Dose–response associations between modifiable lifestyle behaviours and anxiety, depression and psychological distress symptoms in early adolescence

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Abstract

Objective: To investigate associations between key modifiable lifestyle behaviours (sleep; physical activity; fruit, vegetable and sugar-sweetened beverage consumption; screen time; alcohol use and tobacco use) and mental health among early adolescents in Australia.

Methods: Cross-sectional self-report data from 6,640 Year 7 students (M_{age}:12.7[0.5]; 50.6% male, 48.9% female, 0.5% non-binary) from 71 schools in New South Wales, Queensland and Western Australia were analysed using multivariate linear regression adjusting for sociodemographic factors and school-level clustering.

Results: All examined behaviours were associated with anxiety, depression and psychological distress ($p \leq 0.001$), with the lowest mental health symptom scores observed in participants who slept 9.5–10.5 hours per night; consumed three serves of fruit daily; consumed two serves of vegetables daily; never or rarely drank sugar-sweetened beverages; engaged in six days of moderate-to-vigorous physical activity per week; kept daily recreational screen time to 31–60 minutes; had not consumed a full standard alcoholic drink (past six months); or smoked a cigarette (past six months).

Conclusions: Targeting modifiable risk behaviours offers promising prevention potential to improve adolescent mental health; however, further longitudinal research to determine directionality and behavioural interactions is needed.

Implications for public health: While Australian Dietary, Movement and Alcohol Guidelines target physical health, findings indicate similar behaviour thresholds may offer mental health benefits.

Key words: adolescent health, mental health, lifestyle behaviours, population health, prevention

Almost half of all Australians experience a mental disorder in their lifetime and mental illness is costing the economy ~$200–220 billion per year.[1] For Australians aged 12–24, mental health and substance use disorders account for three of the five leading causes of disease burden, with anxiety disorders being the leading cause of burden in females and suicide and self-harm leading in males.[2] For younger Australians aged 5–14, mental disorders are the second highest cause of disease burden (after asthma).[3] Young people have consistently reported that mental health is one of their "top three personal concerns"[4-6] and epidemiological data suggest that 75% of all mental disorders emerge before an individual reaches 24 years of age.[7] Therefore, prevention of mental ill-health in adolescence is crucial.

There is growing evidence that lifestyle behaviours are associated with mental ill-health among youth, especially psychological distress, anxiety disorders and major depressive disorder, which are the most prevalent mental health concerns in Australian adolescents.[8,9] Six key lifestyle behaviour domains – hereafter referred to as the '**Big 6**' – have been shown to be associated with these mental health outcomes: i) diet (specifically fruit, vegetable and sugar intake); ii) physical activity; iii) recreational screen time; iv) sleep; v) tobacco use; and vi) alcohol use.[10-26] There is no established, singular mechanism through which the Big 6 are related to mental health. For diet and physical activity, emerging evidence suggests that it may be through their impact on biomarkers such as inflammation and cortisol.[27-29] With recreational screen time, it is posited that both psychosocial

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mechanisms (via harms from cyberbullying or social comparison[30,31]) and physical mechanisms (via increased sedentary behaviour and disrupted sleep patterns[19]) play a role. In the case of sleep, there is growing evidence that sleep deprivation in adolescence results in atypical development of the uncinate fasciculus tract that connects the prefrontal cortex and the amygdala in the brain, in turn impeding cognitive emotion regulation and heightening sensitivity to threat.[10,11] Similarly for tobacco, emerging evidence in rat models suggests that nicotine exposure elicits changes to the prefrontal cortex.[32] Finally for alcohol, in addition to social mechanisms,[24] neurological mechanisms have been identified in rat models, with alcohol use found to disrupt neurogenesis and induce neuroinflammation.[33] In addition to associations with mental health, the Big 6 are implicated in physical health concerns such as overweight and obesity and chronic diseases including type 2 diabetes, heart disease and cancers in the longer term.[34-37]

Epidemiological studies show that throughout adolescence, there is a general decline in protective behaviours - and increase in risk behaviours - across the Big 6 domains.[38-41] In Australia (and in many countries globally), there are National Guidelines for most of the Big 6 that indicate behavioural thresholds associated with optimum physical health and safety,[42-44] and unfortunately, the vast majority of Australian adolescents do not meet these guidelines.[45,46] Therefore, improvements in the Big 6 lifestyle domains among emerging adolescents may be associated with both physical and mental health benefits for young people, offering enormous prevention potential.

While previous studies have examined the associations between individual or subsets of the Big 6 and mental health outcomes in adolescents, there is a dearth of studies that examine *all six* domains in *early* adolescence (age 10 to 13 years). In addition, several recent reviews and studies have highlighted that existing research rarely adjusts for sociodemographic factors beyond gender when examining the relationship between lifestyle behaviours and mental health outcomes.[17,47,48] However, there is evidence that sociodemographic factors including geographic remoteness, relative affluence and cultural and linguistic diversity are associated with lifestyle behaviours[49,50] and that these same factors are known social determinants of mental health.[51] Finally, most existing studies examine proxy diagnoses (based on symptom thresholds) of depression, anxiety or severe psychological distress as the outcome/s of interest,[21,23] which facilitates interpretability but loses sensitivity to smaller or subclinical differences. Early adolescence is a time where depression and anxiety symptomology may be increasing but not yet reaching a cut point for proxy diagnosis, yet subclinical symptoms still impact an individual's quality of life and functioning.[52] To enable the prevention of mental disorders, it is essential that behaviours associated with even small, subclinical differences in mental health outcomes are identified as these may offer promising intervention targets to improve young people's quality of life.

To address these gaps in the literature, the current study utilises the largest dataset to date to examine mental health and lifestyle behaviours in Australian early adolescents (aged 11–14). Specifically, this study aims to investigate the dose–response associations between the Big 6 (sleep, physical activity, diet [fruit, vegetable and sugar-sweetened beverage consumption], screen time, tobacco use and alcohol use) and anxiety, depression and psychological distress symptomology, while adjusting for key sociodemographic factors.

Methods

Study design and procedure

This study uses baseline data from the 'Health4Life' study, a large cluster randomised controlled trial evaluating the effectiveness of a multicomponent eHealth intervention to improve the Big 6 lifestyle domains among Australian secondary school students.[53] Year 7 Students from 71 participating schools across New South Wales (NSW), Queensland (QLD) and Western Australia (WA) completed online self-report surveys in class in 2019. The Health4Life trial is registered with the Australian and New Zealand Clinical Trials Registry (ACTRN12619000431123) and has ethical approval from ten relevant committees (University of Sydney HREC2018/882, NSW Department of Education SERAP 2019006, University of Queensland 2019000037, Curtin University HRE2019-0083 and several Catholic Diocese committees). As is standard practice for school-based cluster randomised controlled trials,[54] schools were recruited through convenience and purposive sampling with strata to ensure a near-even gender split in the total sample. Further details, including sample size calculations, recruitment procedures and consent procedures are in the published study protocol.[53]

Measures

Sociodemographic factors

Sociodemographic factors included age, gender identity, cultural and linguistic diversity (CALD), relative socioeconomic position, school socio-educational advantage and school geographical remoteness. Gender identity was measured using a question from community organisation ACON, that included "male", "female", "non-binary/gender fluid", "other identity", and "prefer not to say".[55] Responses to "other identity" and "prefer not to say" were treated as missing (as the few "other identity" responses were determined to be phoney, such as "helicopter"). Three-category gender was used for descriptive analysis, but for regressions, gender was dichotomised, with "non-binary/gender fluid" treated as missing due to low numbers. CALD was defined as per recommendations from a recent Australian review[56] to include participants who were born in a non-English speaking country and/or primarily speak a language other than English at home. Relative family affluence was identified using the Family Affluence Scale III (FASIII), which has demonstrated good test–retest reliability (r=0.9) and strong correlation with parental report.[57] The FASIII generates a summed score across indicators of familial wealth (e.g. number of computers, number of bathrooms in the home, etc) as a proxy for familial socioeconomic status, as parent or carers' income, education and other socioeconomic indicators are often unknown by children and adolescents.[57] The summed score is then transformed into a normally distributed ridit score, which represents a participant's relative family affluence position within the overall sample. The Index of Socio-Educational Advantage (ICSEA) from the Australian Curriculum and Reporting Agency ascribes each school in Australia with a relative position (scaled to a normal distribution) capturing characteristics of the school student cohort including parental occupation and education level, student Indigenous status, student geographic remoteness and school remoteness.[58] Finally, the participant's school's geographical remoteness classification – major city, inner regional, outer regional, remote or very remote (per the nationally recognised Australian Statistical Geography Standard Remoteness Structure[59]) – was used as

a proxy for each individual's geographical remoteness, as many participants were unsure of their home postcode.

The Big 6 lifestyle domains (exposures)

Sleep: Average sleep duration per night was measured using the Modified Sleep Habits Survey.[60] Students were asked to reflect on the past week (separately for week nights and weekend nights) and report the time they usually: i) went to bed (12hr time – am/pm); ii) attempted sleep (12hr time); iii) took to fall asleep (hours, minutes); iv) were awake during the night (hours, minutes); and v) woke up in the morning (12hr time – am/pm). These items were then used to calculate the average hours of sleep per night in the past week (weighted to reflect weeknights and weekend nights). The Sleep Habits Survey has been shown to significantly correlate with sleep journal and actigraphy measurements in adolescents.[61] In addition, other studies have demonstrated the validity and accuracy of self-report bedtime, wake time and sleep duration among adolescents.[62] For the present study, sleep time was categorised into 30-minute intervals (<5hrs per night, 5hr to 5hr29m, 5hr30m to 5hr59min, etc., with the highest category as 12+hrs).

Diet: Three key components of diet – fruit, vegetable, and sugar-sweetened beverage (SSB) consumption – were measured using items from the Student Physical Activity and Nutrition Survey (SPANS).[63] To report their SSB consumption, students were presented with visual cues on serving sizes of beverages and asked how many cups they consume in a typical week. For fruit and vegetable intake, participants were presented with visual cues of serving sizes (reflecting National guidelines on fruit and vegetable serving sizes) and asked to report the number of servings they "usually" have per day.

Physical activity: Moderate-to-vigorous physical activity (PA) is measured using a standardised measure recommended by the Active Healthy Kids Australia Research Working Group, which allows comparison with national PA guidelines.[64] Participants are presented with an explanation of moderate-to-vigorous PA ("activity that increases your heart rate and makes you get out of breath some of the time") and are asked to report the number of days they engage in 60 minutes or more of moderate-to-vigorous PA in a "typical/usual" week.

Screen time: Recreational screen time was measured using the International Sedentary Assessment Tool.[65] Participants reported their average daily time spent sitting or lying down while watching television/videos (with examples provided including Netflix and online videos) or using an electronic device (with examples provided including gaming consoles, smartphones and tablets). Participants were instructed not to double count time, so if they were watching videos on their smartphone, they allocated time to one or the other.

Alcohol: Given the low prevalence of alcohol use in 11–13-year-olds,[49] the present study used a single binary variable where participants reported whether they had consumed a full standard alcoholic drink in the past six months. Participants were presented with a chart that indicated the number of standard drinks in a range of different alcohol types (wine, beer, spirits, premixed drinks) and sizes (can, bottle, case, etc), sourced from the Alcohol and Drug Foundation.[66]

Tobacco: Given the low prevalence of tobacco use in 11–13-year-olds,[49] the present study used a single binary variable from the Youth Risk Behavior Survey (YRBS) where participants reported whether they had smoked a cigarette ("even one or two puffs") in the last six months.[67]

Mental health outcomes

Psychological distress: Symptoms of psychological distress in the past four weeks were measured using the Kessler six-item scale (K6) where participants report the frequency of feelings such as nervousness, hopelessness, restlessness, and worthlessness among others.[68] The K6 is widely used worldwide and has demonstrated good internal consistency and predictive validity in adolescents.[69,70] In addition to a summed symptom score from 0–24 for the K6, it can be dichotomised to indicate the probable presence or absence of severe mental illness (scores <13 indicate absence SMI, scores ≥13 indicate probable SMI), and has demonstrated very good concordance with independent clinical ratings of serious mental illness.[69,70]

Anxiety: Anxiety symptoms over the past seven days were measured with the PROMIS Anxiety Paediatric (PROMIS-AP) scale, which is a 13-item scale where participants report the frequency of symptoms such as feelings of nervousness, worry, fear, dread, and difficulties relaxing, among others.[71] In psychometric testing in adolescents, the PROMIS-AP was found to have a reliability coefficient of approximately 0.85, substantially higher than two other paediatric anxiety measures used for comparison.[71] The raw scores are summed to a total score between 13 and 65 – prorated if 75% of items are answered – and this score is then converted to a T-Score, which allows the classification of anxiety severity based on published cut points.[72]

Depression: The presence of depressive symptoms over the past seven days was assessed using the Patient Health Questionnaire for Adolescents scale (PHQ-A), which is a nine-item scale where participants report the frequency of symptoms such as "feeling down, depressed, irritable or hopeless", sleep issues, tiredness, appetite and weight changes, and behavioural changes.[73] The ninth item (measuring thoughts of death and self-harm) was removed on request of the ethics board, in essence creating an adolescent version of the PHQ-8, which has demonstrated strong correlation (0.996) and minimal decreases in sensitivity and specificity in comparison with the PHQ-9.[74] The PHQ-A(8-item) is scored out of a possible range of 0–24, with scores of 0 to 4 representing no significant depressive symptoms, 5 to 9 representing mild depressive symptoms, 10 to 14 representing moderate, 15 to 19 moderately severe, and 20 to 24 representing severe.[75]

Statistical analysis

Descriptive analysis was used to determine the prevalence of anxiety, depression and psychological distress in the overall sample and by sociodemographic subgroup. Linear models (using the lm function in R) were used to examine the relationships between sociodemographic factors (age, gender, remoteness, CALD status, relative family affluence and school ICSEA tertile) and anxiety, depression and psychological distress symptomology. Multivariate linear models with analysis of variance were used to examine the associations between the lifestyle behaviours and anxiety, depression and psychological distress symptom scores, while adjusting for age, gender, CALD status and relative family affluence and clustering at the school level. Models used complete case analysis, and – as the sample size is very large and missing data was below 7% for all mental health outcomes – no further examination of missing data was conducted. Models were built using the estimatr package (lm_robust function) in R, which generates cluster-robust standard errors.

Results

Participant characteristics

Parental consent was provided for 7,164 of 9,280 Grade 7 students at recruited schools, of whom 6,779 provided personal consent. One hundred and thirty-nine students did not complete the baseline survey or withdrew after completion, leaving a final baseline sample of 6,640 students (M_{age} 12.7; *SD*=0.5; 50.6% Male-identifying, 48.9% Female-identifying, 0.5% non-binary/gender fluid). Participants were from New South Wales (53.2%), Queensland (26.9%) and Western Australia (19.8%) and the majority (89.1%) were attending schools in major city areas (the remaining 10.9% in regional areas). A total of 12.2% of participants were culturally and linguistically diverse (CALD – born in a non-English speaking country and/or primarily speak a language other than English at home). The majority of participants (76.9%) attended schools in the highest tertile of the index of socio-educational advantage (ICSEA), followed by 19.5% in the middle tertile and 3.5% in the lowest tertile.

Mental health symptomology

Overall sample

Table 1 reports mental health symptomology among the overall sample and by sociodemographic subgroup. In the total sample, the mean anxiety symptomology score was 23.06 (*SD* 10.59), with 73.2% of participants' scores indicating "none-to-slight" anxiety, 10.7% indicating "mild" anxiety, and 16.4% indicating "moderate-to-severe" anxiety. The mean depression symptomology symptom score was 5.08 (*SD* 5.15), with 57.4% of participants' scores indicating "no or minimal" depression, 25.8% indicating "mild" depression, and 16.7% indicating "moderate-to-severe" depression. The mean score for psychological distress was 6.86 (*SD* 5.40), with 85.9% of participants' scores indicating an absence of serious mental illness and 14.1% of participants' scores indicating probable serious mental illness.

Sociodemographic subgroups

Mean symptomology scores and severity prevalence by subgroup are specified in Table 1. Female-identifying participants had significantly higher scores than male-identifying participants for anxiety, depression and psychological distress symptomology, and the same was observed for culturally and linguistically diverse (CALD) participants compared to non-CALD participants. There were no statistically significant differences in the anxiety, depression or psychological distress scores for participants in regional areas compared to major city areas. Those in the highest relative family affluence tertile had significantly lower depression and psychological distress when compared to those in the lowest tertile but no significant difference was observed for anxiety. Similarly, those who attended schools in the highest ICSEA tertile had significantly lower scores for depression and psychological distress but not anxiety. Age had a weak negative association with anxiety, depression and psychological distress.

The Big 6 lifestyle domains and mental health symptomology

The prevalence of each of the behaviours in the Big 6 lifestyle domains is summarised in Table 2. When examining the association between each of the behaviours and mental health symptomology, all modelling adjusted for gender identity (dichotomized to male or female due to very low numbers identifying as gender diverse), age (excluding 11-year-olds and 14-year-olds due to very low numbers), CALD status, and relative family affluence. Cluster-robust standard errors were used to account for school-level clustering effects. Figures 1 and 2 indicate the adjusted percentage difference in symptomology for each behavioural category.

Physical activity

After adjusting for sociodemographic factors, greater frequency of moderate-to-vigorous PA was associated with lower anxiety, depression and psychological distress symptomology (anxiety: $F_{7,5800}$=3.7262, p=<0.001; depression: $F_{7,5780}$=10.3634, p<0.001; psychological distress: $F_{7,5807}$=7.3519, p<0.001). The lowest mean symptom scores were observed in participants that engaged in six days of moderate-to-vigorous PA (for ≥60 minutes per day) in a typical week, who had an average anxiety score 12% lower (Difference in M_{score}: 2.7, 95%CI: 0.8-4.7), depression score 37% lower (ΔM_{score}: 2.3, 95%CI: 1.5-3.1) and psychological distress score 30% lower (ΔM_{score}: 2.4, 95%CI: 1.5-3.4) than those who reported 0 days of 60+ minutes of moderate-to-vigorous PA.

Diet

Higher fruit consumption was associated with lower anxiety, depression and psychological distress symptomology (anxiety: $F_{7,5567}$= 5.8111, p<0.001; depression: $F_{7,5548}$=13.3192, p<0.001; psychological distress: $F_{7,5574}$=7.1183, p<0.001). The lowest mean symptom scores were observed in participants who consumed three serves of fruit in a typical day, who had an average anxiety symptom score 14% lower (ΔM_{score}: 3.3, 95%CI: 1.9-4.8), depression symptom score 37% lower (ΔM_{score}: 2.5, 95%CI: 1.9-3.2) and mean psychological distress score 22% lower (ΔM_{score}: 1.8, 95%CI: 1.0-2.5) than those who consumed less than one serve of fruit in a typical day.

Higher vegetable consumption was associated with lower anxiety, depression and psychological distress symptomology (anxiety: $F_{7,5616}$ =6.1495, p<0.001; depression: $F_{7,5597}$=10.7202, p<0.001; psychological distress: $F_{7,5623}$=5.0857, p<0.001). The lowest mean symptom scores were observed in participants who consumed two serves of vegetables in a typical day, who had an average anxiety symptom score 14% lower (ΔM_{score}: 3.5, 95%CI: 2.1-4.9), depression symptom score 34% lower (ΔMscore: 2.3, 95%CI: 1.6-3.1) and mean psychological distress score 21% lower (ΔMscore: 1.6, 95%CI: 0.9-2.2) than those who consumed less than one serve of vegetables in a typical day.

Finally, lower consumption of sugar-sweetened beverages (SSB) was associated with lower anxiety, depression and psychological distress symptomology (anxiety: $F_{6,55806}$=11.3352, p<0.001; depression: $F_{6,5786}$=21.0525, p<0.001; psychological distress: $F_{6,5812}$=13.0627, p<0.001). The lowest mean scores were observed in those who did not drink SSB, who had an average anxiety symptom score 24% lower (ΔM_{score}: 6.3, 95%CI: 3.8-8.8), an average depression score 49% (ΔM_{score}: 3.9, 95%CI: 2.6-5.1), and an average psychological distress symptom score 31% lower (ΔM_{score}: 2.6, 95%CI: 1.2-4.1) than those who drank 14 or more cups per week.

Recreational screen time

Greater daily recreational screen time was associated with higher anxiety, depression and psychological distress symptomology

Table 1: Anxiety, depression and psychological distress symptomology mean score and severity, by socio-demographic subgroup.

Anxiety symptomology: Mean PROMIS-A score and prevalence by severity category						
		Mean score (SD)	None to slight anxiety n (%)	Mild anxiety n (%)	Moderate anxiety n (%)	Severe anxiety n (%)
Total sample (n= 6,185)		23.06 (10.59)	4525 (73.2%)	659 (10.7%)	777 (12.6%)	224 (3.6%)
Gender (n= 6,172) $F_{1,\ 6079}$=256.62, p<0.001[a]	Male (n=3,047)	20.86 (9.37)	2462 (80.8%)	272 (8.9%)	247 (8.1%)	66 (2.2%)
	Female (n=3,034)	25.08 (11.10)	2004 (66.1%)	379 (12.5%)	505 (16.6%)	146 (4.8%)
	Non-binary/ gender fluid (n=28)	31.5 (15.77)	13 (46.4%)	4 (14.3%)	6 (21.4%)	5 (17.9%)
	Prefer not to say (n=63)	28.11 (14.68)	36 (57.1%)	4 (6.3%)	16 (25.4%)	7 (11.1%)
Age (n= 6,163) $F_{1,\ 6088}$=19.65, p=<0.001[b]	11-years (n= 8)	25.63 (16.34)	5 (62.5%)	0 (0.0%)	2 (25.0%)	1 (12.5%)
	12-years (n= 2208)	23.84 (11.01)	1553 (70.3%)	239 (10.8%)	330 (14.9%)	86 (3.9%)
	13-years (n= 3882)	22.59 (10.28)	2903 (74.8%)	412 (10.6%)	435 (11.2%)	132 (3.4%)
	14-years (n= 65)	22.51 (9.89)	50 (76.9%)	6 (9.2%)	7 (10.8%)	2 (3.1%)
Geographic remoteness (n= 6,185) $F_{1,\ 6183}$=1.51, p=0.22	Major city (n= 5,572)	23.12 (10.63)	4053 (72.7%)	600 (10.8%)	716 (12.9%)	203 (3.6%)
	Regional (n=613)	22.45 (10.15)	472 (77.0%)	59 (9.6%)	61 (9.9%)	21 (3.4%)
Cultural and Linguistic diversity (n= 6,176) $F_{1,6174}$=22.09, p<0.001	Non-CALD (n=5,429)	22.82 (10.40)	4014 (73.9%)	572 (10.5%)	657 (12.1%)	186 (3.4%)
	CALD (n=747)	24.75 (11.72)	506 (67.7%)	84 (11.2%)	120 (16.1%)	37 (5.0%)
Relative affluence tertile (n=6,005) $F_{2,6002}$=2.69, p=0.07	Low relative affluence (n=1,751)	23.33 (10.81)	1257 (71.79%)	196 (11.19%)	231 (13.19%)	67 (3.83%)
	Medium relative affluence (n=2,661)	22.69 (10.21)	1990 (74.78%)	265 (9.96%)	321 (12.06%)	85 (3.19%)
	High relative affluence (n=1,593)	23.32 (10.97)	1149 (72.13%)	176 (11.05%)	201 (12.62%)	67 (4.21%)
School ICSEA tertile (n=6,185) $F_{2,6182}$=1.26, p=0.28	First tertile (n=229)	24.05 (11.46)	154 (67.25%)	29 (12.66%)	35 (15.28%)	11 (4.80%)
	Second tertile (n=1,198)	23.20 (10.45)	875 (73.04%)	122 (10.18%)	164 (13.69%)	37 (3.09%)
	Third tertile (n=4,758)	22.97 (10.58)	3496 (73.48%)	508 (10.68%)	578 (12.15%)	176 (3.70%)

Depression symptomology: Mean PHQA-8 score and prevalence by severity category							
		Mean score (SD)	No or minimal depression	Mild depression	Moderate depression	Moderately severe depression	Severe depression
Total sample (n=6,193)		5.08 (5.15)	3557 (57.4%)	1597 (25.8%)	624 (10.1%)	277 (4.5%)	138 (2.2%)
Gender (n=6,180) $F_{1,6088}$=74.16, p<0.001[a]	Male (n=3052)	4.46 (4.93)	1913 (62.7%)	746 (24.4%)	231 (7.6%)	97 (3.20%)	66 (2.2%)
	Female (n=3038)	5.58 (5.19)	1604 (52.8%)	826 (27.2%)	377 (12.4%)	168 (5.50%)	146 (4.8%)
	Non-binary/ gender fluid (n=28)	9.54 (7.60)	9 (32.1%)	10 (35.7%)	2 (7.1%)	2 (7.10%)	5 (17.9%)
	Prefer not to say (n=62)	8.58 (7.09)	23 (37.1%)	12 (19.4%)	13 (21%)	9 (14.50%)	7 (11.1%)
Age (n=6,171) $F_{1,6096}$= 4.68, p=0.03	11-years (n= 8)	9.50 (9.71)	4 (50.0%)	0 (0.0%)	0 (0.0%)	3 (37.5%)	1 (12.5%)
	12-years (n= 2212)	5.25 (5.16)	1217 (55.0%)	593 (26.8%)	248 (11.2%)	107 (4.8%)	47 (2.1%)
	13-years (n= 3886)	4.95 (5.10)	2284 (58.8%)	989 (25.5%)	365 (9.4%)	161 (4.1%)	87 (2.2%)
	14-years (n= 65)	5.60 (5.42)	37 (56.9%)	14 (21.5%)	9 (13.8%)	4 (6.2%)	1 (1.5%)
Geographical remoteness (n=6,193) $F_{1,\ 6191}$=0.02, p=0.88	Major city (n=5579)	5.08 (5.14)	3196 (57.3%)	1444 (25.9%)	569 (10.2%)	245 (4.4%)	203 (3.6%)
	Regional (n=614)	5.03 (5.19)	361 (58.8%)	153 (24.9%)	55 (9.0%)	32 (5.2%)	21 (3.4%)
Cultural and Linguistic diversity (n=6,183) $F_{1,6181}$=7.74, p=0.01	Non-CALD (n=5437)	5.00 (5.05)	3137 (57.7%)	1412 (26.0%)	547 (10.1%)	231 (4.2%)	186 (3.4%)
	CALD (n=746)	5.56 (5.72)	416 (55.8%)	181 (24.3%)	76 (10.2%)	46 (6.2%)	37 (5.0%)
Relative affluence tertile (n=5,984) $F_{2,5981}$=4.64, p=0.01	Low relative affluence (n=1,743)	5.37 (5.42)	959 (55.02%)	457 (26.22%)	195 (11.19%)	80 (4.59%)	67 (3.83%)
	Medium relative affluence (n=2,656)	4.89 (4.92)	1557 (58.62%)	684 (25.75%)	264 (9.94%)	106 (3.99%)	85 (3.19%)
	High relative affluence (n=1,585)	5.02 (5.22)	929 (58.61%)	393 (24.79%)	143 (9.02%)	83 (5.24%)	67 (4.21%)

(continued)

TABLE 1. Continued

Depression symptomology: Mean PHQA-8 score and prevalence by severity category							
		Mean score (SD)	No or minimal depression	Mild depression	Moderate depression	Moderately severe depression	Severe depression
School ICSEA tertile (n=6,193) $F_{2,6190}=6.98$, $p<0.001$	Lowest tertile (n=226)	6.26 (6.10)	115 (50.88%)	55 (24.34%)	26 (11.50%)	21 (9.29%)	11 (4.80%)
	Middle tertile (n=1,203)	5.20 (5.22)	676 (56.19%)	305 (25.35%)	136 (11.31%)	64 (5.32%)	37 (3.09%)
	Highest tertile (n=4764)	4.99 (5.07)	2766 (58.06%)	1237 (25.97%)	462 (9.70%)	192 (4.03%)	176 (3.70%)

Psychological distress symptomology: Mean K6 score and prevalence of serious mental illness (SMI)				
		Mean score (SD)	No SMI (K6<13)	SMI (K6 ≥13)
Total sample (n=6278)		6.86 (5.40)	5392 (85.9%)	886 (14.1%)
Gender (n=6,265) $F_{1,6170}=74.81$, $p<0.001$[a]	Male (n=3099)	6.21 (5.16)	2770 (89.4%)	66 (2.2%)
	Female (n=3073)	7.38 (5.46)	2555 (83.1%)	146 (4.8%)
	Non-binary/ gender fluid (n=28)	10.71 (7.12)	19 (67.9%)	5 (17.9%)
	Prefer not to say (n=65)	11.26 (7.04)	37 (56.9%)	7 (11.1%)
Age (n=6,256) $F_{1,6180}= 3.81$, $p=0.05$	11-years (n= 8)	8.50 (10.24)	5 (62.5%)	3 (37.5%)
	12-years (n= 2238)	7.04 (5.37)	1906 (85.2%)	332 (14.8%)
	13-years (n= 3944)	6.76 (5.40)	3403 (86.3%)	541 (13.7%)
	14-years (n= 66)	6.53 (4.71)	60 (90.9%)	6 (9.1%)
Geographic remoteness (n= 6,278) $F_{1,6276}=1.65$, $p=0.20$	Major city (n=5,660)	6.89 (5.43)	4846 (85.6%)	203 (3.6%)
	Regional (n=618)	6.58 (5.14)	546 (88.4%)	21 (3.4%)
Cultural and Linguistic diversity (n= 6,268) $F_{1,6266}=13.25$, $p<0.001$	Non-CALD (n=5511)	6.77 (5.32)	4764 (86.4%)	186 (3.4%)
	CALD (n=757)	7.53 (5.87)	620 (81.9%)	37 (5.0%)
Relative affluence tertile (n=6,012) $F_{2,6009}=4.35$, $p=0.01$	Low relative affluence (n=1,752)	7.15 (5.58)	1480 (84.47%)	67 (3.83%)
	Medium relative affluence (n=2,665)	6.72 (5.29)	2319 (87.02%)	85 (3.19%)
	High relative affluence (n=1,595)	6.67 (5.31)	1372 (86.02%)	67 (4.21%)
School ICSEA tertile (n=6,278) $F_{2,6275}=6.02$, $p=0.002$	Lowest tertile (n=229)	8.00 (6.31)	181 (79.04%)	11 (4.80%)
	Middle tertile (n=1,210)	6.99 (5.44)	1039 (85.87%)	37 (3.09%)
	Highest tertile (n=4,839)	6.78 (5.34)	4172 (86.22%)	176 (3.70%)

[a]Gender F-test only between male/female due to small number of non-binary participants.
[b]Age F-test only between ages 12/13 due to low numbers in 11 & 14-years.

Table 2: Prevalence of behaviours across the Big 6 lifestyle domains.

Lifestyle behaviour	Response	n (%)
Alcohol: Consumed a full standard drink in the past 6months (n=6,346)	No	6165 (97.1%)
	Yes	181 (2.9%)
Tobacco: Smoked a cigarette (including a puff) in past 6months (n=6,306)	No	6209 (98.5%)
	Yes	97 (1.5%)
Fruit: Number of serves "usually" consumed per day (n=6,444)	Less than 1 serve per day	454 (7.0%)
	1 serve per day	1038 (16.1%)
	2 serves per day	1874 (29.1%)
	3 serves per day	1440 (22.3%)
	4 serves per day	746 (11.6%)
	5 serves per day	329 (5.1%)
	6 serves per day	91 (1.4%)
	More than 6 servings per day	195 (3.0%)
	Don't know	277 (4.3%)
Vegetables: Number of serves "usually" consumed per day (n=6,439)	Less than 1 serve per day	419 (6.5%)
	1 serve per day	1094 (17.0%)
	2 serves per day	1565 (24.3%)
	3 serves per day	1361 (21.1%)
	4 serves per day	924 (14.4%)
	5 serves per day	462 (7.2%)
	6 serves per day	206 (3.2%)
	More than 6 serves per day	185 (2.9%)
	Don't know	223 (3.5%)
Sugar-sweetened beverage: Amount and frequency of SSB "usually" consumed over a week (n=6,466)	Never/ Rarely drink	2561 (39.6%)
	1 cup or less a WEEK	2142 (33.1%)
	2 to 4 cups a WEEK	1058 (16.4%)
	5 to 6 cups a WEEK	275 (4.3%)
	1 cup a DAY	186 (2.9%)
	1½ cups or more a DAY	98 (1.5%)
	2 or more cups a DAY	146 (2.3%)
Screen time: Average hours' recreational screen time per day in the past week	≤ 1hr	231 (3.9%)
	>1hr ≤ 2hr	671 (11.3%)
	>2hr ≤ 3hr	972 (16.4%)
	>3hr ≤ 4hr	899 (15.2%)
	>4hr ≤ 5hr	820 (13.8%)
	>5hr ≤ 6hr	667 (11.3%)
	>6hr ≤ 7hr	473 (8.0%)
	>7hr ≤ 8hr	360 (6.1%)
	>8hr	832 (14.0%)
Sleep: Average hours' sleep per night in the past week	<5hrs	183 (3.0%)
	5hr to 5hr59min	206 (3.4%)
	6hr to 6hr59min	400 (6.6%)
	7hr to 7hr59min	892 (14.8%)
	8hr to 8hr59min	1878 (31.2%)
	9hr to 9hr59m	1810 (30.0%)
	10hr to 10hr59min	502 (8.3%)
	11hr to 11hr59min	131 (2.2%)
	12+hrs	24 (0.4%)
Moderate-to-vigorous physical activity: Number of days of 60mins+ MVPA in a typical week (n=6,394)	No days	257 (4.0%)
	1 day	480 (7.5%)
	2 days	878 (13.7%)
	3 days	1086 (17.0%)
	4 days	1071 (16.8%)
	5 days	915 (14.3%)
	6 days	542 (8.5%)
	All days	1165 (18.2%)

(anxiety: $F_{16,5308}$=8.4365, p<0.001; depression: $F_{16,5290}$=15.5914, p<0.001; and psychological distress: $F_{16,5314}$=13.7356, p<0.001). As shown in Table 2, the average recreational screen time varied widely in the sample. The lowest mean anxiety, depression and psychological distress scores were observed in those who reported an average of 31 to 60 minutes of recreational screen time per day. This group had a mean anxiety symptom score 22% lower (ΔM_{score}: 5.2, 95%CI: 3.7-6.7), mean depression score 57% lower (ΔM_{score}: 3.4, 95%CI: 2.7-4.2), and mean psychological distress score 48% lower (ΔM_{score}: 3.7, 95%CI: 3.0-4.4) compared to those who engaged in eight or more hours of recreational screen time per day.

Sleep duration

Greater sleep duration was associated with lower anxiety, depression and psychological distress symptomology (anxiety: $F_{15,5365}$=14.4364, p<0.001; depression: $F_{15,5349}$=29.2624, p<0.001; psychological distress: $F_{15,5372}$=22.2177, p<0.001). The lowest mean anxiety scores were observed in those who slept an average of 10–10.5 hours per night, who had a score 30% lower (ΔM_{score}: 7.8, 95%CI: 5.3-10.3) than those who slept for less than five hours. For depression and psychological distress, the lowest mean scores were observed in those who slept an average of 9.5–10 hours per night, who had a mean depression score 64% lower (ΔM_{score}: 5.2, 95%CI: 6.0-4.3), and a mean psychological distress score 48% lower (ΔM_{score}: 4.4, 95%CI: 3.1-5.7) than those who slept for less than five hours.

Alcohol use

Having not consumed a full standard drink in the prior six months was associated with an anxiety symptom score 20% lower (ΔM_{score}: 5.5, 95%CI: 3.2-7.8, $F_{1,5807}$=43.3169, p<0.001), a depression score 38% lower (ΔM_{score}: 3.0, 95%CI: 2.0-4.0, $F_{1,5787}$=52.0128, p<0.001), and a psychological distress score 28% (ΔM_{score}: 2.5, 95%CI: 1.5-3.4, $F_{1,5813}$=33.1058, p<0.001) compared to those who had consumed a standard drink in the prior six months.

Tobacco use

Having not smoked a cigarette in the prior six months was associated with an anxiety symptom score 29% lower (ΔM_{score}: 8.6, 95%CI: 4.9-12.3, $F_{1,5800}$=58.5171, p<0.001), a depression score 49% lower (ΔM_{score}:4.6, 95%CI: 2.6-6.3, $F_{1,5780}$=67.9652, p<0.001), and a psychological distress score 39% lower (ΔM_{score}: 4.2, 95%CI: 5.3-3.0, $F_{1,5806}$=51.9500, p<0.001) than those who had smoked a cigarette in the prior six months.

Multi-behaviour model

In a model including all behaviours and adjusting for sociodemographic factors, the relationship with anxiety remained significant for sleep ($F_{15,4638}$=8.0005, p<0.001), screen time ($F_{16,4638}$=3.5601, p<0.001) and tobacco-use ($F_{1,4638}$=9.1452, p=0.003). The relationship with depression remained significant for moderate-to-vigorous PA ($F_{7,4623}$=2.2358, p=0.03), fruit consumption ($F_{7,4623}$ =2.3038, p=0.02), SSB consumption ($F_{6,4623}$=2.7934, p=0.01), sleep ($F_{15,4623}$=14.9503, p<0.001), screen time ($F_{16,4623}$=5.7318, p<0.001) and tobacco-use ($F_{1,4623}$=9.9597, p=0.002). Finally, the relationship with psychological distress remained significant for moderate-to-vigorous PA ($F_{7,4645}$=2.2902, p=0.03), sleep ($F_{15,4645}$=10.9472, p<0.001), screen time ($F_{16,4645}$=4.5937, p<0.001)

Figure 1: Percentage difference in mean mental health symptomology scores between behavioural categories, compared to reference categories as indicated.

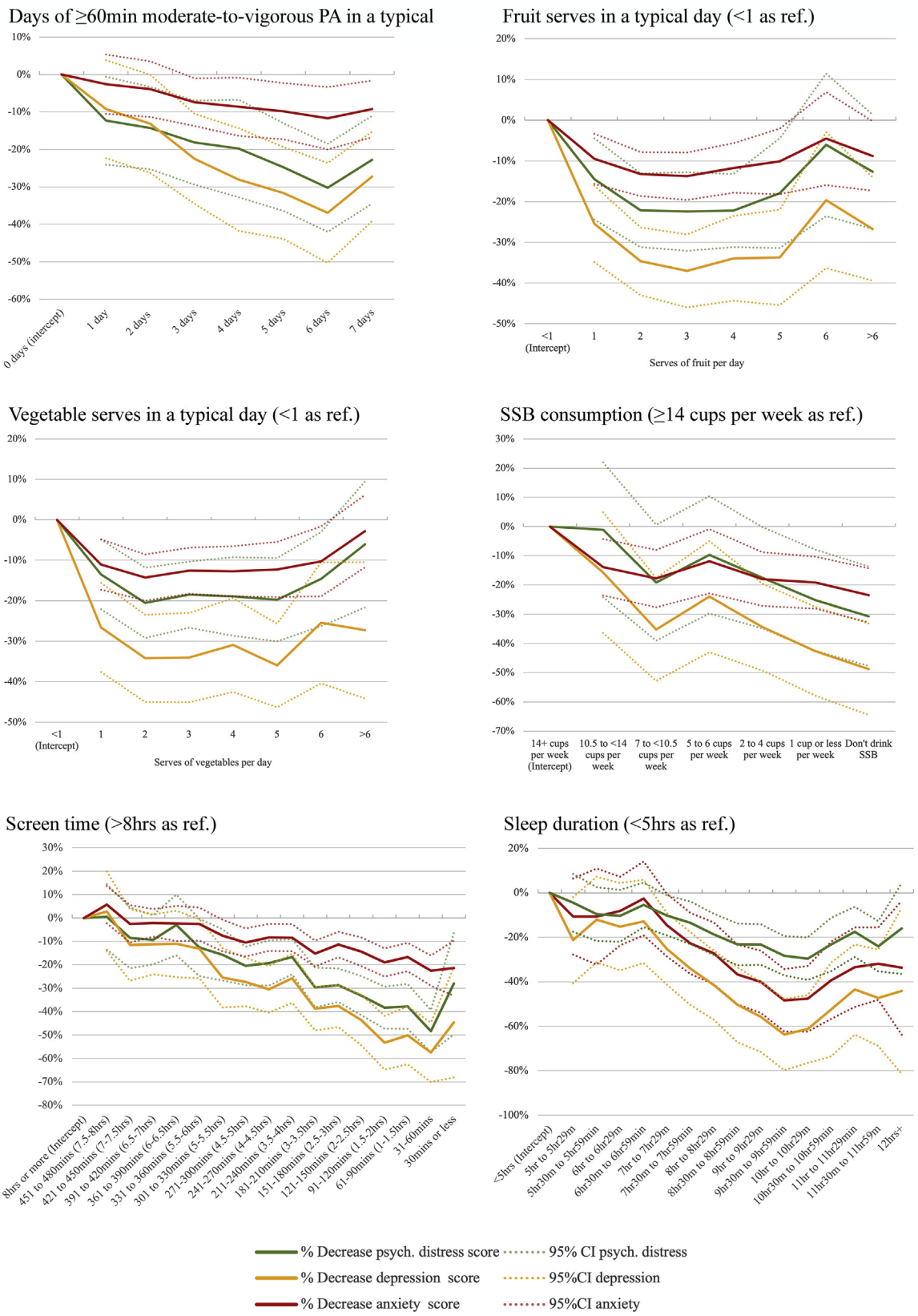
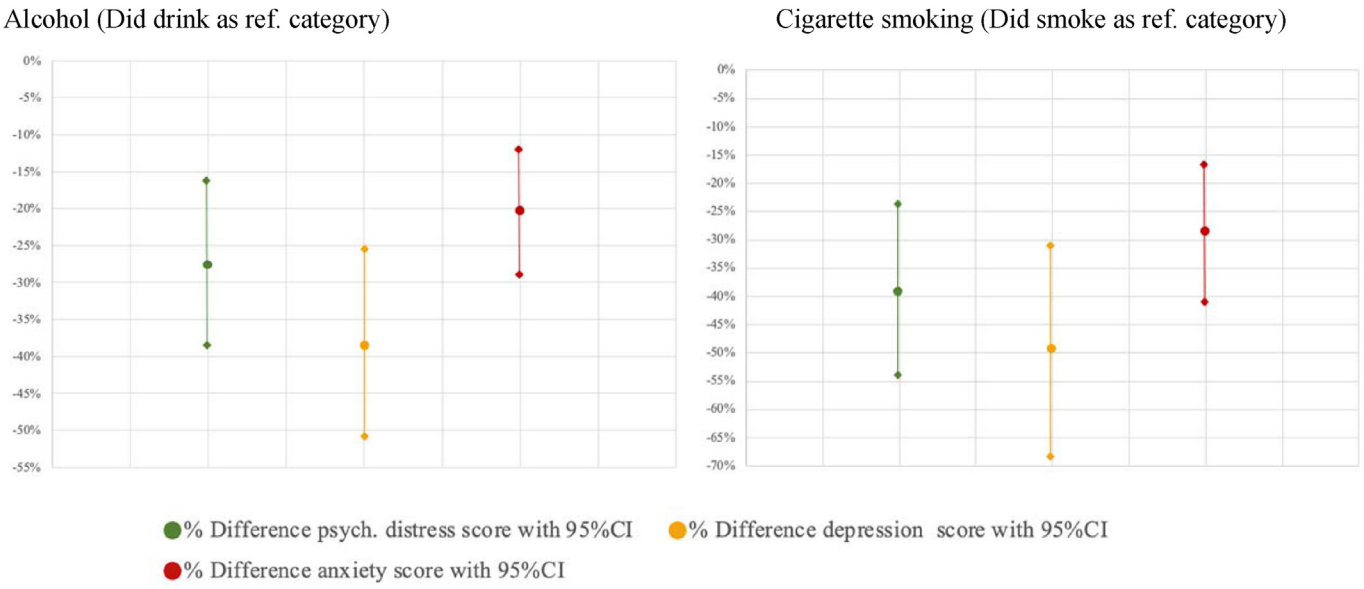


Figure 2: Percentage difference in mean mental health symptomology scores in those who didn't consume a full standard drink or smoke a cigarette in the past 6 months, compared to those who did do so as reference category.



and tobacco-use ($F_{1,4645}$=18.3207, p<0.001). Multicollinearity was low across all the behaviours (VIF <1.9), suggesting independence.

Discussion

This is the first study to examine a comprehensive set of six key lifestyle domains (the 'Big 6': sleep, moderate-to-vigorous physical activity, diet [fruit, vegetable and SSB consumption], screen time, tobacco use and alcohol use) and associations with mental health in early adolescents (age 10–13 years), building on previous research that has identified associations among older adolescents and adults.[23] These results show clear associations between the Big 6 and symptoms of common mental health disorders among this cohort of early adolescent Australians.

Mental health symptoms were common among this large cohort (n=6,640, M_{age}=12.7). with 16% reporting moderate-to-severe anxiety, 17% reporting moderate-to-severe depression, 14.1% indicating high psychological distress and a large portion displaying sub-clinical symptoms. These rates are higher than the most recent nationally representative Young Minds Matter Survey (2013-14),[76] consistent with global evidence that prevalence is increasing in adolescents,[77] and demonstrating the importance of identifying methods to improve mental health in this age group.

This study explored a comprehensive set of social determinants of mental health. Consistent with recent findings from a large review across 73 countries,[77] female-identifying participants had significantly higher mental ill-health symptomology than male-identifying participants. There is a scarcity of research exploring the association between cultural and linguistically diversity (CALD) and mental health among Australian adolescents; the present study fills an important gap, finding that CALD participants had significantly higher mental ill-health symptomology than non-CALD participants. This is consistent with a small 2001 study, which found that Asian-Australian high school students reported higher levels of depression than Anglo-Australian students.[78] Depression and psychological distress symptoms were both higher in those of lower socioeconomic status, which aligns with a large body of literature,[79,80] however, there was no significant difference observed for anxiety. Older age showed a weak association with reduced anxiety, depression and psychological distress, which is in contrast to a significant body of research showing that the prevalence of these conditions increases over adolescence.[81] However, the age range of the present study was narrow and the observed effect size was small, thus not strongly contesting these well-established epidemiological trends.

After controlling for age, gender, cultural and linguistic diversity, relative family affluence and school socio-educational advantage, all Big 6 domains were associated with anxiety, depression and psychological distress, with the lowest mental health symptom scores observed in participants who slept 9.5–10.5 hours per night; consumed three serves of fruit daily; consumed two serves of vegetables daily; never or rarely drank sugar-sweetened beverages; engaged in six days of moderate-to-vigorous PA per week; kept daily recreational screen time to 31–60 minutes; had not consumed a full standard alcoholic drink in the past six months; or had not smoked a cigarette in the past six months. Of note is that individuals reporting the highest measured dose of the 'healthy' behaviours did not always have the best mental health outcomes, as indicated by the U-shaped dose association for fruit and vegetable consumption, and slightly higher mental ill-health symptoms in those who slept greater than 11 hours (Figure 1). However, these individuals at the highest dose of healthy behaviours still had lower mental ill-health symptoms than those at the lowest dose. When all behaviours were modelled together, most remained significantly associated with depression and psychological distress, while sleep, screen time and tobacco use remained significant for anxiety. Most participants had not consumed a full standard drink in the past six months and most had not smoked a cigarette in the past six months; however, the portion in the optimum range for sleep, screen time, diet and physical activity was low (Table 2). This is consistent with existing research demonstrating that only 2% of Australian adolescents meet all three *24-hour Movement Guidelines* (covering sleep, screentime and physical activity), and only

13% and 71% of adolescents meet the vegetable and fruit guidelines, respectively.[45,46]

Existing intervention research shows that modifying adolescent behaviours in each of these Big 6 domains is achievable, with school-based programs presenting a commonly used method of universal delivery.[82-85] Evidence is limited on the secondary benefits of these interventions in improving mental health outcomes as these have not typically been assessed during evaluation.[82,86] However, provided further longitudinal research confirms the directionality of the associations between these behaviours and mental health, intervening to target these behaviours may offer a substantial potential to improve *both* physical and mental health outcomes.

Limitations and opportunities for future research

Like the Australian Guidelines, the present study considers each behaviour and its associations with mental health individually. Future research would benefit from the development of a combined lifestyle behaviour metric that accounts for ratios of 'healthy' to 'unhealthy' behaviours and enables exploration of the relative strength of association for each of the behaviours and mental health. Further, despite being a large, multi-state sample, with a close to 50/50 gender split; the sample was not nationally representative and there was not an even split of schools across socio-educational tertiles, so findings may be subject to selection bias. In addition, findings are based on a self-report survey and although self-report of these health behaviours in adolescence has been shown to be largely reliable,[62,87-89] findings may be subject to recall or social desirability bias. While the present study examines tobacco use through cigarette smoking, future research should also examine e-cigarette use, given its rising prevalence in younger people. Finally, the present study is cross-sectional in design and future research is needed to examine the directionality of associations between the Big 6 lifestyle domains and mental health throughout adolescence.

Implications for public health policy and practice

Australia has national guidelines and recommendations for diet, movement, alcohol use, and tobacco use, which recommend that: a) young people aged 9–17 consume two serves of fruit and five serves of vegetables per day and limit the consumption of SSBs; b) young people aged 5–13 years sleep for 9–11 hours per day; c) young people aged 5–17 years engage in at least 60 minutes of moderate-to-vigorous PA seven days per week; d) young people aged 5–17 years keep recreational screen time to 2 hours or less; e) young people aged under 18 years do not consume any alcohol; and f) all Australians avoid tobacco use.[42-44,90] These guidelines are predominately based on evidence for physical health benefits,[42-44] however the present study found that similar thresholds are associated with lower mental disorder symptomology. Provided further longitudinal research confirms the directionality of these associations, public health initiatives could address *both* physical and mental health outcomes in adolescents through targeting improvements in the Big 6, thus reducing the substantial disease burden from chronic diseases and mental disorders.

Ethics

The Health4Life trial is registered with the Australian and New Zealand Clinical Trials Registry (ACTRN12619000431123) and has ethical approval from ten relevant committees (University of Sydney HREC2018/882, NSW Department of Education SERAP 2019006, University of Queensland 2019000037, Curtin University HRE2019-0083 and several Catholic Diocese committees).

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Conflict of interest

The authors have no conflicts of interest to report.

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