillsdon, 2017).

The contemporary lifestyle of adolescents and young adults includes a vast amount of SB and often an insufficient amount of daily PA. According to the findings of the National Health and Nutrition

Abbreviations: ANOVA, analysis of variance; BMI, body mass index; fHC, frequency of health complaints; KMO, measure of sampling adequacy – Kaiser-Meyer-Olkin measure of sampling adequacy; PA, physical activity; SB, sedentary behavior; SD, standard deviation; SES, socioeconomic status; SRH, self-rated health; Tukey's HSD test, Tukey's honestly significant difference test; WHO, World Health Organization; YSL 2019, Youth Survey Luxembourg 2019.

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https://doi.org/10.1016/j.pmedr.2023.102316
Received 9 December 2022; Received in revised form 26 May 2023; Accepted 7 July 2023
Available online 8 July 2023

Examination Survey, on average, the daily SB in the US population increased between from 7.0 to 8.2 h and from 5.5 to 6.5 h between 2007 and 2016 for adolescents and adults, respectively (Yang et al., 2019). At the same time, according to a study pooling data from 1.6 million students within 146 countries, 81% of young people aged 11–17 do not meet the PA recommendations set forth by the World Health Organization (WHO) (i.e., at least 60 min of moderate-to-vigorous intensity daily physical activity) (Guthold et al., 2020).

SB is associated with moderate to severe physical and mental health issues in children and adolescents aged 5 to 18 years and in adults from age 18 years onwards (World Health Organization, 2020b), as well as with premature mortality (Ekelund et al., 2016). Moreover, increased SB is linked to poor physical fitness and poor cardiovascular, metabolic-, and bone health in children and adolescents (World Health Organization, 2020a; World Health Organization, 2020b). Watching TV, in particular, is associated with an increased risk of obesity in children between 5 and 19 years (Poorolajal et al., 2020). Older adults have a higher risk of developing various cancer entities, type 2 diabetes, cardiovascular diseases, and adiposity (Hamilton et al., 2014; Jochem et al., 2019; Tremblay et al., 2010; World Health Organization, 2020a). In both younger (3 to 19 years) and older populations (45 to 106 years), prolonged SB can lead to reduced self-rated health (SRH) (Rosenkranz et al., 2013; Zhang et al., 2020), an accurate prognostic indicator of objective health status, health-related quality of life, and longevity (Ge et al., 2019; Lorem et al., 2020; Riediger et al., 2019; Vie et al., 2019).

SB has been shown to differ according to sociodemographic characteristics (Mielke et al., 2017; Proper et al., 2007; Singh et al., 2008; Wallmann-Sperlich et al., 2013). Adults and males engage in SB more frequently than adolescents or females (Yang et al., 2019). While socioeconomically disadvantaged individuals show increased SB due to watching TV, socioeconomically advantaged individuals spend more time on computers (Liangruenrom et al., 2019; Mielke et al., 2017; Yang et al., 2019). The magnitude of SB has also been shown to differ according to participants' migration backgrounds (López-Valenciano et al., 2020; Taverno Ross et al., 2014; Williams et al., 2018). Therefore, we evaluated sociodemographic characteristics including age, gender, migration background, and socioeconomic status (SES).

Active children and adolescents aged 5 to 17 years show improved physical fitness, cognitive function, and physical and mental health throughout their lives (Chaput et al., 2020; Piercy et al., 2018). In addition, regular sports practice at an early age lowers the risk of chronic diseases later in life (Fernandes et al., 2015), extends the lifespan (Ekelund et al., 2016), leads to better SRH outcomes (Granger et al., 2017; Zhang et al., 2020), and regulates body mass index (BMI), thereby preventing overweight and obesity (Schmitz et al., 2000).

Although many studies have reported on the relationship between SB and various health outcomes, there is a lack of investigations examining whether PA has a moderating effect on associations between SB, fHC, SRH, and BMI, especially with regard to effects in youth (Chaput et al., 2020; Owen et al., 2010). Therefore, the purpose of this study is to determine the influence of SB and PA on fHC, SRH, and BMI. We hypothesize that higher levels of PA has beneficial effects, and higher levels of SB has negative effects with regard to fHC, SRH, and BMI. We explore the extent to which PA mitigates the effects of SB on fHC, SRH, and BMI.

2. Methods

2.1. Sample and procedure

The evaluated data were obtained from the Youth Survey Luxembourg 2019 (YSL 2019), a multi-thematic large-scale survey consisting of a stratified random sample of all youths between the ages of 16 and 29 years who were living in Luxembourg at the time of the survey (Sozio et al., 2020). The selected participants received a personal postal invitation to complete the online survey between 17 April 2019 and 5 August 2019. A total of 2,802 youths took part in the survey, which was available in five different languages: Luxembourgish, German, English, French, and Portuguese. Participation was voluntary, anonymous, and required parental consent from participants under the age of 18 years. The survey was approved by the ethics review panel of the University of Luxemburg (ERP 19–007) and was conducted in accordance with national and international guidelines with respect to ethical research conduct, including the protection of human subjects.

2.2. Measures and statistical analyses

Health complaints are predictors of psychosomatic health and include a number of symptoms of varying severity (Haugland and Wold, 2001). Previous studies have shown that fHC is a valid indicator of mental health (Gariepy et al., 2016) and can predict mental illness in adulthood (Kinnunen et al., 2010). fHC was assessed by asking how often the participants had experienced headaches, stomachaches, backaches, feeling "low," irritability, nervousness, sleeping difficulties, and dizziness over the past six months. The answer options were: "rarely or never = 0," "around once a month = 1," "around once a week = 2," "several times a week = 3," and "most days = 4." The answer items were added to all eight reported health complaints in order to generate a total metric score. The severity of fHC was rated according to the sum score of the aforementioned health complaints in order to represent overall psychosomatic diseases (ranging from 0 [low] to 32 [high]) (Haugland and Wold, 2001; Ravens-Sieberer et al., 2008).

SRH is a subjective and holistic assessment of health that reflects the severity of chronic diseases (Ge et al., 2019) and can prognosticate morbidity and mortality (Lorem et al., 2020; Riediger et al., 2019; Vie et al., 2019) as well as health in advanced age (Hetlevik et al., 2020). SRH is known to be associated with health behaviors (e.g., smoking, physical activity), social factors (e.g., with regard to family, peers, school, and work), and individual sociodemographic characteristics (e.g., age, gender, and wealth) (Vingilis et al., 2002). SRH was assessed by asking participants to estimate their own health as measured on a five-point Likert scale (1 = very good to 5 = very bad) (Kaplan and Camacho, 1983).

BMI is a commonly implemented measure used to classify the weight status of participants within epidemiologic surveys. High BMI is known to be a risk factor for various diseases, including high blood pressure, osteoarthritis, diabetes, some cancer entities, cardiovascular diseases, and premature mortality (World Health Organization, 2021). A *meta*-analysis of longitudinal studies demonstrated that obesity in childhood and adolescence increases the risk of obesity in adulthood by a factor of five (Simmonds et al., 2016). BMI was calculated according to the following formula: BMI = body weight [kg]/(body length [m])^2) (World Health Organization, 2021).

The data were analyzed using a factor analysis in order to generate SB and PA variables. The data for SB (leisure-time and gaming) and PA were found to be suitable based on factor analyses with regard to the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (KMO = 0.673).

To assess PA, the participants were first asked about how many of the past seven days they had spent a minimum of 60 min on activities that increased their heart rate or caused shortness of breath (answer options: one to seven days) (Prochaska et al., 2001). Second, the participants were asked how often they normally exercised during leisure time to the extent of sweating or being out of breath. The available answer options were as follows: "never," "less than once a month," "once a month," "once a week," "2–3 times a week," "4–6 times a week," or "every day" (Albert et al., 2010; Inchley et al., 2018). To build the PA variable, both question items were combined using factor analysis.

To measure SB, the YSL asked about two aspects of SB: leisure-time SB and SB in the form of gaming. The following five items were evaluated in the question used to construct the leisure-time SB variable, as follows: "How many days a week do you spend watching TV, surfing the

Internet, listening to music, chilling, and streaming TV or series?" For gaming, two items were asked: 1) "How many days do you play consoles or computer games?" and 2) "How often do you play on a smartphone, tablet, laptop, PC, mac, or console (e.g., PlayStation, Wii, Xbox)?" (Albert et al., 2010). Factor analysis revealed that the items loaded up on the respective factors as expected.

SES was determined based on the Family Affluence Scale (FAS, for participants who still live with their parents or do not have their own income), the participants' individual income (for participants who live alone, in a home, or with friends), or household income (for participants who live in their own household with their partner). The FAS score and both income variables were normalized on a scale ranging from 0 to 100 (CEPS/INSTEAD, 2014; Currie et al., 2008; Wasmer and Baumann, 2018).

To determine migration status, the participants were asked about their birthplace as well as the birthplace of their parents. "No migration background" indicated that the participant and both parents were born in Luxembourg. If at least one parent was not born in Luxembourg but the participant was born in Luxembourg, then the participants' migration background was designated as "second generation." Participants who immigrated by themselves regardless of where their parents were born were designated as "first generation" (Wasmer and Baumann, 2018).

Statistical analyses were performed using SPSS statistical software (version 26.0, Chicago, IL, USA). We calculated the descriptive characteristics of the study sample, with data presented as frequencies and percentages and/or as means and standard deviations (SD) as appropriate. Differences between groups were assessed using t-tests for independent samples or one-way ANOVA. *Post-hoc* tests were used to determine within-group differences using categorized variables.

The Tukey-HSD (honestly significant difference) *post-hoc* test was applied given an assumption of homogeneity of variances. The Games-Howell post-hoc test was used when the assumption of homogeneity of variances was violated. The assumption of homogeneity was tested using Levene's test. When the assumption of homogeneity was violated, we interpreted the robust Welch's F-correction instead of the ANOVA output.

Multiple regression models were used to assess the association of fHC, SRH, and BMI with PA and SB (leisure-time and gaming), adjusted for age, sex, SES, and migration status, considering all relevant assumptions (Field, 2018). Finally, the moderating effects of PA on the relationships between SB, fHC, BMI, and SRH were analyzed by examining the respective interaction terms using the PROCESS Model (version 3.5) (Hayes, 2022). Data were analyzed using pairwise deletion.

3. Results

Our data indicate that the majority of the enrolled participants were female (54.5%), and approximately 31.2% had no migration background (Table 1). The mean age of the enrolled participants was 22±4 years and the mean SES value was 42±29. The mean fHC was 8.9±6.1 and the average SRH was rated as 1.8±0.8. The mean BMI was 23.4±4.4 kg/m^2, corresponding to a normal weight.

As shown in Table 2, males reported statistically significantly fewer health complaints as well as better SRH as compared with females, whereas females had a lower BMI as compared with males. No statistically significant differences were detected with regard to migration status. *Post-hoc* pairwise comparisons showed that participants with low SES reported more frequent health complaints than the medium-and high-SES groups. In contrast, youth in the high-SES group showed better SRH and BMI values. Participants with a high amount of PA profited most in terms of fHC, SRH, and BMI in comparison with the other PA levels. Participants with low levels of leisure-time SB showed lower fHC values than those with a higher level of leisure-time SB. Moreover, BMI increased when participants reported high levels of SB during gaming.

Table 1
Descriptive characteristics of the study sample (Youth Survey Luxembourg 2019).

	Mean ± SD (min–max)	N (%)
Gender		2,802 (100)
Female		1,527 (54.5)
Male		1,275 (45.5)
Age (years)	22±4 (16–29)	2,509
Socioeconomic status	42±29 (0–100)	2,494
Migration status		2,516
No migration background		785 (31.2)
First generation		841 (33.4)
Second generation		890 (35.4)
Frequency of health complaints	8.9±6.1 (0–32)	2,587
Self-rated health	1.8±0.8 (1–5)	2,618
Body mass index (kg/m^2)	23.4±4.4 (14.4–46.8)	2,383

SD = standard deviation.

3.1. Main effects

Multiple regression analyses showed that higher leisure-time SB was associated with more severe fHC. No statistically significant associations were found between SRH, BMI, and leisure-time SB. An increase in gaming-associated SB was associated with worse fHC, SRH, and BMI values. However, higher PA was statistically significantly associated with improved values with regard to these metrics. While fHC values improved with increasing age, SRH and BMI progressively worsened. Females experienced worse fHC and SRH values, whereas males had a higher mean BMI. Moreover, low SES was shown to worsen fHC, SRH, and BMI, and first-generation migrants showed statistically significantly lower mean BMI values as compared with youth without a migration background (Table 3).

3.2. Moderating effect of physical activity

The interaction analysis showed that PA did not mitigate the effects of leisure-time and gaming-associated SB on fHC. PA also did not improve the effects of leisure-time and gaming-associated SB on SRH. No statistically significant interaction effects were found with respect to BMI (Table 3).

4. Discussion

The main aim of this study was to investigate the associations of SB and PA with fHC, SRH, and BMI, as well as whether PA can attenuate the negative impacts of SB in youth. Our results showed that leisure-time SB in young people was associated with more frequent psychosomatic complaints. Young people rated their health more poorly and demonstrated higher BMI values given higher levels of gaming-associated SB. Fewer psychosomatic complaints, a better assessment of self-rated health, and lower levels of BMI were observed in those reporting higher levels of PA (Table 3). The results of our moderation analysis suggested that PA does not mitigate the relationships between SB (leisure-time and gaming), fHC, SRH, and BMI in young people, though we cannot draw causal inferences within a cross-sectional investigation (Table 3).

Although PA is likely not able to directly mitigate and remove health issues caused by SB, the aforementioned results still magnify the importance of PA, which is associated with better fHC, SRH, and BMI metrics. Our research findings align with the current body of evidence that an increase in PA is beneficial to overall health and should therefore be considered clinically relevant with regard to preventing adverse health effects (Chaput et al., 2020; Ekelund et al., 2016; Schmitz et al., 2000; World Health Organization, 2020a; Zhang et al., 2020).

Both leisure-time and gaming SBs were found to be negatively associated with fHC. One approach to explain this outcome is that leisure-time and gaming SB, in addition to the various psychological and

Table 2
Descriptive statistics of health complaints, self-rated health, and body mass index according to sociodemographic characteristics (Youth Survey Luxembourg 2019).

	Health complaints	Self-rated health	Body mass index
	Mean ± SD (N)	Mean ± SD (N)	Mean ± SD (N)
Gender			
Female	10.2±6.2[a] (1,437)	1.9±0.8[a] (1,449)	23.1±4.6[a] (1,311)
Male	7.3±5.5[b] (1,150)	1.8±0.8[b] (1,169)	23.6±4.1[b] (1,072)
Migration status			
No migration background	9.0±6.0[a] (781)	1.8±0.7 [a] (785)	23.4±4.3[a] (747)
First generation	9.2±6.1[a] (837)	1.9±0.8 [a] (840)	23.6±4.7[a] (757)
Second generation	8.7±6.1[a] (878)	1.8±0.7 [a] (885)	23.1±4.1[a] (812)
Socioeconomic status			
Low	9.7±6.4*[a] (445)	1.9±0.8*[a] (456)	23.4±4.8*[a] (402)
Middle	8.8±6.1[b] (1,472)	1.9±0.7[a] (1,485)	23.6±4.5[a] (1,376)
High	8.7±5.6[b] (515)	1.7±0.7[b] (520)	22.5±3.8[b] (470)
Physical activity			
Quartile 1	9.9±6.2*[a] (622)	2.0±0.8*[a] (625)	24.1±5.2*[a] (566)
Quartile 2	9.1±5.8[a,b] (624)	1.9±0.7[b] (626)	23.3±4.4[b] (584)
Quartile 3	8.8±6.2[b,c] (624)	1.7±0.7[c] (625)	23.3±4.2[b] (580)
Quartile 4	8.0±5.9[c] (621)	1.6±0.8[c] (624)	22.7±3.5[b] (583)
Sedentary behavior (leisure)			
Quartile 1	8.3±6.2*[a] (616)	1.9±0.8 (624)	23.4±4.4 (565)
Quartile 2	8.6±6.1[a] (623)	1.8±0.8 (625)	23.1±4.2 (576)
Quartile 3	8.8±5.6[a] (625)	1.8±0.7 (626)	23.4±4.3 (587)
Quartile 4	10.1±6.2[b] (626)	1.8±0.8 (624)	23.5±4.6 (585)
Sedentary behavior (gaming)			
Quartile 1	9.5±5.9 (622)	1.8±0.7 (625)	23.0±4.0*[a] (582)
Quartile 2	8.8±6.0 (622)	1.8±0.8 (625)	23.0±4.3[a] (577)
Quartile 3	8.9±6.3 (622)	1.8±0.8 (625)	23.6±4.6[a,b] (573)
Quartile 4	8.6±6.0 (624)	1.9±0.8 (624)	23.8±4.6[b] (581)

SD = standard deviation; *= a statistical significance level of <0.05 via one-way ANOVA.
Means not sharing superscripts differ statistically significantly ($p < 0.05$) within groups, as indicated by t-tests and *post-hoc* Tukey-HSD (honestly significant difference) or Games-Howell tests.
Quartile outcome magnitude levels ranged from 1 to 4 (1 = low to 4 = high); low SES = 20% of the respondents with the lowest SES, medium SES = 60% of the respondents with medium SES, high SES = 20% of the respondents with the highest SES; no migration background = the participant and both parents were born in Luxembourg, second generation = at least one parent was not born in Luxembourg, but the participant was, first generation = participants who immigrated by themselves.

physiological aspects associated with these behaviors, are specifically known to negatively impact shoulder, neck, and lower back pain due to unfavorable ergonomics (Brindova et al., 2015; Meziat Filho et al., 2015; Torsheim et al., 2010). Moreover, these behaviors can cause sleeping difficulties (Schroeder et al., 2020), increase psychological ill-being, and decrease psychological well-being (Rodriguez-Ayllon et al., 2019), all of which are related to fHC.

Table 3
Regression analysis summary predicting the health complaints, self-rated health and body mass index value (Youth Survey Luxembourg 2019).

	Health complaints (n = 2,308) *	Self-rated health (n = 2,318) *	Body mass index (n = 2,153) *
	ß (95% CI) p	ß (95% CI) p	ß (95% CI) p
Main effects			
Leisure-time sedentary behavior	0.447 (0.206 – 0.689) <0.001	−0.017 (−0.048 – 0.013) 0.261	−0.010 (−0.196 – 0.176) 0.919
Gaming-associated sedentary behavior	0.545 (0.261 – 0.830) <0.001	0.076 (0.039 – 0.112) <0.001	0.498 (0.281 – 0.714) <0.001
Physical activity	−0.510 (−0.755 – −0.264) <0.001	−0.149 (−0.180 – −0.118) <0.001	−0.333 (−0.522 – −0.145) 0.001
Age	−0.079 (−0.142 – −0.016) 0.014	0.015 (0.007 – 0.023) <0.001	0.174 (0.126 – 0.223) <0.001
Gender	−3.386 (−3.946 – −2.826) <0.001	−0.149 (−0.220 – −0.078) <0.001	0.039 (−0.389 – 0.466) 0.859
Socioeconomic status	−0.013 (−0.022 – −0.005) 0.002	−0.001 (−0.002 – 0.000) 0.014	−0.011 (−0.018 – −0.004) <0.001
Migration background			
First generation	−0.473 (−1.070 – 0.123) 0.120	−0.047 (−0.122 – 0.029) 0.225	−0.650 (−1.104 – −0.195) 0.005
Second generation	−0.114 (−0.707 – 0.479) 0.705	0.066 (−0.009 – 0.141) 0.085	0.353 (−0.102 – 0.809) 0.128
Interaction effects			
Leisure-time sedentary behavior*physical activity	0.180 (−0.056 – 0.416) 0.134	0.001 (−0.028 – 0.031) 0.924	−0.034 (−0.246 – 0.178) 0.753
Gaming sedentary behavior*physical activity	0.004 (−0.245 – 0.252) 0.978	−0.009 (−0.040 – 0.023) 0.583	0.145 (−0.046 – 0.336) 0.136

Note: Data are presented as follows: ß = unstandardized coefficients, 95% CI = the lower and upper limit of the 95% confidence interval (CI), p = statistical significance level, * = a statistical significance level of <0.05; gender was coded as 1 = female and 2 = male; the reference variable with regard to migration background was "no migration background;" adjusted R^2 value were as follows: frequency of health complaints, 9%, self-rated health, 7%, and body mass index, 6%.

SRH was lower when participants reported higher levels of gaming-associated SB. Evidence suggests that overall SB is generally associated with a decrease in SRH (Zhang et al., 2020). For example, studies have determined that prolonged gaming is a risk factor for reduced perceived health (Huard Pelletier et al., 2020; Wallenius et al., 2009).

No association was found between leisure-time SB and BMI in the current study. The results of our regression analyses also indicated that increasing age was associated with higher BMI values (Table 3), which could be attributed to increased metabolism in youth (Krems et al., 2005). However, a negative association has been found between gaming-associated SB and BMI within prior studies (Huard Pelletier et al., 2020). Therefore, deeper insight into the type of gaming associated with SB is needed in order to understand the causative factors underlying these findings more comprehensively, as there are games that focus on improving health as well as games that are more likely to cause a worsening in health.

We evaluated sex differences with regard to fHC, SRH, and BMI. We found that females were more likely to report worse levels of fHC and SRH, whereas males had a higher mean BMI level. Previous studies have reported similar differences by sex (Boerma et al., 2016; Stock et al., 2008).

Moreover, this study investigated the influence of migration status on health outcomes. Our results suggest that having a first-generation migrant status negatively influenced BMI. A possible explanation for this outcome is that BMI can be negatively affected due to cultural differences and the impact of acculturation, including resulting changes in social and psychological factors, nutrition, physical activity, and genetic susceptibility (Goulão et al., 2015). Interestingly, migration status had no effect on fHC and SRH. We expected to see different results (i.e., similar to those reported in previous studies) (Heinz et al., 2020; Saint-Fort et al., 2023). One reason for our unexpected findings may be the heterogeneity of origins among the migrants enrolled in our sample, which should be further investigated in future research efforts.

Low SES was negatively associated with fHC, SRH, and BMI. Our findings confirm the results of a number of previous studies (Heinz et al., 2020; Lago et al., 2018). Future research efforts should focus on targeting social inequalities for the purpose of improving health in this demographic.

Furthermore, we conducted a comprehensive examination of the potential interactions between sex and age within our regression models to assess any potential impact on our findings. However, no substantial differences were observed. Nonetheless, the interaction between sex and age yielded a statistically significant and positive association with both fHC and BMI. The effect size of this interaction term was relatively small and indicated a gradual increase in fHC and BMI among females as age advances.

This study has several limitations. First, our SB measures are based on a diverse set of variables. However, they all tap into aspects that are deemed indicative of leisure-time and gaming SB based on the current literature. We also evaluated regression models with single items in order to control for potential differences in study results. However, no statistically significant differences were observed. In fact, using factor variables strengthened our results, as we evaluated different dimensions with regard to sedentary activities. Nevertheless, the specific operationalization of our SB variables should be considered when conducting comparisons with other studies. Future research may benefit from acquiring more detailed and nuanced data pertaining to SB, particularly with regard to the allocation of time towards distinct activities. Second, information retrieved from self-reports might be biased. For example, some people may have provided inaccurate information about their physical or sedentary activity time. Although objective device-based measures (e.g., measures collected through accelerometry) might provide a better alternative, such exposure assessment methodologies are both expensive and more burdensome than questionnaire-based evaluations, and we can be confident that most of the measures we collected are accurate based on prior validations conducted within the epidemiologic literature (Brühmann et al., 2014; Haskell, 2012; Warren et al., 2010). Similarly, while self-reporting is a simple and common method for determining weight, it is less accurate than more precise measures based on bioelectrical impedance analysis or classic weight scales and can lead to an underestimation of the occurrence of overweight and obesity (O'Neill, 2015).

5. Conclusion

Although engaging in physical activity is crucial for improving health, our results suggest that its effectiveness in combating and reversing the negative impacts of a sedentary lifestyle is limited. Hence, based on our findings as well as those reported in the overall literature, increasing physical activity alone is not sufficient from a public health perspective. Instead, it is important for youths to reduce overall sedentary behavior, as some of the damage resulting from a sedentary lifestyle is irreversible and can lead to poor health outcomes. Our findings, though reported within a rigorous and highly powered investigation, are based on a cross-sectional evaluation and should be confirmed within future prospective cohort studies. Our results inform research directions as well as directly informing preventive medicine and public health policy considerations.

CRediT authorship contribution statement

Emanuel Schembri: Conceptualization, Methodology, Software, Formal analysis, Writing – original draft, Visualization, Project administration. **Andreas Heinz:** Methodology, Validation, Writing – review & editing. **Robin Samuel:** Methodology, Validation, Investigation, Resources, Writing – review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

We are grateful to the Youth Survey Luxembourg Team for collecting and providing data. We would also like to thank all participants of this study.

Funding

This research was partly funded by the Ministère de l'Education Nationale, de l'Enfance et de la Jeunesse, and the University of Luxembourg. More specifically, the gathering and analysis of the YSL 2019 data were funded by the Ministère de l'Education Nationale, de l'Enfance et de la Jeunesse, and the University of Luxembourg.

Role of the funding source

These funders had no role in the design, conduct, or publication of this research. The analyses and interpretations presented in this report are those of the authors and do not necessarily represent the views of institutions that have provided financial or other support.

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