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Mental Health and Physical Activity 24 (2023) 100497

Contents lists available at ScienceDirect

Mental Health and Physical Activity

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

Associations between physical activity and mental health and behaviour in early adolescence

Josephine N. Booth [a,*], Andy R. Ness [b], Carol Joinson [c], Phillip D. Tomporowski [d], James M.E. Boyle [e], Sam D. Leary [b], John J. Reilly [e]

[a] University of Edinburgh, United Kingdom
[b] School of Oral and Dental Sciences, University of Bristol, Bristol Dental School, United Kingdom
[c] School of Social and Community Medicine, University of Bristol, United Kingdom
[d] University of Georgia, Athens, United States
[e] School of Psychological Sciences and Health, University of Strathclyde, United Kingdom

ARTICLE INFO

Keywords:
Physical activity
Mental health
Emotional and behavioural difficulties
Adolescents
ALSPAC

ABSTRACT

Background: We examined associations between objectively-measured physical activity, depressive-symptoms, and emotional and behavioural difficulties in adolescents from a UK cohort.
Method: Data from 4755 participants (45% male) from the Avon Longitudinal Study of Parents and Children (ALSPAC) with physical activity assessed by accelerometry at age 11 was analysed. Indication of depressive symptoms (Short Moods and Feelings questionnaire) were obtained from parental reports at age 11 and self-reports at age 13. Behavioural and emotional problems were assessed by parents and teachers at age 11 and 13 using the Strengths and Difficulties Questionnaire (SDQ).
Results: At age 11, males averaged 29 minutes (SD = 17) of daily moderate-to-vigorous physical activity (MVPA) compared with 18 minutes (SD = 12) among females. Higher MVPA at age 11 was associated with decreased depressive-symptoms in females at age 11 after adjusting for confounders. Among males, a positive change in MVPA between the ages of 11 and 13 was associated with a reduction in depressive symptoms. Negative associations were also found between MVPA at age 11 and the emotional symptoms scale of the SDQ at age 11 and age 13 in females. Higher MVPA predicted a decreased score on the hyperactivity subscale of the SDQ at 11 and 13 for both sexes. All effect sizes were small.
Conclusions: Higher MVPA was associated with reduced depressive symptoms, behavioural and emotional-difficulties in early adolescence, however the magnitude of effects was small. Efforts to support MVPA in this age group are therefore warranted.

1. Introduction

Mental health and behavioural difficulties in adolescence are characterized by many adverse outcomes, including poor physical health and poor educational outcome (National Research Council, 2009; Petito et al., 2020; Thapar, Collishaw, Potter, & Thapar, 2010). Depression, an aspect of mental ill-health, is common among adolescents (Compton, Conway, Stinson, & Grant, 2006; Gladstone, Beardslee, & O'Connor, 2011; Thapar et al., 2010), is increasing in prevalence (Patalay & Gage, 2019), and is one of the top contributors to the global burden of disease (Liu et al., 2020). Furthermore, evidence shows that the recent COVID-19 pandemic has exacerbated mental health difficulties in young people assessed using the Strengths and Difficulties Questionnaire (SDQ), particularly at times of school closures (Creswell et al., 2021). Earlier onset of depressive-symptoms in adolescence is also becoming more common (Thapar et al., 2010; Williams et al., 2012), with a poorer prognosis than onset in adulthood (Gladstone et al., 2011; Thapar et al., 2010). Low physical activity (PA) is widely believed to be a modifiable

Abbreviations: ALSPAC, Avon Longitudinal Study of Parents and Children; cpm, counts per minute; BMI, Body Mass Index; DAWBA, Development and Well-being Assessment; ICC, Intra-class correlation coefficient; MVPA, moderate-vigorous intensity physical activity; OPCS, Office of population censuses and surveys; PA, Physical activity; SDQ, Strengths and Difficulties Questionnaire; SMFQ, Short Moods and Feelings questionnaire.

* Corresponding author.
E-mail address: josie.booth@ed.ac.uk (J.N. Booth).

https://doi.org/10.1016/j.mhpa.2022.100497
Received 11 April 2022; Received in revised form 8 November 2022; Accepted 18 November 2022
Available online 26 November 2022

risk factor for depressive disorder in adults (Mutrie, 2000), although the evidence base is limited by methodological weaknesses, most notably over-reliance on self-reported measures of PA (Vallance et al., 2011). There is evidence in adolescence from both reviews and observational studies that, in addition to depression, PA is also positively associated with reduced emotional and behavioural difficulties (Allison, Faith, & Franklin, 1995; Biddle, Ciaccioni, Thomas, & Vergeer, 2019; CentersforDiseaseControlandPrevention, 2010; Khan, Lee, Rosenbaum, Khan, & Tremblay, 2021; Trudeau & Shephard, 2008), although the evidence base is also limited, with many cross-sectional studies and with small sample sizes.

1.1. Methodological considerations

Systematic reviews of associations between PA and risk of depression in adolescents (Biddle et al., 2019; Janssen & LeBlanc, 2010; Strong et al., 2005) have found that the evidence which exists is largely of low quality. This is due to methodological limitations including small samples; cross-sectional designs; lack of adequate adjustment for confounding variables; use of subjective methods of PA measurement (Reilly et al., 2008). For example in terms of mental health, recent observational work by Khan and colleagues (Khan et al., 2021) reported dose dependent relationships between PA and mental wellbeing in a large sample of adolescents (n = 577, 475). Outcomes considered were psychosomatic complaints (feeling low, irritability, nervousness, sleep difficulties, dizziness, headaches, and stomach and back ache), and satisfaction with life (using the Cantril ladder). While this sample was impressive, the research was cross-sectional and relied on self-reported measures of PA. A recent systematic review of physical activity, sedentary behaviour, and physical and psychological outcomes (Chaput et al., 2020) concluded that there was a need for research involving longitudinal study designs, larger population-based samples, and objective measures of PA; they specifically commented on the need for more high quality research around physical activity and mental health in young people. The present study therefore aims to address some of the limitations in the evidence base.

1.2. Longitudinal examinations of depressive symptoms

Birkeland, Torsheim, and Wold (2009) examined change in self-reported leisure time physical activity and depressed mood between the ages of 13 and 23 years. Depressed mood was measured using a 7 item inventory from Alsaker (1992). While relationships were detected between leisure time PA and depressed mood, no evidence of predictive relationships were identified; that is, PA did not predict changes in depressed mood, and depressed mood did not predict change over time in PA. Similar findings emerged in work by Rothon et al. (2010) who considered change in depressive symptoms measured with the Short Moods and Feelings Questionnaire (SMFQ), and change in PA outside of school hours between the ages of 11/12 and 13/14. Cross-sectional associations were detected when participants were 11/12 years old, but no associations between change in PA and later depressive symptoms were found. Furthermore, there was no evidence for changes in depression being related to changes in PA.

However, more recently, Gunnell and colleagues (Gunnell et al., 2016) examined the longitudinal bidirectional relationship between leisure time PA and depression in young people using data from the Research on Eating and Adolescent Lifestyles (REAL) study (Flament et al., 2015). They found associations between depression, as measured by the Children's Depression Inventory (CDI), and screen time. They also found that higher baseline levels of depression were associated with greater decreases in PA. While these are valuable findings in the literature, the use of self-reported measures and the focus of PA in a single domain in these studies (i.e. leisure time) is a limitation.

There have been fewer studies in this area employing objective measures of physical activity. One study by Toseeb and colleagues (Toseeb et al., 2014) examined the relationship between device measured PA and depressed mood assessed using the MFQ between the ages of 14.5 years and 17.5 years. They found no evidence for longitudinal associations with MVPA for either depressive symptoms, or clinical index of major depressive disorder. However it is also important to consider these relationships at earlier ages.

Research by Kandola and colleagues (Kandola, Lewis, Osborn, Stubbs, & Hayes, 2020) addressed some of the previous limitations in the literature and examined the longitudinal associations between objectively measured PA and depression in the Avon Longitudinal Study of Parents and Children (ALSPAC) cohort between the ages of 12 and 18 years. They reported that persistently high levels of sedentary behaviour and low levels of light intensity PA were associated with greater depressive symptoms as measured with the self-report version of the SMFQ. They also found negative associations between MVPA at age 12 and depression as assessed by Clinical Interview. However it is also useful to consider multiple sources of information (i.e. self, parent and teacher report) when considering mental health and behaviour in adolescents (Aebi et al., 2017), as well as a broader range of outcomes than just depression.

1.3. More than depression

Umbrella reviews by Biddle and colleagues (Biddle & Asare, 2011; Biddle et al., 2019) considered a broader range of mental health outcomes then just depression, by also synthesizing literature around anxiety and self-esteem.[1] They concluded that there was evidence of a small protective effect on anxiety, but that the literature around self-esteem was more variable. However, for all the outcomes they considered it was maintained that there is a need for further robust evidence.

There are two relatively recent studies which use objective measures of physical activity and examine a broader range of outcomes than depression alone. Bell and colleagues (Bell, Audrey, Gunnell, Cooper, & Campbell, 2019) examined the longitudinal relationship between device measured physical activity at age 12/13 years and self-report measures of mental wellbeing (Warwick Edinburgh Mental Wellbeing Scale) and symptoms of mental health disorder (measured with the SDQ) at age 15/16 years. In their sample of 928 young people, they found higher levels of physical activity were associated with lower scores on the emotional symptoms subscale of the SDQ, but no other robust associations were detected for either MVPA, or total volume of PA. Furthermore, Hagemann et al. (2021) also examined a broader range of outcomes and found no substantial associations between device measured physical activity (MVPA or light PA) and symptoms of general psychopathology, depression, anxiety, and psychoticism in adolescents (mean age 13 years). However, neither of these studies was able to consider whether changes in physical activity over time were associated with changes in mental health outcomes, or if the relationship was bidirectional.

1.4. The present study

In summary, there is little evidence on associations between objective measures of physical activity and mental health and behavioural problems in early adolescence, and even less evidence using longitudinal study designs and taking a range of confounders into consideration. The primary aim of the present study was therefore to determine whether there are associations between objectively measured habitual PA, depressive symptoms, and emotional and behavioural difficulties in participants in the ALSPAC cohort at 11 and 13 years. Due to the unique nature of ALSPAC, we were able to include multiple measures from a range of informants (young people, parents, and teachers) which have

[1] Both reviews also include cognition but this is not discussed in the present paper.

not previously been reported in the literature. Changes between the age of 11 and 13 are key for development of mental health issues, especially in girls due to the relationship with menarche (Blakemore, 2019; Sequeira, Lewis, Bonilla, Smith, & Joinson, 2017) so we chose to focus on this time period. We also examined whether change in PA was associated with change in depressive symptoms and whether these relationships were bidirectional or not.

2. Methods

The sample comprised participants from the ALSPAC birth cohort (http://www.alspac.bris.ac.uk). The phases of enrolment to ALSPAC are described in detail in the cohort profile papers (Boyd et al., 2013; Fraser et al., 2013). ALSPAC is an on-going population-based study investigating a wide range of influences on health and development of children. Ethical approval for the study was obtained from the ALSPAC Ethics and Law Committee and the Local Research Ethics Committees. Pregnant women resident in the former Avon Health Authority in south-west England, having an estimated date of delivery between 1/4/91 and 31/12/92 were invited to take part, resulting in a cohort of 14,541 pregnancies and 13,988 children (n = 6762 girls) alive at 12 months of age. Attempts to bolster the sample resulted in data available from 14,901 children alive at 1 year of age.

2.1. Study design and procedures

The present study examined associations between total volume of PA and MVPA at the age 11 ALSPAC research clinic, and measurement of depressive-symptoms and emotional and behavioural difficulties at age 11 and 13.

2.2. Exposure and outcome measures and covariates

2.2.1. PA measurement

Free-living PA was measured objectively with the Actigraph AM 7164 2.2 accelerometer (Fort Walton Beach, Florida). Systematic reviews have concluded that the Actigraph has high criterion validity, acceptable reliability, and low reactivity for measurement of PA in children and adolescents (DeVries et al., 2009). Moreover, the ability to detect associations between PA and health outcomes is much greater when PA is measured objectively (Basterfield et al., 2012; Ekelund et al., 2012; Leary et al., 2008; Ness et al., 2007).

The Actigraph was used in the present study as described previously (Mattocks et al., 2008; Mattocks et al., 2007; Mattocks et al., 2007; Ness et al., 2007; Penpraze et al., 2006). Briefly, participants wore the accelerometer for 7 consecutive days during waking hours on the right hip. Strings of consecutive zero's lasting 10 min or more were considered non wear time and removed (Mattocks et al., 2008; Mattocks et al., 2007). Accelerometry output per unit time is presented as counts per minute (cpm) and was based on 60 s epochs. This was used in the present study to provide a valid measure of the total volume of PA (Reilly et al., 2008). Accelerometry data was considered acceptable for inclusion if there was at least 3 days and 10 h of wear time per day (Mattocks et al., 2007; Penpraze et al., 2006); including a weekend day is not required in this sample (Mattocks et al., 2008). For school-aged children and adolescents current international PA recommendations are expressed in terms of MVPA (Chaput et al., 2020). Objectively measured total volume of PA and MVPA can have different biological effects in children and adolescents (Basterfield et al., 2012; Leary et al., 2008; Ness et al., 2007). In order to quantify MVPA from accelerometry we applied the cut-point of 3600 counts-per-minute (cpm) derived from the validation and calibration study conducted in ALSPAC participants at age 11 (Mattocks et al., 2007).

2.2.2. Outcome measures

Two outcome measures were employed for the present analyses: depressive-symptoms measured using the Short Moods and Feelings Questionnaire (SMFQ) (Angold, Costello, Messer, & Pickles, 1995; Messer, Angold, Costello, Loeber, & et al., 1995) and general emotional and behavioral difficulties assessed using the Strengths and Difficulties Questionnaire (SDQ) (R. Goodman, 1997). The SMFQ is a 13-item questionnaire designed to give an indication of depressive-symptoms and includes items such as "I felt miserable or unhappy". Items are scored on a three point Likert scale (true, sometimes true, not true) and summed to give a final score ranging from 0 to 26. We use data from the SMFQ when it was completed by parents when participants were 11 years old (reliability coefficient .87 (Angold et al., 1995) and by the participants themselves (reliability coefficient .85 (Angold et al., 1995) at 13 years old. Alpha coefficient in the ALSPAC sample shows good reliability of the self-report version at age 13 (alpha = .865, Kwong, 2019).

The SDQ is a 25 item questionnaire which assesses emotional symptoms, conduct problems, hyperactivity/inattention, peer relationship problems, and prosocial behaviour. Each item is scored on a three point Likert scale and a total difficulties score is derived based on the sum of the subscale scores excluding the prosocial behaviour subscale, with scores ranging from 0 to 40. A prorating system is used if up to two items are missing in a subscale. The SDQ was completed by participants parents and class teachers at 11 years, and by parents only at 13 years. Validation studies of the SDQ demonstrate good reliability of both parent completed versions (Total Difficulties Score internal consistency reliability .80 (Stone, Otten, Engels, Vermulst, & Janssens, 2010) and teacher reported versions (Total Difficulties Score internal consistency reliability .82 (Stone et al., 2010). Goodman (2001) reported adequate/good reliability, with coefficients ranging from .57 (peer problems scale) to .77 (hyperactivity –inattention scale) for parent completed versions (age 5–15), and .70 (peer problems scale) to .88 (hyperactivity-inattention) for teacher completed versions. Similar internal consistency was reported for subscales by Stone and colleagues (Stone et al., 2010) based on their synthesis of 26 studies. Specifically, for parent report, coefficients were: prosocial =0.67; hyperactivity/inattention = .76; emotional symptoms = .66; conduct problems = .58; peer problems = .53. For teacher reports, coefficients were: prosocial = .82; hyperactivity/inattention = .83; emotional symptoms = .73; conduct problems = .70; peer problems = .63. In the ALSPAC sample, Speyer and colleagues (Speyer, Auyeung, & Murray, 2022) report McDonald's omega values for parent reported SDQ subscales showing good internal consistency at age 11 (Prosocial Behaviours = .83; Peer Problems: .81; Hyperactivity/Inattention: .85; Conduct Problems: .84; Emotional Problems: .82) and age 13 (Prosocial Behaviours = .84; Peer Problems: .81; Hyperactivity/Inattention: .84; Conduct Problems: .83; Emotional Problems: .82). Support for the five-factor structure of the SDQ has also been reported in clinical and epidemiological samples (Fernández de la Cruz et al., 2018; Gomez & Stavropoulos, 2019). Recently, longitudinal measurement invariance was also established for the SDQ in young people (aged 7–16) from the ALSPAC cohort (Speyer et al., 2022) thus suggesting this instrument is a suitable for longitudinal studies.

2.2.3. Confounders

A number of potential confounders were included due to previously reported associations with the exposure or outcome (or both). Age; birth weight; gestation; age of mother at delivery; maternal smoking in the first three months of pregnancy; ethnicity; socio-economic status based on maternal educational attainment (none/CSE to University degree); and occupational social class as classified by the Office of Population Censuses and Surveys (OPCS) in 1991 (classes I [professional/managerial] to V [unskilled manual workers]) (Survey, 1991) are all reported to be associated with depression (for a review, see Su, D'Arcy, & Meng, 2021). We also included mothers oily fish intake during pregnancy as assessed by questionnaire at 32 weeks gestation. This has been found to be associated with negative outcomes on some subscales of the SDQ in

the ALSPAC cohort (Hibbeln et al., 2007) and is also associated with maternal depression, which in turn is associated with child depression (Khanna, Chattu, & Aeri, 2019). Furthermore, weight status based on research clinic measurements of height and weight, expressed as a Body Mass Index (BMI) Z score relative to UK 1990 reference data, as this is related to mental health (Bohon & Welch, 2021), as is pubertal status (Blakemore, 2019; Sequeira et al., 2017) which was based on Tanner pubic hair stage for males (stage I [least advanced] to V [most advanced]) and menarche (started periods or not) for females evaluated at age of outcome (Leary et al., 2008; Tanner, 1986; Wiles, Haase, Lawlor, Ness, & Lewis, 2011).

2.3. Exclusions

The following criteria were used to exclude participants at baseline: any participant with a psychiatric diagnosis based on evaluation of the Development and Well-being Assessment (DAWBA)(R. Goodman, Ford, Richards, Gatward, & Meltzer, 2000) which provides information to make a DSM-IV(APA, 2000) clinical diagnosis (Ford, Goodman, & Meltzer, 2003); any Statement of Educational Needs as reported by school or parents; those with Total Difficulties scores of 16 and greater on the teacher completed version of the Strengths and Difficulties Questionnaire (R. Goodman, 1997) at age 11.

2.4. Statistical analyses

SPSS version 25 was used for all analyses. Scores on the SDQ were analysed separately for each subscale with higher scores indicating greater difficulties, except for the pro-social scale where higher score is better. The associations between total volume of PA, and percentage of time spent in MVPA (adjusted for wear time) and depressive-symptoms and emotional and behavioural difficulties were assessed using multiple linear regression analyses.[2] As males and females have been found to differ in relation to both PA levels (Ness et al., 2007) and emotional and behavioural difficulties (Piccinelli & Wilkinson, 2000), the interaction between sex and PA was tested formally. The SMFQ was treated as a continuous variable (Kandola et al., 2020), with higher scores indicating greater depressive-symptoms. Furthermore, the relationship between change in MVPA between ages 11 and 13 and change in depressive symptoms between ages 11 and 13 were also explored using linear regression analysis. Change scores for MVPA and depressive symptoms were calculated by subtracting age 11 data from age 13 data and then entered into regression analysis. Preliminary analysis suggested that the residuals for the SMFQ were skewed; previous studies have treated the SMFQ as a categorical variable (Kwong, 2019), which is preferred over transforming the data as this can introduce bias (Feng et al., 2014) and make interpretation challenging. Therefore in additional to the analysis which employed a continuous variable approach, scores were also categorized into tertiles (lower depressive symptoms, no change in depressive symptoms, higher depressive symptoms) for further analysis using multinomial-logistic regression. To explore the bidirectional relationship, we also conducted regression analysis with change in depressive symptoms as the exposure variable and change in MVPA between the ages of 11 and 13 as the outcome, and examined the associated model fit.

For all analysis, a series of models were used to explore the impact of confounding. Model 1 (minimally adjusted model) was adjusted for age of participants. Model 2 additionally adjusted for birth weight and gestation; model 3 additionally adjusted for age of mother at delivery, mother's oily fish intake and maternal smoking during the first three months of pregnancy; model 4 additionally adjusted for BMI Z score relative to UK 1990 reference data and pubertal stage of participant recorded at time of outcome, and finally, model 5 additionally adjusted for ethnicity, maternal educational attainment and occupational social class. For models examining the relationship between MVPA and SMFQ score at age 13, adjustment was also made for parent reported SDQ Total difficulties score at age 11. The Variance Inflation Factor was examined to determine multicollinearity. No values above 2 were detected indicating no multicollinearity.

Models 1 to 5 were fit for percentage of time spent in MVPA (% MVPA) and then refit with both total volumes of PA (i.e. cpm) and % MVPA entered simultaneously. This allows for conclusions regarding the impact of % MVPA, that is, the intensity of PA, to be made independently of the total volume of PA and sedentary time (Wiles et al., 2011). Standardised regression coefficients are reported to allow comparison across multiple outcome measures.

Sensitivity analysis was also undertaken to assess whether changes in effect sizes identified in models 2 to 5 were due to bias relating to missing data or not. Model 1 was repeated for only those participants who had complete data in model 5 (complete confounder information). Furthermore, multiple imputation was undertaken using the full models to assess associations between PA at age 11 and SMFQ at age 11 and 13 and SMFQ change score, and also SDQ at age 11 and 13. Imputation was undertaken using fully conditioned specification which is an iterative Markov chain Monte Carlo (MCMC) method (regression) with the number of imputations equal to percentage of missing observations (Dong & Peng, 2013). For example, in models examining associations between PA at age 11 and SDQ at age 13, there was 48% missing data in some confounders so 48 imputations were undertaken. Results are shown in eTables 12, 13 and 14.

The intra-class correlation coefficient (ICC) was used to make adjustment for regression dilution calculated from a subset of the ALSPAC sample (n = 315) who were asked to wear the Actigraph on four separate occasions over a year at age 11 in order to examine seasonal and intra-individual variation (Mattocks et al., 2007). The ICC derived from this subset was 0.53 for total volume of PA and for MVPA was 0.45 and these figures were used to make the necessary adjustment in the present analyses.

3. Results

3.1. Characteristics of study participants

Of the 11, 952 participants invited to attend the 11-year clinic, 60% attended. 93% of those who attended agreed to wear an Actigraph, and 85% of those, provided valid activity data (Leary et al., 2008; Mattocks et al., 2008; Ness et al., 2007). Following the application of all exclusion criteria, data from 4755 participants (2128 males and 2627 females) remained for analyses; Table 1 provides the characteristics of these participants. When comparisons of characteristics were made between children who attended the clinic and those who did not, only small differences were found; similarly for those who provided valid accelerometer data compared to those who did not (Leary et al., 2008; Mattocks et al., 2008; Ness et al., 2007). Due to evidence for interactions between sex and PA, analyses were conducted separately for males and females.

The mean total volume of PA in males was 662 (SD = 186) cpm and 553 (SD = 153) cpm in females. Daily number of minutes of MVPA for males was 29 (SD = 17) and for females was 18 (SD = 12) and % MVPA was 8% (SD = 4%) for males and 5% (SD = 3%) for females. Descriptive statistics for depressive-symptoms (SMFQ) and emotional and behavioural difficulties (SDQ) are shown in Table 2.

3.2. Associations with depressive symptoms

Associations between PA and depressive symptoms at 11 and 13 years old are shown in Table 3 with standardised beta coefficients reported. For females, a 1 SD increase in % MVPA was associated with a 0.042 decrease in depressive symptoms in the minimally adjusted model

[2] The same associations were also examined using counts per minute and minutes of MVPA. These are displayed in eTables 2-9.

Table 1
Characteristics of participants.

Characteristic		Males		Females	
		n	Mean (SD)	n	Mean (SD)
Age in months at PA monitoring		2128	140.8 (2.8)	2627	140.9 (2.8)
Birth weight (g)		1996	3457.1 (579.6)	2446	3375.2 (490.5)
Gestation		2020	39.4 (2.0)	2484	39.5 (1.6)
Age of mother at delivery		2020	29.2 (4.6)	2484	28.9 (4.5)
BMI Z score at 11		2117	0.34 (1.17)	2609	0.27 (1.17)
BMI Z score at 13		1093	0.27 (1.18)	1392	0.18 (1.16)
MVPA age 11		2128	29 (17)	2627	18 (12)
MVPA at age 13		1347	29 (19)	1724	20 (15)
Percentage of time spent in MVPA at age 11		2128	8 (4)	2627	5 (3)
Percentage of time spent in MVPA at age 13		1347	9 (5)	1724	7(5)
		n	Percentage	n	Percentage
Ethnicity	White	1846	95.6	2281	96.4
	Non-white	84	4.4	85	3.6
BMI at 11 years	Healthy weight	1512	71.4	1917	73.5
	Overweight	288	13.6	339	13.0
	Obese	317	15.0	353	13.5
BMI at 13 years	Healthy weight	810	74.1	1061	76.0
	Overweight	143	13.1	192	13.8
	Obese	140	12.8	139	10.0
Mother's oily fish intake	Never/rarely	714	37.2	900	38.3
	Once in 2 weeks	674	35.2	806	34.3
	1-3 times a week	508	26.5	615	26.1
	4-7 times a week	20	1.0	30	1.3
	More than once a day	1	0.1	1	0.0
Mother smoked during pregnancy	Yes	308	15.5	411	16.8
	No	1681	84.5	2029	83.2
Mothers Education	CSE	244	12.4	310	12.9
	Vocational	171	8.7	186	7.8
	O level	695	35.4	874	36.4
	A level	536	27.3	632	26.3
	Degree	317	16.1	397	16.5
Occupational social class	I (professional)	134	7.8	142	6.8
	II	600	35.1	710	34.2
	III (non-manual)	734	42.9	894	43.0
	III (manual)	103	6.0	121	5.8
	IV	122	7.1	180	8.7
	V (unskilled)	15	0.1	30	1.4
	Armed forces	1	0.1	0	0
Pubertal status at 11	Experienced menarche	–	–	298	15.0
	Tanner stage I	528	39.0	–	–
	Tanner stage II	565	41.7	–	–
	Tanner stage III	206	15.2	–	–
	Tanner stage IV	53	3.9	–	–
	Tanner stage V	3	0.2	–	–
Pubertal status at 13	Experienced menarche	–	–	1123	60.5
	Tanner stage I	151	11.9	–	–
	Tanner stage II	301	23.7	–	–
	Tanner stage III	358	28.2	–	–
	Tanner stage IV	398	31.3	–	–
	Tanner stage V	62	4.9	–	–

Table 2
Descriptive statistics for SMFQ and SDQ.

Outcome	Males		Females	
	n	Median (IQR)	n	Median (IQR)
SMFQ at 11 years old	1784	1.00 (0–3)	2201	1.00 (0–3)
SMFQ at 13 years old	1744	3.00 (1–5)	2164	4.00 (2–8)
SDQ at 11(Parent rated)		Mean (SD)		Mean (SD)
Prosocial behaviour	1800	8.21 (1.67)	2210	8.71 (1.48)
Hyperactivity	1797	2.72 (2.04)	2205	2.18 (1.89)
Emotional symptoms	1797	1.11 (1.46)	2205	1.49 (1.68)
Conduct problems	1798	1.05 (1.29)	2208	1.04 (1.24)
Peer problems	1801	0.99 (1.42)	2207	0.91 (1.34)
Total difficulties	1800	5.86 (4.28)	2207	5.59 (4.24)
SDQ at 11 (Teacher rated)				
Prosocial behaviour	1194	7.82 (2.24)	1521	8.93 (1.66)
Hyperactivity	1194	2.00 (2.22)	1521	1.01 (1.60)
Emotional symptoms	1194	0.87 (1.39)	1521	0.97 (1.53)
Conduct problems	1194	0.54 (1.01)	1521	0.28 (0.77)
Peer problems	1194	0.94 (1.48)	1521	0.78 (1.34)
Total difficulties	1194	4.35 (3.92)	1521	3.03 (3.47)
SDQ at 13 (Parent rated)				
Prosocial behaviour	1723	8.13 (1.68)	2115	8.57 (1.55)
Hyperactivity	1725	2.92 (2.14)	2111	2.34 (1.93)
Emotional symptoms	1723	1.06 (1.46)	2112	1.48 (1.67)
Conduct problems	1722	1.08 (1.28)	2114	1.08 (1.26)
Peer problems	1723	1.18 (1.58)	2111	0.95 (1.31)
Total difficulties	1718	6.23 (4.42)	2108	5.58 (4.31)

at age 11 (β = -0.042, 95%CI = −0.08 to 0.00, p = 0.047) and a 0.075 decrease when fully adjusted for all confounders and cpm (β = -0.075, 95%CI = −0.15 to 0.00, p = 0.037). There was no association between MVPA at age 11 and depressive symptoms at age 13 in females.

For males, % MVPA was not associated with depressive symptoms at either 11 or 13 years old. There was a trend for increased % MVPA to be associated with depressive symptoms however this was attenuated in the adjusted model.

3.3. Change in PA associated with change in depressive symptoms

Table 3 also shows results from regression analysis reporting whether change in PA between the ages of 11 and 13 was associated with change in depressive-symptoms between ages 11 and 13. For males, change in MVPA was associated with change in depression (β = -0.097, 95%CI = −0.032 to −0.008, p = 0.001). This pattern remained in the fully adjusted model (β = -0.099, 95%CI = −0.039 to −0.003, p = 0.021).

In females, there was weak evidence that a change in MVPA was positively associated with change in depression (β = 0.050, 95% CI = 0.00 to 0.033, p = 0.051), but this association was attenuated in the adjusted model (β = 0.032, 95%CI = −0.013 to 0.034, p = 0.383).

3.4. Tertiles of depression

To explore this further, participants were categorized into groups corresponding to those who experienced (i) a reduction, (ii) an increase or (iii) no change in levels of depressive symptoms between the ages of 11 and 13. In the minimally adjusted model, a one unit increase in MVPA between the ages of 11 and 13 was associated with an increase in the

Table 3
Associations between physical activity at 11 years old and depressive symptoms at 11 and 13 years.

Model	Males % time in mvpa			Females % time in mvpa		
	β	95% CI	p value	β	95% CI	p value
Depressive symptoms at 11						
Minimally adjusted	−0.04	−0.09 to 0.00	0.08	**−0.04**	**−0.08 to 0.00**	**0.05**
Fully adjusted	−0.00	−0.07 to 0.06	0.98	−0.05	−0.10 to 0.00	0.07
Additional adjustment total volume	−0.00	−0.09 to 0.08	0.92	**−0.08**	**−0.15 to 0.00**	**0.04**
Depressive symptoms at 13						
Minimally adjusted	0.05	0.00 to 0.09	0.05	−0.02	−0.06 to 0.02	0.28
Fully adjusted	0.04	−0.03 to 0.12	0.27[a]	−0.04	−0.11 to 0.02	0.20
Additional adjustment total volume*	0.07	−0.04 to 0.18	0.20	−0.02	−0.11 to 0.07	0.69
	Males Change in MVPA			**Females Change in MVPA**		
Change in depressive symptoms 11 and 13	**β**	**95% CI**	**p value**	**β**	**95% CI**	**p value**
Minimally adjusted	**−0.10**	**−0.03 to -0.01**	**0.00**	0.05	0.00 to 0.03	0.05
Fully adjusted	**−0.10**	**−0.04 to -0.00**	**0.02**	0.03	−0.01 to 0.03	0.38
Additional adjustment total volume	−0.05	−0.05 to 0.03	0.57	0.07	−0.02 to 0.07	0.27

Note: Tables include standardised beta coefficients (β) and 95% confidence intervals for physical activity variables predicting SMFQ. For % MVPA, 1SD = 4% for males, 3% for females. * Fully adjusted longitudinal models which were adjusted for total volume of PA also include adjustment for SDQ total difficulties score (model 6).
[a] Evidence of heteroscedasticity was detected so analysis was also run with robust standard errors. This resulted in minimal impact on estimates: Beta = 0.04, 95% CI = −0.03 to 0.11, p = 0.30.

odds of being in the lower depressive symptoms group compared to the higher depressive symptoms group by 1.008 for the males (95% CI = 1.001 to 1.016, p = 0.027). This association attenuated in the adjusted model. There were no substantial associations when tertiles of depressive symptoms were examined in females. Results from multinomial logistic regression with higher depressive symptoms as the reference group are shown in online supplement eTable 1 and illustrated in online supplement eFig. 1.

3.5. Bidirectional relationship

The bidirectional relationship was examined with change in depressive symptoms as the exposure and change in MVPA as the outcome in a regression model. For males, the resulting model accounted for a small proportion of the variance (Adjusted $R^2 = 0.008$, SE = 19.20) with change in depression associated with a negative change in MVPA (β = −0.097, 95% CI = −0.732 to −0.191, p = 0.001). When the full range of confounders were entered, a greater proportion of the variance was explained (Adjusted $R^2 = 0.018$, SE = 18.89) with change in depression continuing to be associated with a negative change in MVPA (β = −0.10, 95% CI = −0.859 to −0.071, p = 0.021). However this accounted for less of the variance than when change in MVPA was the exposure and change in depression the outcome (Adjusted R^2 of the fully adjusted model = 0.019, SE = 4.04).

For females, change in MVPA accounted for 1.3% of the variance in change in depressive symptoms in the fully adjusted model (Adjusted R^2 = 0.013, SE = 4.81, see Table 3 for coefficients). When the bidirectional relationship was explored, it was found that change in depressive symptoms accounted for 0.2% of the variance in MVPA in the unadjusted model (Adjusted $R^2 = 0.002$, SE = 15.28) and only 0.7% of the variance in the fully adjusted model (Adjusted $R^2 = 0.007$, SE = 15.00), with no substantial association between change in depressive symptoms and change in MVPA (β = 0.03, 95% CI = −0.126 to 0.329, p = 0.383). This suggests that the model with change in MVPA as the exposure and change in depressive symptoms as the outcome was a better fit to the data.

3.6. Associations with emotional and behavioural difficulties (SDQ scores)

Table 4 shows associations between PA and SDQ scores reported by parents at age 11 and 13. For males, % MVPA was associated with decreased hyperactivity score at age 11 and age 13 when the full range of confounders were entered into the model. For the peer problems subscale, MVPA was associated with decreased problems at age 11 and age 13, although the confidence intervals were wide in the fully adjusted models. No other robust associations were found for the males.

For females, a similar pattern of results was found. For the hyperactivity subscale, % MVPA was associated with decreased hyperactivity at age 11 and age 13 in the fully adjusted models. For the peer problems subscale, higher MVPA was associated with decreased score at age 13 (i.e. less parent reported peer problems). Furthermore, when emotional symptoms were examined, it was found that MVPA was associated with a decrease on this subscale at age 11 and age 13 for females, even after adjustment for all confounding variables. % MVPA was also associated with a decrease in parent rated conduct problems and Total Difficulties score at age 11 and age 13 after controlling for the full range of confounders. It is also worth noting that a similar pattern was found for both parent and teacher completed versions of the SDQ (see supplementary material) suggesting that these are not chance findings.

3.7. Sensitivity analysis

In order to assess whether changes in effect sizes identified in models 2 to 5 were due to bias due to missing data or not for each association, model 1 was repeated for participants who had complete data at model 5. The resulting regression coefficients were slightly larger than when all available data were included but the pattern of results remained the same (data provided in supplementary material etables 10 and 11).

Analysis was repeated using the data set following the multiple imputation. Full results are shown in eTables 12-14. Results using the imputed data set revealed no substantial differences, however, confidence intervals were narrower. This suggests that our results are not due to bias due to missing data.

4. Discussion

4.1. Depressive symptoms

The present study found that, for females, higher levels of MVPA at age 11 were associated with lower depressive-symptoms after adjusting for confounders. When we examined change in depressive symptoms between the ages of 11 and 13 years old, we found that an increase in MVPA between the ages of 11 and 13 in males was associated with a

Table 4
Associations between physical activity at 11 and SDQ (parent report) at age 11 and 13.

	Associations in males % time in MVPA at age 11						Associations in females % time in MVPA at age 11					
	SDQ Age 11			SDQ Age 13			SDQ Age 11			SDQ Age 13		
SDQ	**β**	**95% CI**	**p value**	**β**	**95% CI**	**p value**	**β**	**95% CI**	**p value**	**β**	**95% CI**	**p value**
Prosocial behaviour												
Minimally adjusted	−0.03	−0.08 to 0.01	0.18	−0.02	−0.07 to 0.03	0.42	0.03	−0.02 to 0.07	0.23	0.01	−0.04 to 0.05	0.78
Fully adjusted	−0.02	−0.08 to 0.04	0.47	−0.03	−0.10 to 0.05	0.47	0.03	−0.03 to 0.08	0.34	0.01	−0.06 to 0.07	0.86
Adjusted total volume	−0.03	−0.12 to 0.06	0.47	0.01	−0.10 to 0.11	0.88	0.01	−0.06 to 0.08	0.87	0.03	−0.06 to 0.12	0.52
Hyperactivity												
Minimally adjusted	0.03	−0.01 to 0.08	0.17	0.01	−0.04 to 0.06	0.69	0.03	−0.01 to 0.07	0.17	**0.06**	**0.01 to 0.11**	**0.01**
Fully adjusted	0.04	−0.02 to 0.09	0.25	0.01	−0.06 to 0.08	0.79	0.03	−0.02 to 0.08	0.24	0.06	0.00 to 0.12	0.07
Adjusted total volume	**−0.12**	**−0.21 to -0.04**	**0.01**	**−0.16**	**−0.26 to -0.05**	**0.01**	**−0.13**	**−0.19 to -0.06**	**0.00**	**−0.12**	**−0.21 to -0.03**	**0.01**
Emotional symptoms												
Minimally adjusted	−0.04	−0.08 to 0.01	0.14	−0.01	−0.06 to 0.04	0.79	**−0.06**	**−0.11 to -0.02**	**0.00**	**−0.08**	**−0.13 to -0.04**	**0.00**
Fully adjusted	−0.00	−0.06 to 0.05	0.92	0.00	−0.07 to 0.07	0.98	**−0.07**	**−0.12 to -0.02**	**0.01**	**−0.07**	**−0.13 to -0.01**	**0.03**
Adjusted total volume	0.03	−0.06 to 0.12	0.48	0.04	−0.07 to 0.15	0.48	−0.06	−0.13 to 0.01	0.11	−0.08	−0.17 to 0.01	0.08
Conduct problems												
Minimally adjusted	0.00	−0.04 to 0.04	0.92	0.00	−0.05 to 0.06	0.92	−0.01	−0.05 to 0.03	0.61	−0.01	−0.06 to 0.04	0.74
Fully adjusted	0.05	−0.01 to 0.10	0.13	0.01	−0.07 to 0.08	0.81	−0.03	−0.08 to 0.02	0.19	−0.00	−0.07 to 0.06	0.93
Adjusted total volume	−0.04	−0.13 to 0.04	0.32	−0.05	−0.16 to 0.06	0.38	**−0.11**	**−0.18 to -0.04**	**0.00**	**−0.10**	**−0.19 to -0.01**	**0.02**
Peer problems												
Minimally adjusted	**−0.11**	**−0.15 to -0.06**	**0.00**	**−0.12**	**−0.17 to -0.07**	**0.00**	−0.03	−0.07 to 0.02	0.24	**−0.05**	**−0.09 to 0.00**	**0.04**
Fully adjusted	**−0.08**	**−0.14 to -0.02**	**0.01**	−0.06	−0.13 to 0.02	0.13	−0.03	−0.08 to 0.02	0.22	−0.06	−0.13 to 0.00	0.06
Adjusted total volume	−0.03	−0.11 to 0.06	0.51	0.03	−0.08 to 0.14	0.58	0.00	0.00 to 0.00	1.00	−0.03	−0.12 to 0.05	0.45
Total difficulties												
Minimally adjusted	−0.03	−0.08 to 0.02	0.19	−0.04	−0.09 to 0.01	0.14	−0.02	−0.09 to 0.03	0.26	−0.02	−0.09 to 0.04	0.38
Fully adjusted	0.00	−0.06 to 0.06	0.96	−0.01	−0.09 to 0.07	0.73	−0.03	−0.11 to 0.02	0.18	−0.02	−0.12 to 0.06	0.51
Adjusted total volume	−0.08	−0.16 to 0.01	0.09	−0.06	−0.19 to 0.05	0.26	**−0.11**	**−0.24 to -0.06**	**0.00**	**−0.12**	**−0.29 to -0.05**	**0.01**

Note: Tables include standardised beta coefficients (β) and 95% confidence intervals for physical activity variables predicting parent report SDQ.

reduction in depressive symptoms in the adjusted model, but we did not find this association in females. Furthermore, in females higher levels of MVPA were associated with lower scores on the emotional subscale of the SDQ at both 11 and 13 and when both parent and teacher reports were considered. These associations were stronger for females than males, but were small in magnitude. We also found associations between MVPA and the peer problems subscale of the SDQ, which together can be considered "internalizing" difficulties (A. Goodman, Lamping, & Ploubidis, 2010).

Furthermore, we found that using MVPA as the exposure variable and depressive symptoms as the outcome was a better fit to the data than the alternative model of depression as the exposure. This is a complex area and while support for the bi-directional relationship has been reported (Gunnell et al., 2016), examination of bi-directional relationships using device measured PA is still a relative novelty in the research literature. Toseeb et al. (2014) found no association between device measured PA and depression between the ages of 14.5 and 17.5. However Kandola et al. (2020) report associations between MVPA at age 12 and depression at age 18 also in participants from ALSPAC. While a strength of the current work is the consideration of bi-directional relationships, this finding would benefit from further exploration in longitudinal models with more than two time points.

Cross-sectional analysis of the associations between PA and depressive-symptoms at age 14 in the ALSPAC cohort suggested a protective influence of the total volume of PA (Wiles et al., 2011) and longitudinal work by Kandola and colleagues (Kandola et al., 2020) implicated high levels of sedentary behaviour and low levels of light PA as detrimental for depression. However in both studies only one measure of depressive-symptoms was examined, highlighting a need for triangulation across measures and sources of reporting (Aebi et al., 2017).

4.2. Broader outcomes

When exploring associations between the hyperactivity and conduct problems subscales, which can be considered as "externalizing" difficulties (A. Goodman et al., 2010), % MVPA was associated with decreased scores on these subscales (approx. 10–30% of a SD decrease). The finding for hyperactivity was consistent for both males and females, at ages 11 and 13, and for both teacher and parent ratings. Further findings for the conduct problems subscale were apparent for females at both age 11 and age 13. These findings suggest that MVPA is the construct of PA which may influence externalizing difficulties in adolescents who are not diagnosed with ADHD. A recent review reported that physical activity interventions benefit symptoms of ADHD in children/adolescents with a clinical diagnosis of ADHD (Xie et al., 2021). However, Xie and colleagues found that moderate intensity interventions were more beneficial for the reduction of hyperactivity/impulsivity than MVPA, however the particular subgroup analysis included the adult literature and participants with a clinical diagnosis of ADHD which might explain the nuanced differences in comparison to the present study.

In terms of broader outcomes, Bell et al. (2019) also examined associations between device measured PA and outcomes from the self-reported version of the SDQ. They detected associations between volume of PA and scores on the emotional symptoms scale at age 15/16 but found no evidence of associations with hyperactivity or other

components of the SDQ. The present study extends these findings by examining parent and teacher reports on the SDQ and detecting wider impact though. Taken together, this evolving evidence base suggests that physical activity may have small but protective impact on mental health and emotional and behavioural difficulties of adolescents.

4.3. Possible mechanisms and biological plausibility

There are a number of candidate mechanisms by which increased PA might reduce risk of depression (Kandola, Ashdown-Franks, Hendrikse, Sabiston, & Stubbs, 2019), and/or improve behavioural and emotional difficulties. In particular, PA is likely to have a beneficial influence on psychological constructs such as self-esteem (Biddle et al., 2019; Stewart et al., 1994) which in turn influence risk of depression in adolescence (Orth, Robins, & Roberts, 2008). Furthermore, MVPA is likely to have a favorable effect on the release of neurotransmitters which enhance mood (Ernst, Olsen, Pinel, Lam, & Christie, 2006; Phillips, Kiernan, & King, 2001). It was not possible to test these underlying mechanisms in the present study, however examination of bi-directionality adds to the evidence base. Further work examining underlying mechanisms is therefore needed.

4.4. Study strengths and limitations

The effect sizes and β coefficients for the apparently 'protective' associations of PA observed are small, but two issues complicate interpretation. First, levels of objectively measured MVPA were, as in many other studies of children and adolescents in the western world (Ekelund et al., 2012), very low and more substantial influence on outcomes might be achieved with higher 'doses' of MVPA. Second, PA is variable and a measure over a minimum of three days does not fully capture habitual physical activity. Measurement error correction (Mattocks et al., 2007) approximately doubled standardised β coefficients and so the influence of PA on our outcome measures without correction is highly conservative.

The present study makes a unique contribution to the evidence base by using robust measures taken over two time points to demonstrate the positive associations between physical activity and mental health in young people. The effect sizes observed were small though suggesting this may not be the ultimate "panacea" (McIntosh, 2021) and instead part of a complex pattern of factors which together support young people's mental health (Lagerberg, 2005).

The main strengths of the present study were the large sample size, the broadly socio-economically representative nature of the sample, the objective measurement of habitual PA, and longitudinal design. The present study also benefitted from multiple sources of reporting (parent, teacher and self-report) and that conclusions were based on two different instruments, therefore adding weight to the conclusions. In addition, participants who had received a psychiatric diagnosis of depression or behavioural difficulties at age 11 measurement were excluded from the present analyses meaning the results are reflective of non-clinical levels of depressive symptoms which may differ from those with more profound difficulties.

The present study also had a number of limitations. Both parents and teachers completed the SDQ, however self-reported versions were not included in the ALSPAC cohort at the ages in this study. It is possible that differences in pattern of results may have been found if self-reports had been used for this instrument. The use of self-report from the SMFQ adds to this study though. The relatively low levels of MVPA within the cohort may limit conclusions about the impact of effects of higher levels of PA. Alternative cut points to define MVPA would have produced different estimates of the amount of MVPA, but previous studies which have examined variation of cut points have found they have not altered the associations observed markedly (Ekelund et al., 2012), albeit in cardiometabolic risk factors. The accelerometry cutpoints used to define MVPA were based on a calibration study specific to participants in the present study. While the loss of data in the fully adjusted models could be considered a limitation, it is worth noting that when models were re-analysed including only participants with complete confounding information, no substantial differences were detected. While only small differences have been found in characteristics in participants who attended the research clinic compared to those who did not, sample attrition in ALSPAC is associated with socioeconomic disadvantage and it is possible that less active and/or overweight participants might have been more likely to be missing PA measurement which may also have implications for interpretation. Furthermore, information about family history of behavioural and emotional symptoms was not available.

5. Conclusions

The present study suggests that MVPA may have small beneficial effects on behavioural difficulties (i.e. hyperactivity and conduct problems) in adolescence for both males and females, and may also be beneficial for depressive and emotional symptoms. These findings build on existing literature with older adolescents (e.g. Kandola et al.) and add to literature from other stages of life, such as the evidence of a causal relationship between device measured PA and reduced depression in adults (Choi et al., 2019). Our findings also highlight that if PA was to be used in primary prevention of depressive-symptoms, and/or emotional and behavioural problems in adolescence, the present study suggests that MVPA should be one factor promoted. Given the impact of the COVID-19 pandemic on physical activity and association with mental health (Caroppo et al., 2021), efforts to support young people to engage in more moderate to vigorous physical activity should be supported.

Funding

The UK Medical Research Council and Wellcome Trust (Grant ref: 217065/Z/19/Z) and the University of Bristol provide core support for ALSPAC. This research was specifically funded by the Bupa Foundation (Grant ref: TBF-08-031). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

What's known on this subject

Physical activity is believed to be protective against depressive-symptoms and emotional and behavioural difficulties in adolescents but little robust evidence exists.

What this study adds

Higher moderate-vigorous intensity physical activity (MVPA) was associated with decreases in depressive symptoms and emotional difficulties and reduced hyperactivity and conduct problems after controlling for confounders. The findings suggest that physical activity may have a small protective influence on adolescent mental health.

Contributor's statement

All authors were responsible for study conceptualization.

Josephine N. Booth conducted data analyses with all authors contributing to interpretation.

Josephine N. Booth and John J. Reilly wrote the first draft of the paper. All authors commented on subsequent drafts and the final version of the paper.

The sponsor of the study had no role in the study design, data collection, analysis and interpretation, drafting of the manuscript, or in the decision to submit the paper. All authors had full access to all of the data in the study and take responsibility for the integrity and accuracy of the data analysis.

Declaration of competing interest

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

Data availability

The authors do not have permission to share data.

Acknowledgements

We are extremely grateful to all the families who took part in this study, the midwives for their help in recruiting them, and the whole ALSPAC team, which includes interviewers, computer and laboratory technicians, clerical workers, research scientists, volunteers, managers, receptionists and nurses. This publication is the work of the authors and JNB and JJR will serve as guarantors for the contents of this paper. For the purpose of open access, the author has applied a Creative Commons Attribution (CC BY) licence to any Author Accepted Manuscript version arising from this submission.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.mhpa.2022.100497.

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