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The longitudinal impact of diet, physical activity, sleep, and screen time on Canadian adolescents' academic achievement: An analysis from the COMPASS study

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ABSTRACT

Adequate amounts of physical activity, sleep, and screen time along with a healthy diet have been demonstrated to have positive associations with academic achievement. No longitudinal study has investigated the simultaneous relationship between all of these behaviours and academic achievement. Data from 11,016 adolescent participants of the COMPASS study in Alberta and Ontario were analysed. Students self-reported their adherence to Canadian recommendations for health behaviours and academic achievement in Math and English on school-based surveys administered in the 2015/16 and 2016/17 waves of COMPASS. Multinomial generalized estimating equations were used to evaluate the association between longitudinal changes in adherence to recommendations and academic achievement at follow-up. Models were adjusted for self-reported socio-demographic information, body weight status, and baseline academic achievement. Students who adhered to a greater number of recommendations performed better than students who adhered to fewer recommendations. Meeting recommendations for Meat and Alternatives (protein-rich foods) and screen time were consistently associated with higher academic achievement compared to students who did not meet these recommendations. A change from not meeting recommendations for Vegetables and Fruit to meeting the recommendation in the following year was associated with higher achievement in both subjects. There was no association between sleep behaviours or physical activity and academic achievement. Results indicate that adherence to recommendations for protein-rich foods, screen time, and vegetables and fruit show promise as behavioural targets for higher academic achievement among youth. Further study using objectives measurements of behaviours and further consideration of socioeconomic variables is merited.

1. Introduction

Academic achievement is a crucial social determinant of health (Mikkonen and Raphael, 2010). As educational attainment increases, the likelihood of ill health throughout the lifespan is greatly reduced (Feinstein et al., 2006). In particular, high educational attainment in developed countries is negatively associated with the likelihood of contracting a non-communicable disease (Smith et al., 2015). Because of this, improving educational outcomes for children is an appropriate upstream target for public health initiatives aiming to effectively reduce the incidence of chronic disease, among other beneficial outcomes associated with increased educational achievement.

Academic achievement is influenced by myriad factors (Kohl, 2013). From a health promotion perspective, evidence has been mounting to show that the improvement of modifiable lifestyle behaviours can be an effective means to improve academic achievement with the added benefit of positively contributing to students' health (Michael et al., 2015; Basch, 2011). Healthy diet (Burrows et al., 2017),

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appropriate amounts of sleep (Schmidt and Van der Linden, 2015; Destin et al., 2017), and lower screen time (Hancox et al., 2005) have consistently demonstrated positive associations with academic achievement. Relationships between physical activity and academic achievement have been frequently investigated but results have inconsistently suggested either positive or neutral effects (Esteban-Cornejo et al., 2015; Rasberry et al., 2011; Singh et al., 2012; Donnelly et al., 2016). Systematic reviews continue to indicate further high-quality longitudinal studies examining the relationships between these individual behaviours and academic achievement are needed, particularly in adolescents (Burrows et al., 2017; Esteban-Cornejo et al., 2015; Rasberry et al., 2011).

Physical activity, diet, sleep, and screen time are interrelated behaviours that have been posited to have synergistic effects on health (Tremblay et al., 2016a). However, they are infrequently considered simultaneously in their relationship with academic achievement. Because healthy behaviours tend to cluster together, there is the potential that individual relationships may be confounded by the presence of other behaviours. Acknowledging this interrelatedness, recent manuscripts have begun to consider the relationships between these behaviours and academic achievement simultaneously, or via mediation or moderation analyses (Faught et al., 2017a; Faught et al., 2017b; Vassiloudis et al., 2014; Rasberry et al., 2017; Nigg and Amato, 2015; Sigfusdottir et al., 2007; Martinez-Gomez et al., 2012; Ickovics et al., 2014; Poulain et al., 2018). However, no study has evaluated the longitudinal relationship between all of these behaviours and academic achievement simultaneously among adolescents. Longitudinal and combined analyses of these behaviours are necessary to better inform effective health promotion efforts that aim to both improve youth health and academic achievement to prevent chronic diseases (Roberts et al., 2016; Lister-Sharp et al., 1999).

Therefore, the purpose of this study was to investigate the relationship between adolescents' adherence to Canadian recommendations for diet, physical activity, screen time, and sleep with academic achievement in a large, longitudinal cohort of adolescents. We hypothesized that adhering to recommendations would be associated with greater academic achievement, and that meeting more recommendations at baseline and follow-up would have an additive effect on achievement.

2. Methods

2.1. Participants

The COMPASS Study (hereby referred to as COMPASS) is a prospective cohort study that aims to collect longitudinal data from a sample of grade 9–12 (ages 13–18 years) students and their schools in the provinces of Alberta and Ontario in Canada (Leatherdale et al., 2014a). Students were recruited within participating COMPASS schools using active-information passive-consent parental permission protocols. The current study is based on data from grade 9, 10 and 11 students in Year 4 (Y4: 2015/16) who also provided follow-up data in Year 5 (Y5: 2016/17) when they were in grades 10, 11 or 12. The overall participation rate was 80.3% in Y4 and 77.5% in Y5; < 1% of missing eligible respondents was due to refusal, and the remainder of missing respondents was due to absenteeism during data collection.

In Y4, 81 secondary schools (72 Ontario schools, 9 Alberta schools) with 31,376 grade 9, 10 and 11 students completed the student-level questionnaire for COMPASS (Cq). An additional 286 students were removed due to missing data on sex, resulting in a final cross sectional Y4 sample of 31,090 grade 9, 10, and 11 students. In Y5, 65 of the Y4 COMPASS schools were still participating (58 Ontario schools, 7 Alberta Schools). Self-generated identification codes were used to link the within school data sets between Y4 to Y5 creating our longitudinal data set using the COMPASS data linkage procedure described elsewhere (Qian et al., 2015). Due to the rolling sample design (Leatherdale et al., 2014a), it was not possible to link the grade 12 students in Y4 that graduated before Y5, or the grade 9 students that were newly admitted to participating schools in Y5. We linked data from 31,376 eligible grade 9, 10 and 11 students in Y4 with data available from 29,327 grade 10, 11, and 12 students in Y5 in those 65 schools to create a data set that included 14,454 students tracked from Y4 (baseline) to Y5 (follow-up). Among 14,454 participants in the COMPASS study who had a successful data linkage between 2015–16 (Y4) and 2016–17 (Y5), 3438 participants were removed from the analyses due to missing data resulting in a final sample of 11,016 students. Included participants were older, more likely to be White than other listed ethnicities, had more disposable income, and had higher self-reported grades than those who were excluded.

2.2. Procedures

The Cq collects individual student self-reported data pertaining to multiple behavioural domains (e.g., physical activity, diet, screen time) and demographic characteristics, for the interest of this study. In each school, the Cq was used to collect whole-school samples during class time. The cover page contains measures to create a unique self-generated code for each respondent to ensure the anonymity of participants, while still allowing COMPASS researchers to link each student's anonymous identifier data over multiple years. A full description of the COMPASS study methods is available in print (Leatherdale et al., 2014a) or online (https://uwaterloo.ca/compass-system/compass-system-projects/compass-study). The University of Waterloo Office of Research Ethics (ORE #17264) and appropriate school board committees approved all procedures.

2.3. Academic achievement

Students were asked: “In your current or most recent Math course, what is your approximate overall mark?” The same question was asked for English marks. Possible response selections were: 90%–100%, 80–89%, 70–79%, 60–69%, < 60%. Follow-up academic achievement was treated as the outcome variable and analyses were adjusted for academic achievement reported at baseline. The subjects were not merged into an average score because previous research has found that health behaviours impact school subjects differently (Donnelly et al., 2016; Fedewa and Ahn, 2011; Wagner et al., 2004) and the variables were categorical making them challenging to collapse.

2.4. Diet

Students were asked, using a questionnaire in the Cq deemed to produce valid and reliable estimates of dietary intake (Leatherdale and Laxer, 2013), to report the number of servings that they ate the day before from food groups described by Eating Well with Canada's Food Guide (CFG) (*Eating Well with Canada's Food Guide*, 2011). CFG describes four distinct food groups: Vegetables and Fruit, Meat and Alternatives, Milk and Alternatives, and Grain Products (*Eating Well with Canada's Food Guide*, 2011). A description of what constitutes a serving as defined by the CFG is provided and examples of servings are pictured. An example of the question for Meat and Alternatives is described: “YESTERDAY, *from the time you woke up until the time you went to bed, how many servings of meats and alternatives did you have? One ‘Food Guide’ serving of meat and alternatives includes cooked fish, chicken, beef, pork, or game meet, eggs, nuts or seeds, peanut butter or nut butters, legume (beans), and tofu*”. Possible responses were: None, 1 serving, 2 servings, 3 servings, 4 servings, 5 or more servings. The responses for each food group varied based on the recommended number of servings from CFG.

Students' adherence to CFG recommendations was assessed, where students were denoted a ‘1’ for meeting the recommendation, and ‘0’ when they did not meet the recommendation. The CFG has age- and

sex-specific recommendations that are described in the results tables.

2.5. Physical activity

Students were asked about their engagement in moderate-to-vigorous intensity physical activity (MVPA) and strengthening exercises. The MVPA measure has previously been shown to have sufficient validity and reliability properties for use among adolescents (Wong et al., 2006). To assess engagement in MVPA, students were asked how many minutes of moderate (defined in the survey as lower intensity activities such as walking, biking to school, and recreational swimming) physical activity they had done in the last seven days, and how much hard (vigorous – defined as physical activities that increase your heart rate and make you breathe hard and sweat) activity over the past seven days. For each day in the previous week, students could select the number of hours and minutes they engaged in each intensity level of physical activity. Students were designated as meeting the MVPA component of the Canadian 24-hour Movement Guidelines (Tremblay et al., 2016b) if they engaged in an average of 60 min of MVPA every day over a one week period. To ascertain whether reported MVPA represents usual behaviour, the responses from the survey question: 'Were the last 7 days a typical week in terms of the amount of physical activity that you usually do?' (potential responses: Yes, No, I was more active in the last 7 days, No, I was less active in the last 7 days) were included in models including MVPA.

To assess engagement in strength-based exercises, students were asked 'On how many days in the last 7 days did you do exercises to strengthen or tone your muscle? (e.g., push-ups, sit-ups, or weight-training).' If students reported engaging in these strength-based exercises at least 3 days in the past week, they were deemed to have met the strength training recommendations provided in the Canadian 24-hour Movement Guidelines (Tremblay et al., 2016a).

2.6. Screen time

To assess screen time, students were asked 'How much time per day do you *usually* spend doing the following activities?' using a questionnaire determined to be of sufficient validity and reliability for this age group (Leatherdale et al., 2014b). They were prompted to fill in the number of hours and minutes for all of: watching/streaming TV shows or movies, playing video/computer games, surfing the internet, and texting/messaging/emailing. Students were asked to separately report their homework time, which was not included in our assessment of screen time use. These response categories were totalled to represent total average daily screen time. If this amount was equal to or below 2 h/day, the student was deemed to be meeting recommendations from the Canadian 24-hour Movement Guidelines (Tremblay et al., 2016a).

2.7. Sleep

Students reported their sleep duration in hours and minutes. If their total daily average sleep time was between 8 and 10 h as recommended for this age group by the Canadian 24-hour Movement Guidelines (Tremblay et al., 2016a), students were deemed to be meeting this recommendation.

2.8. Total recommendations met

All students were given a 'point' if they met a recommendation at both baseline and follow-up, resulting in a 'score' for total number of recommendations met, with one score calculated for baseline and one for follow-up. This was calculated with the intention of determining if cumulative meeting of recommendations would affect academic scores at baseline and follow-up.

2.9. Additional covariates

Students were asked their sex, age, race/ethnicity, and the amount of money they usually get each week to spend on themselves or to save, which was used to denote socioeconomic status. No other socioeconomic variables were requested on the COMPASS survey. Students self-reported their height and weight in the metric of their choosing, used to calculate their body mass index (BMI) based on the World Health Organization's age- and sex-specific cutoffs (*Growth Reference 5–19 Years. BMI-for-Age 5–19 Years*, 2007). BMI has been previously shown to be associated with academic achievement (Martin et al., 2018).

2.10. Data analysis

Multinomial generalized estimating equation (GEE) models were used to explore the longitudinal associations between the outcomes (categorical Math scores/English scores) and predictors. School clustering was specified to account for within-school associations. Model 1 investigated associations between each individual predictor (adhering to specific recommendation) and the outcomes. In Model 2, the predictors were simultaneously included in the same model. Finally, model three assessed associations between the number of recommendations met at baseline or follow-up and the outcomes. In each model, all associations were adjusted for the control variables and the outcome at baseline. All analyses were implemented in SAS 9.4. Proc FREQ and Proc TTEST were used for descriptive statistics and Proc GENMOD was used for multinomial GEE models.

3. Results

3.1. Descriptive results

Table 1 describes the sample characteristics. Participants were 13–18 years old (mean = 15.2 years) at baseline. Most students were categorized as having a healthy body weight (72.5%) and most students identified as White (74.6%). In English, 40.3% of students indicated grades between 80%–89% at baseline, and 40.5% indicated the same at follow-up. In Math, 31.0% and 29.8% of students indicated grades of 80%–89% at baseline and follow-up, respectively. For all subjects and time points, 15.4–23.0% of students indicated they achieved scores of 90%–100% and 4.7–10.5% of students indicated they achieved scores < 60%.

Results for adherence to recommendations are provided in Tables 3 and 4 for ease of reference. Students met, on average, a total of 2.9 (SD = 1.4) and 2.7 (SD = 1.4) recommendations out of a possible eight. The vast majority of students did not meet recommendations at both time points for Vegetables and Fruits (92.5%) and screen time (91.1%), while the vast majority of students did meet recommendations at both time points for Grain Products (88.7%). Most students also met recommendations for MVPA at both time points (65.3%) while 11.0% did not meet MVPA recommendations at either time point. Although 36.4% of students met recommendations for strength-based physical activity at both time points, 32.4% did not meet the recommendation at both time points. Similarly, 37.2% of students met recommendations for Meat and Alternatives at both time points, while 28.3% of students did not meet the recommendation at either time point. Just under half (45.4%) of students did not meet recommendations for Milk and Alternatives at either time point, while a quarter of students (24.9%) met at both time points. Finally, 45.1% of students did not meet recommendations for sleep duration at either time point while 24.7% of students met the recommendation at both time points.

3.2. Multinomial GEE models

Table 2 provides a visual summary of all fully adjusted relationships

Table 1
Descriptive statistics for 11,016 Canadian students with complete information on the COMPASS surveys in Year 4 (2015–16) and Year 5 (2016–17).

Variable	Mean (SD)	Students (N = 11,016)
Age at Y4		15.2 (0.93)
% (N)		
Sex	Girls	52.0 (5727)
	Boys	48.0 (5289)
Race	White	74.6 (8222)
	Black	3.4 (372)
	Asian	5.8 (637)
	Aboriginal	2.5 (276)
	Hispanic	1.9 (213)
	Other	3.9 (432)
	Mixed	7.7 (843)
	Missing	0.2 (21)
Body mass index category (Y5)	Underweight	1.7 (189)
	Healthy weight	72.5 (7982)
	Overweight	17.2 (1899)
	Obese	8.6 (946)
Available spending money (Y5)	$0	14.1 (1554)
	$1 to $20	22.3 (2455)
	$21–$100	29.2 (3219)
	More than $100	24.6 (2715)
	I don't know	9.7 (1073)
Response to question about whether PA was typical or not	Yes	67.7 (7453)
	No, I usually do more	9.7 (1064)
	No, I usually do less	22.7 (2499)
Academic outcomes		
English scores at Y4	90%–100%	15.4 (1677)
	80%–89%	40.3 (4372)
	70%–79%	28.9 (3138)
	60%–69%	10.4 (1134)
	< 60%	5.0 (538)
English scores at Y5	90%–100%	17.0 (1861)
	80%–89%	40.5 (4424)
	70%–79%	27.8 (3033)
	60%–69%	9.9 (1086)
	< 60%	4.7 (516)
Math scores at Y4	90%–100%	23.0 (2509)
	80%–89%	31.0 (3376)
	70%–79%	23.4 (2549)
	60%–69%	12.6 (1367)
	< 60%	10.0 (1085)
Math scores at Y5	90%–100%	21.3 (2322)
	80%–89%	29.8 (3259)
	70%–79%	24.6 (2686)
	60%–69%	13.9 (1514)
	< 60%	10.5 (1144)

related to the research question. It shows that predominantly, being a student who meets recommendations at baseline or at both baseline and follow-up is beneficial for academic achievement compared to students who meet recommendations at neither time point or at baseline only. Table 3 provides results from the longitudinal analysis for results in Math and Table 4 provides these results for English. Where odds ratios (OR) are above 1, the exposure is associated with higher odds of performing well in the specified subject. Where an OR is < 1, the exposure is associated with reduced odds of performing well in the specified subject. Meaningful results, predominantly from Models 2 and 3 unless notable from Model 1, will be described in the subsequent sections.

3.2.1. Math

For every additional recommendation met at baseline and follow-up, respectively, students had a modest 1.05 (95% CI: 1.02, 1.08) and 1.06 (95% CI: 1.03, 1.09) increased odds of achieving a higher grade in Math (Model 3). If students met recommendations for Meat and Alternatives at either or both time points, they had 1.11–1.28 increased odds of achieving a higher level in Math compared to students who did not meet the recommendation at either time point. Compared to students who did not meet recommendations for Milk and Alternatives at either time point, students who met these recommendations at both time points had 1.11 (95% CI: 1.01, 1.22) increased odds of achieving a higher grade in Math. Compared to students who did not meet recommendations for Vegetables and Fruit at either time point, students who met recommendations at follow up had 1.23 times the odds of achieving a higher grade in Math (OR: 1.23 (95% CI: 1.01, 1.49)). In the unadjusted model (Model 1), students who met recommendations for strength-based or moderate-to-vigorous physical activity at baseline at follow up had 0.89 and 0.83 times lower odds of achieving higher grades in Math (OR: 0.89 (95% CI: 0.80, 0.99)) and (OR: 0.83 (95% CI: 0.71, 0.97)), respectively, compared to students who did not meet these recommendations. These negative associations were nullified once other covariates (other recommendations and adjustment variables) were included in Model 2. Compared to students who did not meet recommendations for screen time at either time point, students who met recommendations at follow-up only (OR: 1.27 (95% CI: 1.02, 1.58)), or both time points (OR: 1.95 (95% CI: 1.51, 2.52)) had higher odds of achieving a higher grade in Math. No statistically significant association was found between differences in adhering to recommendations for Grain Products, strength-based PA, MVPA, or sleep over time and grades in Math at follow-up.

Table 2
Overall summary of fully-adjusted relationships (Model 2) between recommendation adherence over time and academic scores at follow-up, adjusted for baseline academic achievement in Canadian adolescents between 2015 and 2017.

Recommendation	Not meeting at either time point (0–0)	Meeting at follow-up only (0–1)	Meeting at baseline only (1–0)	Meeting at both time points (1–1)
Math scores				
Vegetables and fruit	Reference	↑↑	–	–
Grain products	Reference	–	–	–
Milk and alternatives	Reference	–	–	↑
Meat and alternatives	Reference	↑↑	↑	↑↑
Strength-based PA	Reference	–	–	–
MVPA	Reference	–	–	–
Screen time	Reference	↑↑	–	↑↑↑
Sleep	Reference	–	–	–
English scores				
Vegetables and fruit	Reference	↑↑	–	–
Grain products	Reference	–	–	–
Milk and alternatives	Reference	–	–	–
Meat and alternatives	Reference	↑↑	–	↑↑↑
Strength-based PA	Reference	–	–	–
MVPA	Reference	–	–	–
Screen time	Reference	↑↑↑	–	↑↑↑
Sleep	Reference	–	–	–

One arrow: 0–15% difference in odds of achieving a higher score in subject.
Two arrows: 15–30% difference in odds of achieving a higher score in subject.
Three arrows: 30%+ difference in odds of achieving a higher score in subject.

3.2.2. English

For every additional recommendation met at follow-up, respectively, students had a small but significant 1.06 (95% CI: 1.03, 1.09) increased odds of achieving a higher grade in English (Model 3). No significant association was found for total number of recommendations met at baseline. Compared to students who did not meet recommendations for Meat and Alternatives at either time point, meeting recommendations at follow-up and at both time points was associated with 1.23–1.31 higher odds of achieving higher grades in English. Compared to students who did not meet recommendations for Vegetables and Fruit at either time point, students who met recommendations at follow up had 1.33 (95% CI: 1.11, 1.60) increased odds of achieving higher grades in English. Compared to students who did not meet recommendations for screen time at either time point,

Table 3
Longitudinal associations between health behaviours and academic achievement in Math for Canadian students with successful linkages between completed COMPASS surveys in Year 4 (2015–16) and Year 5 (2016–17).

Parameter	N = 11,016	Mean (SD)	Model 1	Model 2	Model 3
			OR (95% CI)	OR (95% CI)	OR (95% CI)
Total number of recommendations met at baseline		2.9 (1.4)	–	–	1.05 (1.02, 1.08)
Total number of recommendations met at follow-up		2.7 (1.4)	–	–	1.06 (1.03, 1.09)
Meat and Alternatives (2 servings if female, 3 if male)	00[a]	3120 (28.3)	–	–	–
	01	1930 (17.5)	1.29 (1.16, 1.44)	1.27 (1.13, 1.42)	
	10	1872 (17.0)	1.12 (1.01, 1.24)	1.11 (1.02, 1.22)	
	11	4094 (37.2)	1.41 (1.30, 1.53)	1.28 (1.17, 1.39)	
Milk and Alternatives (3–4 servings)	00	5002 (45.4)	–	–	
	01	1428 (13.0)	1.02 (0.91, 1.15)	1.03 (0.92, 1.15)	
	10	1843 (16.7)	1.02 (0.92, 1.14)	1.01 (0.92, 1.11)	
	11	2743 (24.9)	1.21 (1.11, 1.31)	1.11 (1.01, 1.22)	
Grain Products (6 servings if female, 7 if male)	00	9766 (88.7)	–	–	
	01	555 (5.0)	1.26 (1.12, 1.43)	1.07 (0.95, 1.21)	
	10	498 (4.5)	1.06 (0.92, 1.22)	0.95 (0.80, 1.14)	
	11	197 (1.8)	1.46 (1.15, 1.85)	1.09 (0.82, 1.44)	
Vegetables and Fruit (7 servings if female, 8 if male)	00	10,190 (92.5)	–	–	
	01	359 (3.3)	1.31 (1.08, 1.60)	1.23 (1.01, 1.49)	
	10	361 (3.3)	1.17 (0.99, 1.38)	1.06 (0.90, 1.23)	
	11	106 (0.9)	1.24 (0.84, 1.81)	0.98 (0.64, 1.50)	
Strength-based physical activity (≥ 3 days/week)	00	3564 (32.4)	–	–	
	01	1498 (13.6)	0.89 (0.80, 0.99)	0.93 (0.82, 1.06)	
	10	1944 (17.7)	1.00 (0.90, 1.10)	1.01 (0.90, 1.13)	
	11	4010 (36.4)	0.96 (0.89, 1.04)	1.02 (0.94, 1.11)	
Moderate-to-vigorous physical activity (60 min/day)	00	1214 (11.0)	–	–	
	01	1120 (10.2)	0.83 (0.71, 0.97)	0.89 (0.77, 1.04)	
	10	1492 (13.5)	1.01 (0.87, 1.17)	1.06 (0.91, 1.23)	
	11	7190 (65.3)	0.97 (0.86, 1.09)	0.99 (0.89, 1.12)	
Screen time (≤ 2 h/day)	00	10,038 (91.1)	–	–	
	01	348 (3.2)	1.49 (1.19, 1.87)	1.27 (1.02, 1.58)	
	10	404 (3.7)	1.35 (1.12, 1.64)	1.12 (0.91, 1.39)	
	11	226 (2.1)	2.32 (1.80, 3.00)	1.95 (1.51, 2.52)	
Sleep (8–10 h/night)	00	4968 (45.1)	–	–	
	01	1222 (11.1)	1.10 (1.00, 1.20)	0.99 (0.89, 1.10)	
	10	2102 (19.1)	1.11 (1.01, 1.23)	1.03 (0.92, 1.15)	
	11	2724 (24.7)	1.23 (1.10, 1.37)	1.05 (0.96, 1.16)	

Model 1 is the association of each individual behaviour recommendation adherence with academic achievement adjusted for sex, race, body mass index category, available spending money, baseline academic achievement in Math, and for MVPA, whether the reported MVPA was representative of a typical week.
Model 2 includes variables representing adherence to all recommendations and is adjusted all covariates described above.
Model 3 represents the association between a single variable representing the total number of recommendations adhered to at baseline and at follow up and all demographic covariates.
[a] 0–0 indicates non-compliance with recommendations at both time points and is used as the reference category, 0–1 is non-compliance at baseline to compliance at follow-up, 1–0 is compliance at baseline and non-compliance at follow-up, and 1–1 is consistent compliance across time points.

students who met recommendations at follow-up or at both time points had 1.40 (95% CI: 1.10, 1.78) and 1.79 (95% CI: 1.27, 2.51) increased odds of achieving a higher grade in English, respectively. No statistically significant association was found between differences in adhering to recommendations for Milk and Alternatives, Grain Products, strength-based PA, MVPA, or sleep over time and grades in English at follow-up.

4. Discussion

This study is the first to simultaneously consider longitudinal relationships between meeting recommendations for all of dietary, physical activity, screen time, and sleep behaviours and academic achievement. We identified that the strongest positive effect sizes for the relationship between adherence to recommendations and academic achievement occurs when adherence to recommendations is sustained over time, with the exception of adherence to recommendations for Vegetables and Fruit which had a strong positive association when adhered to at follow-up only. However, since so few students met recommendations for Vegetables and Fruit at both time points (< 1%), it is challenging to elucidate this relationship. While are numerous studies that have investigated the longitudinal relationships between health behaviours and academic achievement among children and youth (Nigg and Amato, 2015; Poulain et al., 2018; Smith and Richards, 2018; Feinstein et al., 2008; Nyaradi et al., 2016; Blunden et al., 2018), the approach taken in the present work to understand how adherence to lifestyle recommendations at varying time points is unusual in the literature (Suchert et al., 2016). As such, future research using longitudinal data may focus on determining whether sustained adherence to recommendations supports more pronounced benefits for educational outcomes as results from the present work suggests.

The finding that meeting more recommendations is associated with better academic achievement is consistent with previous analyses (Faught et al., 2017a; Martinez-Gomez et al., 2012; Ickovics et al., 2014). While some of the health behaviours investigated in this manuscript did not have an impact on academic achievement individually, when combined with other healthy behaviours, they may support academic achievement in addition to their other established benefits. Interestingly, among the factors examined, only adherence to recommendations for Meat and Alternatives and screen time were consistently and positively related to higher academic achievement over time. Adherence to recommendations for Meat and Alternatives and screen time as per Canadian recommendations have been previously found to be associated with academic achievement (Faught et al., 2017a). Few studies have investigated specifically protein-rich foods as represented by the Meat and Alternatives food group, except in

Table 4
Longitudinal associations between health behaviours and academic achievement in English for Canadian students with successful linkages between completed COMPASS surveys in Year 4 (2015–16) and Year 5 (2016–17).

Parameter	N = 11,016	Mean (SD)	Model 1	Model 2	Model 3
			OR (95% CI)	OR (95% CI)	OR (95% CI)
Total number of recommendations met at baseline		2.9 (1.4)	–	–	1.01 (0.98, 1.04)
Total number of recommendations met at follow-up		2.7 (1.4)	–	–	1.06 (1.03, 1.09)
Meat and Alternatives (2 servings if female, 3 if male)	00[a]	3120 (28.3)	–	–	–
	01	1930 (17.5)	1.23 (1.11, 1.37)	1.23 (1.10, 1.37)	
	10	1872 (17.0)	1.06 (0.95, 1.19)	1.07 (0.96, 1.20)	
	11	4094 (37.2)	1.33 (1.22, 1.45)	1.31 (1.20, 1.43)	
Milk and Alternatives (3–4 servings)	00	5002 (45.4)	–		
	01	1428 (13.0)	1.02 (0.91, 1.15)	0.97 (0.86, 1.10)	
	10	1843 (16.7)	0.97 (0.87, 1.07)	0.95 (0.86, 1.05)	
	11	2743 (24.9)	1.06 (0.96, 1.16)	0.98 (0.88, 1.08)	
Grain Products (6 servings if female, 7 if male)	00	9766 (88.7)	–		
	01	555 (5.0)	1.11 (0.95, 1.30)	1.00 (0.85, 1.18)	
	10	498 (4.5)	1.08 (0.94, 1.24)	1.02 (0.89, 1.17)	
	11	197 (1.8)	1.40 (1.07, 1.84)	1.22 (0.93, 1.60)	
Vegetables and Fruit (7 servings if female, 8 if male)	00	10,190 (92.5)	–		
	01	359 (3.3)	1.42 (1.19, 1.71)	1.33 (1.11, 1.60)	
	10	361 (3.3)	1.06 (0.90, 1.25)	1.01 (0.86, 1.19)	
	11	106 (0.9)	1.60 (1.02, 2.52)	1.40 (0.89, 2.22)	
Strength-based physical activity (≥ 3 days/week)	00	3564 (32.4)	–		
	01	1498 (13.6)	0.98 (0.88, 1.10)	0.99 (0.88, 1.11)	
	10	1944 (17.7)	0.96 (0.86, 1.07)	0.96 (0.86, 1.08)	
	11	4010 (36.4)	1.00 (0.91, 1.09)	0.97 (0.87, 1.08)	
Moderate-to-vigorous physical activity (60 min/day)	00	1214 (11.0)	–		
	01	1120 (10.2)	0.87 (0.74, 1.02)	0.86 (0.73, 1.02)	
	10	1492 (13.5)	0.94 (0.81, 1.08)	0.94 (0.81, 1.10)	
	11	7190 (65.3)	0.92 (0.81, 1.04)	0.89 (0.77, 1.02)	
Screen time (≤ 2 h/day)	00	10,038 (91.1)	–		
	01	348 (3.2)	1.43 (1.13, 1.81)	1.40 (1.10, 1.78)	
	10	404 (3.7)	1.09 (0.94, 1.27)	1.06 (0.91, 1.22)	
	11	226 (2.1)	1.86 (1.33, 2.59)	1.79 (1.27, 2.51)	
Sleep (8–10 h/night)	00	4968 (45.1)	–		
	01	1222 (11.1)	0.94 (0.83, 1.06)	0.93 (0.82, 1.05)	
	10	2102 (19.1)	0.98 (0.87, 1.10)	0.97 (0.86, 1.09)	
	11	2724 (24.7)	1.06 (0.95, 1.19)	1.03 (0.92, 1.15)	

Model 1 is the association of each individual behaviour recommendation adherence with academic achievement adjusted for sex, race, body mass index category, available spending money, baseline academic achievement in Math, and for MVPA, whether the reported MVPA was representative of a typical week.
Model 2 includes variables representing adherence to all recommendations and is adjusted all covariates described above.
Model 3 represents the association between a single variable representing the total number of recommendations adhered to at baseline and at follow up and all demographic covariates.

[a] 0–0 indicates non-compliance with recommendations at both time points and is used as the reference category, 0–1 is non-compliance at baseline to compliance at follow-up, 1–0 is compliance at baseline and non-compliance at follow-up, and 1–1 is consistent compliance across time points.

areas where undernutrition is a prevalent concern (Taras, 2005). In these contexts, and meat-rich diets have been shown to improve academic achievement and cognitive indicators related to previous malnutrition (Taras, 2005). It is worth noting that any adherence at any time point (baseline, follow-up, or both) had very similar effect sizes in the relationship with academic achievement, suggesting that consumption of protein-rich foods at any time appears beneficial, even if it is for a limited time period. There may also be a socioeconomic link to this finding as individuals of higher socioeconomic status are more likely to access and consume protein-rich foods such as meats as well as have higher academic achievement (Kearney, 2010; Sirin, 2005). The current study was only able to adjust for spending money of the student in regard to socioeconomic status Screen time has also been shown to be detrimental to academic achievement across all ranges of youth (Hancox et al., 2005; Poulain et al., 2018; Hale and Guan, 2015; Zimmerman and Christakis, 2007), supporting the current findings.

Findings about vegetable, fruit, and milk and alternative consumption are consistent with literature that shows these nutritious foods are associated with better academic achievement (Burrows et al., 2017; MacLellan et al., 2008). The null findings between sleep and academic achievement are contrary to much of the existing literature (Schmidt and Van der Linden, 2015). A possible explanation of this finding is the potential confounding of the relationship between sleep and academic achievement by screen time – high screen time usage is associated to poorer duration and quality of sleep in adolescents (Hale and Guan, 2015). Indeed, the unadjusted associations between meeting sleep recommendations at any or both time points compared to not meeting recommendations and academic achievement in Math was associated with higher odds of performing better in Math (Model 1, Table 3), but once this relationship was adjusted for other health behaviours these associations were no longer significant (Model 2, Table 3).

The unadjusted, negative longitudinal relationships between MVPA and strength-based physical activity with Math, and lack of relationship when adjusted for all covariates contribute to a large literature base with conflicting findings. Most systematic reviews have concluded that the relationship between physical activity and academic achievement is either positive or neutral (Esteban-Cornejo et al., 2015; Donnelly et al., 2016; Hillman et al., 2008; Lees and Hopkins, 2013; Carson et al., 2016). A recent systematic review concluded that their most striking finding was the general inconsistency of this relationship across studies (Donnelly et al., 2016). Strength-based physical activity is uncommonly evaluated in its relationship with academic achievement, rather, there are numerous studies that have investigated the relationship of existing muscular fitness with academic achievement (Coe et al., 2012; Coe et al., 2013; Santana et al., 2017) and have found weak to moderate

positive associations. The negative association seen in Model 1 between MVPA and academic achievement has been found in other studies (Syvaoja et al., 2013; Esteban-Cornejo et al., 2014; Tremblay et al., 2000). In a contradictory result to our unadjusted findings, Suchert et al. found that 14-year-old German students who did not meet recommendations for MVPA at baseline but did at follow-up had substantial improvements in their academic achievement (Suchert et al., 2016). No other study that we are aware of has investigated the relationship between overall MVPA and academic achievement in this manner, indicating that future research is needed to clarify this relationship. With respect to our negative results, we hypothesize students who accumulate high levels of physical activity may miss school days due to athletic commitments, have less time for homework, or accumulate less sleep (Schmidt and Van der Linden, 2015; Syvaoja et al., 2013).

4.1. Strengths and limitations

This study uses a large, longitudinal cohort of Canadian adolescents. This study considers important confounders in the relationship between physical activity and academic achievement, which has been singled out as a weakness on studies of this topic in a recent systematic review (Donnelly et al., 2016). The measures of diet, physical activity, and screen time have previously been shown to have acceptable validity this population (Leatherdale and Laxer, 2013; Wong et al., 2006; Leatherdale et al., 2014b). The use of recommendations to assess these lifestyle behaviours that are widely used and understood increases the applicability of these results. However, this study does have some limitations. The final included sample may not be representative of the general adolescent population as noted in differences between included and excluded students. The self-reported nature of all of the data is subject to recall and social desirability bias, and potentially differential reporting error. Though self-reported academic achievement is considered to be valid for high-achieving students, lower-achieving students may over report their achievement (Kuncel et al., 2005). The recall period for each of the measures also varies across behaviours – sleep and screen time were assessed as usual engagement while MVPA and diet were the previous 7 days or the past 24 h, respectively. We attempted to correct for usual MVPA by adjusting for whether the past 7 days represented usual activity, however, no such adjustment was possible for the dietary data. Adherence to some recommendations was low, most notably screen time and vegetable and fruit consumption, reducing the power to determine associations between adherence and academic achievement. Multiple statistical tests were performed for the purposes of this manuscript, increasing the likelihood that a significant association would be observed by chance alone. Finally, residual confounding for other characteristics including parental income, education level, and other sociodemographic characteristics, intellectual capacity, mental health indicators, physical fitness and other contributors to academic achievement cannot be ruled out.

5. Conclusions

Results indicate that adherence to recommendations for protein-rich foods, screen time, and vegetables and fruits show promise as intervention targets for improving academic achievement among youth over time in addition to their health benefits. Given the findings regarding number of recommendations met, school-based health promotion initiatives should considering focusing on all relevant health behaviours. Future studies may consider using objective measurements of health behaviours and academic achievement, additional measures of socioeconomic indicators, and the use of mediation models to understand if body weight status, mental health, and/or physical fitness mediate the relationship between health behaviours and academic achievement.

Declaration of Competing Interest

The authors declare there is no conflict of interest.

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