



# Physical activity trajectories from childhood to late adolescence and their implications for health in young adulthood

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## ABSTRACT

Physical activity has been associated with physical and mental health across the life course, yet few studies have used group-based trajectory modeling to examine the effect of longitudinal patterns of physical activity during childhood and adolescence on adult health outcomes. The Raine Study data from Gen2 follow-ups at 8, 10, 14, 17, 20, and 22 years collected between 1998 and 2014 were used. Latent class analysis identified trajectories using parent-reported physical activity for ages 8 to 17. Associations between trajectories and physical and mental health outcomes at ages 20 and 22 were explored, adjusting for current physical activity and considering sex interactions. Analysis in 2019 identified three trajectories: low (13%), mid (65%) and high (22%) physical activity ( $n = 1628$ ). Compared to the low-activity trajectory, those in the high-activity trajectory had lower adiposity, insulin, HOMA-IR and fewer diagnosed disorders, higher HDL-cholesterol, and faster cognitive processing. For example, those in the high-activity trajectory had lower percent body fat at age 20 compared to those in the mid-activity ( $-4.2\%$ , 95%CI:  $-5.8, -2.7$ ) and low-activity ( $-9.5\%$ , 95%CI:  $-11.7, -7.2$ ) trajectories. Physical activity trajectories showed different associations between sexes for self-reported physical and mental health, BMI, systolic blood pressure, and depression symptoms. Being in the high- or mid-activity trajectory was associated with a more favorable cardiometabolic and mental health profile in young adulthood. Strategies are needed to help less active children to increase physical activity throughout childhood and adolescence to improve young adult health outcomes.

## 1. Introduction

Physical activity has been associated with physical and mental health across the life course (2018 Physical Activity Guidelines Advisory Committee, 2018). Childhood and adolescence are critical periods not only for developing adult habits, as physical activity tracks throughout these periods (Arundell et al., 2013; Telama et al., 2005), but also because behaviors during these periods may directly affect later adult health (Allender et al., 2008). Traditional, longitudinal analyses have examined population changes in behavior across time but not sub-groups that may have specific trajectories of behavior (Arundell et al., 2013; Telama et al., 2005). Latent class analysis, or other mixture modeling, identifies groups of individuals with similar trajectories that enable the identification of predictors, outcomes, and targets for

intervention to improve later outcomes. Additionally, using latent class analysis or other trajectory modeling, allows researchers to summarize complex patterns of data across the life course instead of using single data points (Warren et al., 2015). This type of analysis allows the overall developmental course of the behaviors to be examined.

Importantly, one utility of identifying differences in patterns of physical activity behavior may be to predict later health outcomes. A recent review by Lounassalo et al. examined studies that account for group-based patterns of physical activity across time (Lounassalo et al., 2019). Of the 11 examining trajectories in childhood, only three examined how these trajectories were associated with health outcomes. Two examined moderate-to-vigorous physical activity (MVPA) trajectories from age 5 to 17 and 19 years from the Iowa Bone Study in the U.S. (Janz et al., 2014; Kwon et al., 2015) One identified 3 trajectories

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of physical activity of high active decreasing, active decreasing, and inactive (Janz et al., 2014); and the other identified 4 trajectories of consistently active, substantially decreasing, decreasing, and consistently inactive. These trajectories showed relationships with bone health at age 17 (Janz et al., 2014) and obesity trajectories through age 19 (Kwon et al., 2015), although only limited physical health outcomes were reported. Howie et al. identified three sex-specific trajectories of sports participation from ages 5 to 17 in Australian children and showed associations with multiple physical and mental health outcomes at age 20 (Howie et al., 2016), importantly only one type of physical activity, sports, was included. Organized sport, however, has multiple components, such as social interaction (Howie et al., 2018), that may differentially contribute to health outcomes compared to broad physical activity. More recent studies that have identified trajectories of physical activity have also not examined associations with later health outcomes (Cohen et al., 2019; Pate et al., 2019). The few studies in adults that have used trajectory methods to examine long-term patterns of physical activity and health outcomes have shown associations with cardiovascular disease (Aggio et al., 2018) and mortality (Mok et al., 2019). However, both of these studies were in middle-aged to older adults (Aggio et al., 2018; Mok et al., 2019). One reason for the lack of long-term trajectories may be due to a lack of consistent physical activity measures within cohort studies across life stages. Identifying behavioral patterns associated with earlier health risk allows for earlier points of intervention and prevention.

Currently, there are no reported studies examining sub-groups of long-term patterns of physical activity across childhood and adolescence with a range of physical and mental health outcomes in young adulthood. Identifying group-based physical activity trajectories associated with poor health outcomes will help to target populations and design interventions for critical time points using a lifespan approach. This study aimed to identify latent class physical activity trajectories from childhood to late adolescence in a cohort of Australians and determine the associations with physical and mental health in young adulthood, accounting for current adult physical activity.

## 2. Methods

### 2.1. The Raine Study

We analyzed data from the Raine Study, which recruited pregnant mothers between May 1989 and November 1991, from King Edward Memorial Hospital and surrounding private practices in Perth, Western Australia (Straker et al., 2017). The 2868 live births Generation 2 (Gen2) participants have been followed-up at regular intervals from birth to 22 years of age. Detailed methods of the Gen2–22 year follow-up, from March 2012 to January 2014 (Straker et al., 2015a), physical activity findings (McVeigh et al., 2016a), and representativeness of the study sample (Straker et al., 2017) have been published. Participants at each timepoint were similar to non-participants, except for a gradual reduction in participation of infants of Aboriginal and Torres Strait Islander ethnicity (Straker et al., 2017). Details of clinical assessment protocols and questionnaires, are available at [www.rainestudy.org.au](http://www.rainestudy.org.au). Data for the current study were from ages 8, 10, 14, 17, 20, and 22 years and demographic information were collected from earlier assessments. Written, informed consent was obtained from the parents until the children reached 17 years and were able to provide consent. Follow-ups were approved by ethics committees at King Edward Memorial Hospital, Princess Margaret Hospital for Children, the University of Western Australia, and/or Curtin University.

### 2.2. Measures

#### 2.2.1. Physical activity trajectory data

Parents completed a survey when the child was 8, 10, 14, and 17 years of age. A single-item was used to create an ordinal activity

score. At age 8, parents answered the question, “How would you classify your child's current level of activity” with the responses “Sedentary – gets very little exercise” (score = 1, “less active”), “Slightly active – gets some exercise” (score = 2, “equal active”), and “Active – Is involved in organized activity 2 or 3 times per week” (score = 3, “more active”). At ages 10, 14, and 17, parents answered the question, “How would you compare the physical activity level of your child with that of other children of the same age?”, with responses “My child is less active than other children” (score = 1, “less active”), “My child is as active as other children” (score = 2, “equal active”), “My child is more active than other children” (score = 3, “more active”), or “I am unable to make the comparison” (excluded from analysis). To provide evidence for validity of the single-item, these responses were compared to other available measures of physical activity or related constructs at each timepoint as seen in Table 2.

#### 2.2.2. Other physical activity data

To provide validity evidence for the trajectories, additional physical activity measures from young adulthood were compared between the trajectories (see Table 2). Participants completed the International Physical Activity Questionnaire (IPAQ) long at 17 and short at 20 and 22 years (Craig et al., 2003), with accelerometry collected at age 22. Participants wore a hip-mounted activity monitor (Actigraph GT3X+, Pensacola, FL) for 24 h/day for seven days except in water. Vertical axis data in 60 s epochs were processed using a custom automated algorithm (McVeigh et al., 2016b) to identify waking wear time in SAS (v9.3, SAS Institute, Cary, NC, USA). Daily minutes of MVPA were determined using age-appropriate cutpoints ( $\geq 1952$  counts per minute) (Freedson et al., 1998). Participants were included in analyses if they had at least one day of 10+ hours of wear.

#### 2.2.3. Physical health outcome data

Participants completed the physical component scale of the Short Form-12 Health Survey version 2 (SF-12) (Gandek et al., 1998) at 20 and 22 years, which has been cross-validated in Australian populations (Sanderson and Andrews, 2002), as a measure of self-rated, perceived physical health. Scores range from 0 to 100 with higher scores indicating better physical health. Adiposity was assessed during a clinical assessment with body fat percentage measured by dual x-ray absorptiometry (DXA) (Norland XR-36 densitometer, Norland Medical Systems, Inc., Fort Atkinson, WI, USA) at age 20 and height and weight used to calculate body mass index (BMI) at 20 and 22 years (Straker et al., 2015a). At the age 22 follow-up, resting supine blood pressure was assessed along with a fasting blood sample analyzed for total-, LDL-, and HDL-cholesterol, insulin, glucose, high-sensitivity C-reactive protein in the PathWest Laboratory at Royal Perth Hospital (Straker et al., 2015a). Homeostatic model assessment of insulin resistance (HOMA-IR) was calculated (Demmer et al., 2016). Participants reported the number of current diagnosed disorders (e.g. asthma, diabetes, eating disorders).

#### 2.2.4. Mental health outcome data

Participants completed the mental component scale of the SF-12 (Gandek et al., 1998) at 20 and 22 years, as a measure of self-rated, perceived mental health. At age 22, participants completed the Depression Anxiety Stress Scales-short form (DASS-21) (Henry and Crawford, 2005), with higher scores indicating poorer mental health, maximum 42. At age 22, participants completed a computerized battery of cognitive tests (Cogstate Ltd., Melbourne, Australia) (Straker et al., 2015a). Card detection (speed of processing), card identification (vigilance and visual attention) and one back (attention and working memory) tasks were used (Falletti et al., 2003). Reaction times are presented as log10-transformed values.

### 2.3. Statistical analysis

To determine trajectories of physical activity, latent class analysis was conducted using data from ages 8, 10, 14, and 17 (participants were included if they had data on 3+ timepoints). The indicator variable was the ordinal, parent-reported relative activity (less, equal, or more active than peers). Sex was included as an active covariate in model estimation, meaning that posterior probability for membership for each trajectory could vary as a function of sex. Models were run in LatentGold software v 5.1.0.16230 (Arlington, MA) using 200 random sets and 100 iterations. The fit of the model was determined using the following criteria (Collins and Lanza, 2010; Nagin, 2005): 1) Probability and proportion assigned, 2) Average posterior probability > .7, 3) Odds of correct classification > 5, 4) % of iterations converging on the same solution, 5) Number of cluster model selected from those with satisfactory overall fit, 6) the minimum values of the goodness of fit measures Bayes Information Criterion (BIC), Akaike's Information Criterion (AIC) as indicators of the optimal number of classes, 7) the degree to which the trajectory classes identified captured distinct and meaningful patterns in the data, and 8) the quality of the model based on entropy R (Arundell et al., 2013), average posterior probability for each trajectory class, odds of correct classification and classification error. Sensitivity analyses explored separate models for males and females, and including individuals with no missing time points. Trajectories of similar size and pattern were identified in all models, thus the model for the combined sex, one time point missing is presented, with differences between sensitivity analyses discussed in text and full results presented in Supplemental Materials.

To better understand the trajectories, descriptives of physical activity at each time point were compared between trajectories including proportions of relative physical activity scores and other measures of physical activity available including IPAQ at age 17, 20, and 22 as well as device-derived physical activity at age 22. Comparisons in additional physical activity variables between trajectories were made using negative binomial regression weighted for the probability of membership in each latent class using Stata/IC v 14.2.

Linear/binomial regression was used to determine the associations between the latent class trajectories of physical activity and health outcomes in young adulthood. Models were weighted for the probability of membership in each latent class and adjusted for sex to prevent confounding of estimates due to different proportions of males and females across trajectory classes. To determine the effect of current physical activity versus the cumulative earlier physical activity trajectories, separate models were run including current self-reported physical activity from IPAQ at the concurrent time point as the health outcome (age 20 or 22). Interactions were explored between sex and trajectory membership with health outcomes and results are presented separately for males and females where the interaction was significant at  $p < 0.10$ . Analyses were conducted in 2019.

## 3. Results

### 3.1. Descriptives of sample

The primary model included 1628 Gen2 participants (47.9% female, 87.2% Caucasian) with activity level reported on at least three out of four timepoints (Table 1). Of 837 participants with reported family income at age 8, 52.2% had an income of \$25,000 or less. Three percent ( $n = 63$ ) of parents at the Gen2 age 10, 7% ( $n = 140$ ) at age 13, and 9% ( $n = 132$ ) at age 17 were unable to ascertain the level of physical activity of their child and these participants were excluded from further analysis.

### 3.2. Summary of trajectories

Fig. 1 shows the three trajectory solution selected, with low (11%),

**Table 1**  
Distribution of parent-reported relative physical activity across ages and trajectories.

		Age 8	Age 10	Age 14	Age 17
Total participants		2140	2048	1864	1726
Total physical activity sample (n)		2103	2020	1651	1268
	Less <sup>a</sup>	233 (11%)	99 (5%)	309 (19%)	301 (24%)
	Equal	1060 (50%)	1372 (68%)	938 (57%)	677 (53%)
	More	810 (39%)	549 (27%)	404 (25%)	290 (23%)
Low-activity trajectory (n)		176	166	163	147
	Less	48.3%	69.9%	89.0%	84.4%
	Equal	49.4%	30.1%	11.0%	15.7%
	More	2.3%	0%	25.0%	0%
Mid-activity trajectory (n)		1068	1075	1010	779
	Less	7.3%	3.4%	13.1%	20.3%
	Equal	59.5%	85.9%	77.7%	73.4%
	More	33.2%	10.7%	9.2%	6.3%
High-activity trajectory (n)		352	349	343	274
	Less	1.1%	0%	0%	0%
	Equal	23.0%	39.3%	16.3%	17.2%
	More	75.9%	60.7%	83.7%	82.9%

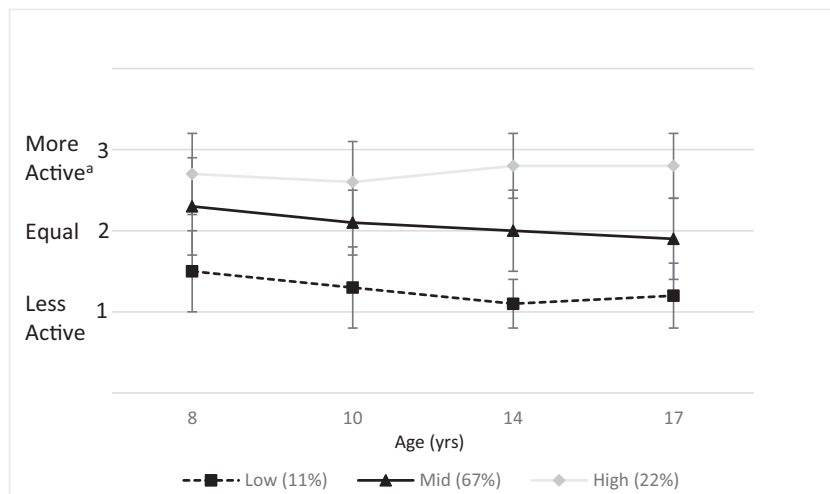
<sup>a</sup> Less = "sedentary – Gets very little exercise" at age 8 or "my child is less active than other children" at ages 10, 14, and 17; equal = "slightly active – Gets some exercise" at age 8 or "my child is as active as other children at ages 10, 14, and 17"; more = "active – Is involved in organized activity 2 or 3 times per week" at age 8 or "my child is more active than other children" at ages 10, 14, 17.

mid (67%) and high (22%) activity trajectories (see Supplemental Table 1 for fit statistics). The low-activity trajectory was 50% female, the mid-activity trajectory was 36% female, and the high-activity trajectory was 51% female (Chi-squared = 24.1,  $p < .001$ ). Sensitivity analyses using separate sex models (Supplement Table 2 for sex-specific model fit statistics and Supplemental Fig. 1 for sex-specific trajectories) confirmed a combined sex model was appropriate, with little differences in fit, prevalence and patterns by sex. Models with no missing time points confirmed a similar three trajectories model (Supplement Table 3).

The percentages of parents reporting less, equal and more active at each time point by trajectory are shown in Table 1. Evidence to support the validity of the parent-report data is provided in Table 2, showing differences between the single-item question in parent-report, self-report and objective measures of physical activity at ages 8, 10, 14 and 17 in the expected directions with the least activity in the parent-reported less-active and the greatest activity in the more-active groups (Table 2). When comparing later physical activity measures between trajectories, self-reported physical activity at 20 and 22 years (IPAQ) was different between trajectories ( $n = 965$ ,  $p < .001$ ), and 22 ( $n = 882$ ,  $p < .001$ ) yet there were no statistical differences between the trajectories in accelerometer measured physical activity at age 22 ( $n = 642$ ,  $p = .748$ ).

### 3.3. Health outcome differences between trajectories

For females and males combined there were associations between physical activity trajectories and measures of adiposity (DXA), HDL-cholesterol, insulin, HOMA-IR, diagnosed disorders and speed of processing reaction time at age 22. There were statistically significant sex interactions (see Table 3 and Supplementary Fig. B) at age 20 for BMI and self-reported mental health, and at 22 years for BMI, systolic blood pressure, self-reported mental health and depression symptoms, and thus these are reported separately for females and males in Table 3 and Supplementary Table 4.



**Fig. 1.** Three latent class trajectories of relative activity levels from age 8 to 17 years

Mean scores were tabulated for each time-point using ordinal variables (less active = 1, equal active = 2, more active = 3), error bars are standard deviation

<sup>a</sup> Less = “Sedentary – gets very little exercise” at age 8 or “My child is less active than other children” at ages 10, 14, and 17; Equal = “Slightly active – gets some exercise” at age 8 or “My child is as active as other children at ages 10, 14, and 17”; More = “Active – Is involved in organized activity 2 or 3 times per week” at age 8 or “My child is more active than other children” at ages 10, 14, 17.

### 3.3.1. Physical health

For self-reported physical health at age 20, physical health was higher in the high-activity compared to both the mid and low-activity trajectories for females but there were no differences between trajectories in males (See Table 3 and Supplemental Table 4 & Fig. 2).

Adiposity, as measured by DXA, differed between all three trajectories ( $p < .001$ ), with those in the high-activity having lower percent body fat. BMI at ages 20 and 22 was lowest in the high-activity

trajectory in females, whereas in males this was only found at age 20.

HDL-cholesterol was higher in the high-activity compared to the low-activity trajectory while insulin and HOMA-IR were lower in the high-activity trajectory compared to the mid-activity trajectory and/or low-activity trajectories (Table 3 and Supplemental Table 4). Insulin and HOMA-IR were also lower in the mid-activity trajectory compared to the low-activity trajectory. In males only, systolic blood pressure was higher in the mid-activity compared to the low-activity trajectory.

**Table 2**

Evidence of validity for single-item parent-reported physical activity and derived physical activity trajectories from additional physical activity measures, n(%), mean (SD), mean (95%CI).

Comparison between parent-reported PA variable to contemporary physical activity measures		Less active	Equal active	More active	p-value
Organized sport participation	Age 8 (n = 2096)	116 (50%)	747 (71%)	759 (94%)	< .001
	Age 10 (n = 1951)	87 (45%)	895 (65%)	292 (77%)	< .001 <sup>a</sup>
	Age 14 (n = 1646)	72 (23%)	572 (61%)	337 (83%)	< .001 <sup>a</sup>
	Age 17 (n = 1407)	26 (9%)	268 (40%)	214 (74%)	< .001 <sup>a</sup>
	Age 10 (n = 1957)	142.7 (24.0)	334.0 (9.0)	455.1 (17.2)	< .001 <sup>b</sup>
MVPA (min/wk)	Age 14 (n = 623)	9952.8 (380.1)	10,967.9 (222.3)	12,358.4 (321.1)	< .001 <sup>c</sup>
	Age 17 (n = 479)	8488.7 (371.2)	9863.9 (261.3)	10,580.4 (369.5)	0.002 <sup>c</sup>
	Age 14 (n = 1419)				< 0.001 <sup>a</sup>
Teen reported exercise out of school	None	33 (12%)	40 (5%)	8 (3%)	
	About half hour per week	67 (25%)	122 (15%)	19 (5%)	
	About 1 h per week	56 (21%)	110 (14%)	29 (8%)	
	About 2–3 h per week	85 (32%)	271 (34%)	101 (29%)	
	About 4–6 h per week	25 (9%)	181 (23%)	98 (28%)	
	7 or more hours per week	5 (2%)	70 (9%)	99 (28%)	
	Age 17 (n = 1155)				< 0.001 <sup>a</sup>
	None	75 (30%)	63 (12%)	11 (4%)	
	About half hour per week	58 (23%)	65 (12%)	7 (3%)	
	About 1 h per week	39 (16%)	81 (15%)	22 (9%)	
	About 2–3 h per week	47 (19%)	170 (32%)	61 (25%)	
	About 4–6 h per week	25 (10%)	104 (19%)	67 (27%)	
	7 or more hours per week	7 (3%)	57 (11%)	81 (33%)	
Comparison between trajectories to later physical activity		Low-activity trajectory	Mid-activity trajectory	High-activity trajectory	
IPAQ MVPA (min/day)	Age 17 (n = 1142)	111.3 (92.3, 130.2)	147.4 (136.8, 158.1)	184.2 (161.1, 207.2)	< .001 <sup>d</sup>
	Age 20 (n = 965)	66.0 (53.6, 78.4)	99.3 (91.4, 107.2)	127.2 (110.0, 145.5)	< .001 <sup>d</sup>
	Age 22 (n = 882)	74.1 (59.8, 88.5)	102.1 (93.5, 110.7)	129.7 (112.0, 147.3)	< 0.001 <sup>d</sup>
Accelerometer MVPA (min/day)	Age 22 (n = 642)	35.1 (27.1, 43.0)	36.1 (32.5, 39.7)	38.4 (32.4, 44.5)	.748

IPAQ: International physical activity questionnaire; MVPA: Moderate-to-vigorous physical activity.

<sup>a</sup> Chi-squared.

<sup>b</sup> Kruskal Wallis.

<sup>c</sup> ANOVA.

<sup>d</sup> Negative binomial regression adjusted for sex and weighted for probability of membership.

**Table 3**

Health outcomes (at age 22 unless otherwise noted) by combined physical activity trajectories, allowing participants to have one missing time point and either adjusted for sex or sex-specific results if sex-interactions were significant.

			Low-activity	Mid-activity Mean (95% CI)	High-activity
<b>Physical</b>					
SF-12 physical	Age 20	Females (n=519) <sup>a</sup>	<b>52.9 (51.3, 54.5)</b>	<b>52.9 (52.2, 52.5)</b>	<b>56.0 (54.8, 57.3)</b>
		Males (n=448)	53.6 (51.9, 55.3)	54.4 (53.7, 55.1)	54.6 (53.5, 55.8)
Body Composition	Age 22 (n=872)		53.1 (51.8, 54.3)	54.0 (53.5, 54.5)	54.8 (53.9, 55.7)
	%Fat DXA at age 20 (n=1050)		<b>36.9 (35.3, 38.5)</b>	<b>30.6 (29.9, 31.3)</b>	<b>26.4 (25.3, 27.5)</b>
BMI at age 20	Females (n=525)		<b>27.5 (26.2, 28.7)</b>	<b>23.9 (23.5, 24.4)</b>	<b>22.9 (21.9, 23.8)</b>
	Males (n=569)		<b>25.9 (24.8, 27.1)</b>	<b>24.3 (23.8, 24.8)</b>	<b>24.1 (23.3, 24.8)</b>
BMI at age 22	Females (n=428)		<b>29.5 (28.1, 30.9)</b>	<b>24.6 (24.0, 25.2)</b>	<b>23.2 (22.1, 24.2)</b>
	Males (n=448)		25.6 (24.1, 27.0)	25.1 (24.5, 25.7)	25.1 (24.2, 26.0)
Blood measures (n=807)	Cholesterol (mmol/L)		4.56 (4.39, 4.73)	4.65 (4.58, 4.72)	4.56 (4.45, 4.68)
	LDL-cholesterol (mmol/L)		2.73 (2.59, 2.88)	2.78 (2.72, 2.84)	2.70 (2.60, 2.80)
	HDL-cholesterol (mmol/L)		<b>1.31 (1.25, 1.38)</b>	<b>1.36 (1.33, 1.39)</b>	<b>1.40 (1.36, 1.45)</b>
	Triglycerides (mmol/L)		<b>1.11 (1.01, 1.21)</b>	<b>1.10 (1.06, 1.14)</b>	<b>1.01 (0.94, 1.08)</b>
	Glucose (mmol/L)		5.03 (4.87, 5.19)	5.01 (4.94, 5.08)	4.94 (4.83, 5.05)
	Insulin (mU/L)		<b>10.9 (9.97, 11.88)</b>	<b>8.10 (7.70, 8.50)</b>	<b>7.04 (6.38, 7.70)</b>
	HOMA-IR		<b>2.5 (2.3, 2.7)</b>	<b>1.8 (1.7, 1.9)</b>	<b>1.6 (1.4, 1.7)</b>
	hsC-reactive Protein (mg/L)		2.53 (1.55, 3.52)	2.61 (2.19, 3.02)	2.31 (1.63, 2.99)
Blood Pressure (mmHg) (n=874)	Systolic	Females (n=426)	115.9 (113.2, 118.6)	113.6 (112.4, 114.7)	114.8 (112.7, 116.8)
		Males (n=448)	<b>121.1 (118.3, 123.9)</b>	<b>124.3 (123.1, 125.5)</b>	<b>123.8 (122.0, 125.6)</b>
Diastolic			67.2 (6.59, 68.6)	67.3 (66.7, 67.9)	67.0 (66.1, 68.0)
# Diagnosed disorders (n=959) <sup>b</sup>			<b>2.2 (1.7, 2.7)</b>	<b>1.6 (1.5, 1.8)</b>	<b>1.5 (1.2, 1.7)</b>
<b>Mental</b>					
SF-12 Mental	Age 20	Females (n=519)	44.7 (42.3, 47.2)	45.5 (44.5, 46.5)	44.8 (42.8, 46.7)
		Males (n=448)	<b>45.4 (42.7, 48.0)</b>	<b>48.4 (47.3, 49.6)</b>	<b>51.4 (49.7, 53.2)</b>
Age 22	Females (n=466)		44.9 (42.3, 47.5)	45.6 (44.5, 46.7)	43.8 (41.8, 45.9)
	Males (n=406)		<b>45.9 (42.9, 48.9)</b>	<b>49.1 (47.8, 50.4)</b>	<b>50.6 (48.8, 52.4)</b>
DASS-21 Depression <sup>b</sup>	Females (n=474)		8.7 (6.4, 11.1)	7.8 (6.9, 8.7)	8.1 (6.4, 9.9)
	Males (n=419)		<b>7.3 (5.0, 9.5)</b>	<b>5.6 (4.8, 6.3)</b>	<b>4.0 (3.2, 4.9)</b>
Anxiety (n=889) <sup>b</sup>			4.6 (3.7, 5.6)	4.8 (4.3, 5.2)	4.4 (3.7, 5.1)
	Stress (n=888) <sup>b</sup>		9.0 (7.1, 10.8)	8.9 (8.1, 9.6)	9.3 (7.9, 10.6)
Cogstate Vigilance (Identification)			2.64 (2.62, 2.65)	2.64 (2.63, 2.64)	2.63 (2.62, 2.64)
	Speed of processing (Detection)		<b>2.47 (2.45, 2.49)</b>	<b>2.45 (2.44, 2.46)</b>	<b>2.44 (2.42, 2.45)</b>
log10 reaction time (s) (n=692)	Attention/working memory (One Back)		2.82 (2.80, 2.83)	2.81 (2.80, 2.82)	2.80 (2.79, 2.81)

Generalized linear models weighted for probability of membership; bold indicates significant difference between trajectories at  $p < .05$ ; <sup>a</sup>shading indicates significant sex-trajectory interactions at  $p < .10$  with p-values for significant interactions: SF-12 physical at age 20 = 0.012, BMI at age 20 = 0.031, BMI at age 22 < 0.001, Systolic Blood pressure = 0.034, SF-12 Mental at age 20 = 0.015, SF-12 Mental at age 22 = 0.040, DASS-21 Depression = 0.065; <sup>b</sup> = negative binomial regression.

Cholesterol, LDL-cholesterol, glucose, hsC-reactive protein and diastolic blood pressure did not differ between trajectories.

Those in the high-activity and the mid-activity trajectories reported fewer diagnosed disorders than those in the low-activity trajectory (see Table 3 and Supplemental Table 4). The most common were vision problems (27% of participants), hay fever or other allergy (20%), back pain (16%), “other” (15%), anxiety problems (12%), asthma (11%), neck pain (10%), depression (9%), and migraine or severe headache (8%).

### 3.3.2. Mental health

Self-reported mental health in males was highest in the high-activity trajectory, but there were no differences in females. Similarly, in males, DASS-21 depression scores were lowest in the high-activity compared to both the low and mid-activity trajectories, and there were no differences in females. There were no differences in DASS-21 anxiety or stress sub-scales.

Cogstate speed of processing reaction times were faster in the high-activity compared to the low-activity trajectory. There were no other differences between trajectories for other cognitive health outcomes.

### 3.4. Adjustment for current young adult physical activity

Models adjusted for current physical activity (i.e. at age 22) retained significant associations between physical activity trajectory and adiposity (DXA) and BMI at age 20 and 22, and diagnosed disorders, insulin, HOMA-IR systolic blood pressure, self-reported mental health and

speed of processing (see Supplemental Tables 5 and 6). Relationships were attenuated between physical activity trajectories and HDL-cholesterol, and some pairwise comparisons were attenuated in males between BMI at age 20, self-reported mental health, and depression symptoms at age 22.

## 4. Discussion

The current study identified three trajectories of consistent relative physical activity from childhood to adolescence: low-, mid- and high-activity trajectories. These physical activity trajectories were associated with measures of adiposity, blood biochemistry and mental health in young adults at 20 and 22 years of age, with some differences between sexes.

Previous studies of trajectories of physical activity from childhood to adolescence have found similar patterns with consistent trajectory groups. In the Iowa Bone Development Study, Janz et al. identified low-, mid- and high- accelerometer-derived MVPA trajectories from ages 5 to 17, all with decreasing levels of physical activity. However, Kwon et al. identified a fourth trajectory in the same study with declining activity. Studies from the Gateshead Millennium Study cohort in the U.K. including children ages 7 to 15 found different accelerometer-derived trajectories depending on whether total physical activity, MVPA (Farooq et al., 2018), or vigorous physical activity measures were used (Beltran-Valls et al., 2019). Similarly, in their review, Lounassalo et al. (2019) found mostly decreasing trajectories of

physical activity across childhood and adolescence. In the review, there were several measures of physical activity with slightly different trajectories, suggesting physical activity trajectory behaviors may differ by context of activity, for example sport vs. afterschool. It is important to note that the current study examined *relative* physical activity (as it compares to peers) at three of the time points and not absolute physical activity. As relative physical activity levels do not seem to change from childhood to adolescence, it appears important to start children in activity from an early age. Future studies should examine potential predictors to identify children in the most at-risk trajectories assessing individual, social, and environmental factors that may influence physical activity and sedentary behaviors trajectories throughout these periods (Pate et al., 2019; Young et al., 2019; Howie et al., 2019).

Importantly, this study showed different patterns of activity associated with measures of adiposity and cardiometabolic health as well as mental and cognitive health. Some of these effects were substantial and likely to have important clinical implications, even after adjustment for current physical activity, such as the nine percentage points difference in body fat between high and low-activity trajectories. Previously identified organized sport trajectories in the same cohort did not differ in body fat in girls, and a smaller magnitude of difference was found in boys (Howie et al., 2016). This highlights differences in health associations between sport and general physical activity, thus illustrating a need for researchers to examine multiple constructs of physical activity. Only systolic blood pressure for males was in the direction opposite to that hypothesized, with those in the low-activity trajectory having the lowest systolic blood pressure, suggesting blood pressure in young adulthood may be more influenced by other behaviors or health factors.

Interestingly, females showed a stronger association with BMI and males with mental health. The lack of difference in BMI for males may be related to BMI not differentiating between fat mass (which did differ between trajectories) and lean body mass, particularly in young males who may have higher lean mass. The lack of difference in mental health measures for females may indicate physical activity is not as important to maintaining mental health as it is for males, as physical activity, particularly sport, may be more associated with male social status (Chase and Machida, 2011). The question asked at ages 10, 14, and 17 did not specify if activity was relative to same-sex peers, so parent responses may represent inherent gender-biases of females being less active compared to male peers.

The majority of health associations with trajectories remained after adjusting for current physical activity, despite previous research suggesting that current physical activity may be more important in relation to health outcomes (Bell et al., 2018). The exception was mental health in males which may be more sensitive to current physical activity. Thus, cumulative behaviors may have a larger influence on some health outcomes compared to current behaviors at a single time point.

The current study suggests being in the high-activity trajectory associates with a better cardiometabolic and mental health profile, but there are also benefits of being in the mid-activity trajectory. The few studies that have examined physical activity trajectories and health outcomes found associations with adiposity (Kwon et al., 2015; Howie et al., 2016), bone (Janz et al., 2014; McVeigh et al., 2019), and mental health (Howie et al., 2018). By examining multiple health outcomes, the current study substantially adds to the limited evidence that long-term physical activity behaviors across childhood and adolescence are related to a range of health outcomes in adulthood. This provides reinforcing evidence of the importance of getting children active early, and keeping them active, to set them up for a healthier adulthood.

Strengths of the study include a representative community-based sample, multiple sensitivity analysis, examination of sex interactions and adjustment for current adult physical activity. A limitation is the use of parent-reports of relative physical activity. Further longitudinal work with device-measured physical activity will help to determine the specific intensity, duration and frequency of physical activity that is important for individual health outcomes. However, in validity

analyses, physical activity measures at ages 8, 10, 14, 17, 20 and 22 were different between groups in the expected directions. That even a simple, parent-reported single question was predictive of health outcomes in young adulthood is encouraging for practical strategies to identify children at risk, as this simple measure can be easily administered to parents. Thus, healthcare professionals in primary care or other settings may be able to identify children at risk and intervene to improve activity behaviors. Additionally, the current study examines a broad array of physical and mental health measures. Future analyses may seek to examine specific outcomes in detail.

## 5. Conclusions

The current study has identified physical activity trajectories across childhood and adolescence in an Australian population. These physical activity trajectories demonstrated clear associations with multiple physical and mental health measures in young adulthood including adiposity, cardiometabolic health, depression and cognitive performance. These findings emphasize the need to promote physical activity in children from an early age so they maximize benefits from an active lifestyle across the lifespan.

## Financial disclosure

EKH, JAM, JZ, ALS, RSB, TAM, LJB, LMS have no financial interests to disclose.

## CRediT authorship contribution statement

**E.K. Howie:** Conceptualization, Methodology, Formal analysis, Data curation, Writing - original draft. **J.A. McVeigh:** Conceptualization, Methodology, Data curation, Writing - review & editing. **A.J. Smith:** Conceptualization, Methodology, Formal analysis, Writing - review & editing, Supervision, Funding acquisition. **J. Zabatiero:** Investigation, Data curation, Writing - review & editing, Project administration. **R.S. Bucks:** Methodology, Data curation, Writing - review & editing, Supervision. **T.A. Mori:** Conceptualization, Methodology, Data curation, Writing - review & editing, Supervision, Funding acquisition. **L.J. Beilin:** Conceptualization, Methodology, Data curation, Writing - review & editing, Supervision, Funding acquisition. **L.M. Straker:** Conceptualization, Methodology, Data curation, Writing - review & editing, Supervision, Project administration, Funding acquisition.

## Declaration of competing interest

EKH, JAM, JZ, ALS, RSB, TAM, LJB, LMS have no COIs to disclose.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ypmed.2020.106224>.

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