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Cardiorespiratory Fitness, Muscular Fitness and Mental Health in Older Adolescents: A Multi-level Cross-Sectional Analysis

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Highlights

- Muscular fitness was not associated with mental health after adjusting for cardiorespiratory fitness.
- Cardiorespiratory fitness was moderately associated with older adolescents' well-being and internalizing problems.
- The association between cardiorespiratory fitness and mental health was stronger for girls, than boys.

Abstract

Physical activity interventions that promote cardiorespiratory (CRF) and muscular fitness (MF) may improve mental health in young adolescents. However, less is known about the links between fitness and mental health in older adolescents, as they are an understudied population. In addition, the association between MF and adolescents' mental health is less clear than it is for CRF. Our primary aim was to investigate whether MF is independently associated with mental health in a sample of older adolescents. Our secondary aim was to determine if the association between fitness and mental health was moderated by sex, socio-economic status (SES) or weight status. Participants were 669 students (16.0 [0.4] years, 44.5% female) from 20 secondary schools in New South Wales, Australia. Mental health (well-being and internalizing problems) was self-reported using the Short Warwick-Edinburgh Mental Wellbeing Scale and the Strengths and Difficulties Questionnaire (emotional and peer problems subscales). We assessed CRF using the Progressive Aerobic Cardiovascular Endurance Run and MF using the push-up and standing long jump tests. After controlling for CRF, MF was not associated with mental health. Conversely, CRF was associated with well-being ($\beta = .20$, $p < .001$) and internalizing problems ($\beta = -.27$, $p < .001$). Interaction tests revealed the strength of association between CRF and mental health was stronger in girls, than boys. No interaction effects were observed for SES or weight status. Although cross-sectional, our findings provide further evidence of the potential benefits of CRF for adolescents' mental health (i.e., well-being and internalizing problems), particularly among girls. However, MF may be less relevant to mental health among this population.

Key words: muscular fitness, cardiorespiratory fitness, well-being, internalizing problems, adolescents.

Introduction

Mental health is defined as 'a state in which the individual realizes his or her own abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community' [1]. Importantly, indicators of mental health can include both positive (i.e., well-being) and negative (i.e., ill-being) constructs. Common indicators of well-being include self-esteem, positive affect, life satisfaction, quality of life and psychological resilience. Alternatively, ill-being constructs include preclinical psychological states (e.g., high levels of perceived stress) and clinically diagnosed mental disorders (e.g., depression and anxiety) [2].

Mental disorders place a significant burden on individuals and society [3]. Evidence suggests secular increases in stress and anxiety among adolescents in recent decades [4], with 'school-related stress' identified as a major driver of this change [5]. Adolescent girls typically report experiencing more stressful events and higher levels of depression and anxiety, compared to boys [6]. The period of late adolescence (15-18 years) is one in which young people may be particularly susceptible to mental health disorders, with the normal challenges of maturation (i.e., changing social roles, formation of identity, commencement of paid work, and physical changes) compounded by the pressure to perform in final school examinations [7]. These changes are occurring against a backdrop of decreases in physical activity, such as the removal of mandatory physical education for senior school students [7].

Participation in physical activity can enhance adolescents' well-being and reduce indicators of internalizing problems [8]. As suggested by Lubans and colleagues [2], the time (i.e., how long), type (i.e., what), intensity (i.e., how hard) and context (i.e., where and with whom) of physical activity may moderate the effects on mental health outcomes, which are thought to operate via a number of possible neurobiological, psychosocial and behavioral mechanisms. For example, in a large sample of adolescents, vigorous intensity physical activity was more strongly associated with mental health benefits than activity of light and moderate intensity [9]. Of note, participating in physical activity of sufficient intensity to improve health-related fitness (i.e., cardiorespiratory fitness [CRF], muscular fitness [MF] and body composition) may be necessary to induce neurobiological adaptations. According to the cross-stressor-adaptation (CSA) hypothesis [10], exposure to a physical stress such as vigorous exercise, triggers a response similar to that following exposure to a psychosocial stressor (i.e., increase in heart rate, respiration, blood cortisol). The CSA hypothesis posits that the beneficial adaptation of the hypothalamic–pituitary–adrenocortical axis and the sympathoadrenal medullary system during physical exercise can generalize to psychosocial stressors and may improve mental health [11].

Although higher levels of CRF have been positively associated with indicators of well-being [12], and negatively associated with internalizing problems [13 14], findings have been inconsistent and most of the research has focused on children and young adolescents (i.e., 12 to 15 years) [15]. For example, some studies have found positive associations between fitness and mental health [16], while others have reported non-significant or even negative associations [17 18]. It has also been suggested that MF may have unique mental health benefits for adolescents [8 19 20]. A recent study found that absolute upper- and lower-body muscular strength was positively associated with self-esteem in a small sample of overweight/obese children [21]. In another study involving adolescents, MF was found to be positively associated with physical self-perceptions (i.e., perceived appearance and sport competence) [22], which are known to generalize to global self-esteem. However, previous studies have failed to control for CRF levels in their statistical analyses, preventing us from drawing conclusions regarding the unique benefits of MF for adolescents' mental health. Additional limitations include the failure to measure both positive and negative indicators of mental health and the focus on children and young adolescents.

Examining the associations between fitness and mental health in older adolescents is particularly important as this is when physical activity levels decline dramatically [23] and many mental health disorders emerge [24]. Therefore, the primary aim of our study was to investigate whether MF is independently associated with mental health (i.e., well-being and internalizing problems) in older adolescents. Our secondary aim was to determine if associations between fitness and mental health were moderated by sex, socio-economic status (SES) and weight status.

Methods

Design and participants

Baseline data from the Burn 2 Learn cluster randomized controlled trial were used for this study [25]. The study sample included data from 669 adolescents in Grade 11 (mean age = 16.0 [0.4] years) from 20 secondary schools participating in a two-arm parallel group cluster randomized controlled trial. Burn 2 Learn is a school-based physical activity intervention designed for Grade 11 students from secondary schools in New South Wales (NSW), Australia. The study is registered with the Australian New Zealand Clinical Trials Registry (ACTRN12617000544370). Ethics approval was provided by the University of Newcastle (H-2016-0424) and the NSW Department of Education (SERAP: 2017116) human research ethics committees.

New South Wales (NSW) government secondary schools with senior school students (i.e., Grades 11 and 12, students aged 16-18) from four geographical areas (i.e., Hunter-Central Coast, Northern and Western Sydney, and New England) were eligible to participate in the study. Schools from the selected geographical regions are broadly representative of urban and regional schools in NSW. Two Grade 11 teachers from each school were recruited and asked to invite their students to participate in the study (there were no restrictions regarding the teaching discipline). The consent rate for students who agreed to participate in the study was 79.4%. Full details of the study protocols and pilot findings are reported elsewhere [25 26].

Measures

Data collection. Baseline data were collected in schools by trained research assistants from February to April in 2018 and 2019, respectively. Measures of self-report (well-being and internalizing problems, and demographic information) were administered using iPads under exam-like conditions. Fitness assessments were conducted in the schools' gym in a sensitive manner by same-sex research assistants.

Well-being. The Short Warwick-Edinburgh Mental Wellbeing Scale was used to assess psychological well-being [27] and consisted of seven statements relating to indicators of well-being (i.e., global self-esteem, psychological and subjective well-being, quality of life and psychological resilience). Statements are scored on a five-point scale ranging from 1 'None of the time' to 5 'All of the time', and are summed to produce a well-being composite.

Internalizing problems. The 'emotional' and 'peer problems' subscales (both include five items) from the Strengths and Difficulties Questionnaire (SDQ) were combined to provide a measure of internalizing problems [28], with items scored on a three-point scale (i.e., 0 = 'Not true', 1 = 'Somewhat true', and 2 = 'Certainly true').

Cardiorespiratory fitness. FITNESSGRAM® testing procedures were used [29] to assess CRF using the Progressive Aerobic Cardiovascular Endurance Run (PACER). The PACER is the most widely accepted field-based measure of CRF and demonstrates high reliability and validity [30].

Muscular fitness. The 90-degree push-up test was used to assess upper body muscular endurance, which has acceptable validity and reliability [31]. Lower body muscular power was assessed using the standing long jump test [32]. A MF index was calculated using the results from the two MF tests (i.e., number of successful repetitions). Scores for the individual tests were standardized [(value – mean)/standard deviation] and then summed to create the MF index.

Body-mass index. Body mass index (BMI) was calculated using the standard equation (weight [kg]/height [m]^2). BMIz-scores were calculated using the lambdamu–sigma method (International Obesity Task Force cut-offs) to determine weight status [33]. Weight and height were assessed using standardized protocols.

Demographics. Sex [i.e., female, male or other], area-level SES (residential postal code), place of birth, language spoken at home, cultural background, and Indigenous status were collected via questionnaires. SES was determined using the Index of Relative Socioeconomic Disadvantage from the Australian Bureau of Statistics census-based Socio-Economic Indexes for Areas [34]. The SEIFA index (scale 1 = lowest to 10 = highest) summarizes the characteristics of people and households within an area. For descriptive purposes, area-level SEIFA values were organized into tertiles (low = 1 to 3, medium = 4 to 7 and high 8 to 10).

Power calculation

The original study power calculation was conducted to determine the sample size needed to detect a change in the primary outcome CRF. Baseline values from our pilot trial [26] and conservative intraclass correlation coefficient (ICC) values of .20 and .03 were used to account for clustering at the class- and school-levels, respectively [35]. Assuming 80% power at a 5% significance level we estimated that 560 students (i.e., 2 classes of 14 students from each of 20 schools) would provide adequate statistical power. Posteriori power estimates were computed using simulated-based method along with Wald test in Mplus. The resulting power estimates for the regression model predicting well-being ranged from .14 for MF to .93

for CRF. The power estimates for the regression model predicting internalizing problems ranged from .10 for MF to .95 for CRF.

Statistical analyses

Analyses were performed using the Mplus 8.3 program [36]. Means and standard deviations were calculated for all normally distributed variables. Bivariate correlations were used to examine correlations between health-related fitness and mental health outcomes (alpha levels set at $p < 0.05$). The robust maximum likelihood estimation procedure was used to account for missing data and the non-independence of students nested within schools by adjusting the standard errors using a sandwich estimator. Linear regression models were run separately for the dependent variables well-being and internalizing problems. All models included the independent variables CRF and MF and the following covariates: sex, SES and BMI. Moderation effects were investigated by testing for the interaction effect of sex, SES and weight status on the association between CRF and mental health outcomes. If the interaction term in the regression model was statistically significant ($p <.10$), we ran separate regression models for the sub-groups (e.g., boys and girls) and report the standardized coefficients. Finally, intraclass correlation coefficients (ICC) were calculated for key variables of interest (i.e., CRF, MF, well-being and internalizing problems).

Results

Descriptive statistics

Participants' characteristics are reported in Table 1. ICC values for cardiorespiratory (ICC = .12) and muscular fitness (ICC = .12) were larger than those observed for well-being (ICC = .04) and internalizing problems (ICC = .04).

Table 1: Characteristics of study sample

Characteristics	**Total (n= 669)**
Age, mean (SD), y [a]	16.0 (0.4)
Female participants, n (%)[a]	298 (44.5)
Born in Australia, n (%)[a]	587 (87.7)
English spoken at home, n (%)[a]	618 (92.4)
Cultural background, n (%)[a]	
Australian	469 (70.1)
European	67 (10.0)
African	6 (0.9)
Asian	39 (5.8)
Middle Eastern	7 (1.0)
Other	78 (11.7)
Indigenous decent, n (%)[a]	61 (9.1)
Socioeconomic status based on household postcode, n (%)[b]	
Low	129 (19.3)
Medium	339 (50.7)
High	196 (29.3)
Weight status, n (%)[c]	
Underweight	26 (3.9)
Healthy weight	445 (66.5)
Overweight	134 (20.0)
Obese	56 (8.4)

[a] Three students did not answer the demographic questions.
[b] Socioeconomic status determined by population tertile using Socio-Economic Indexes For Areas of relative socioeconomic disadvantage based on residential postcode; five participants did not provide their residential postcode.
[c] Eight participants were not measured for weight status

Bivariate correlations between variables

As illustrated in Table 2, CRF was significantly associated with MF, well-being and internalizing problems. The strength of the correlation between CRF and MF was large (r = .72, p < .001), while the strength of the association between CRF and well-being (r = .27, p < .001) and internalizing problems (r = -.33, p < .001) was small to moderate. BMI was not significantly associated with mental health.

Table 2. Descriptive statistics and bivariate correlations between variables

Variable	Descriptive statistics			Bivariate correlations, *r* (*p*-values)				
	n	M	SD	1	2	3	4	5
1. Well-being	666	24.4	4.91	-				
2. Internalizing problems	666	5.5	3.2	-.49 (<.001)	-			
3. BMI z-score	661	.71	1.03	-.01 (.717)	-.01 (.763)	-		
4. Cardiorespiratory fitness	605	48.8	25.4	.27 (<.001)	-.33 (<.001)	-.32 (<.001)	-	
5. Muscular fitness	620	.02	1.83	.24 (<.001)	-.30 (<.001)	-.19 (<.001)	.72 (<.001)	-

Note. M = mean; SD = standard deviation; well-being assessed using the Short Warwick-Edinburgh Mental Wellbeing Scale (possible scores 7 to 35); internalizing problems were assessed using the emotional and peer problems subscales from the Strengths and Difficulties Questions (possible scores 0 to 20); BMI z-score = body mass index z-score; cardiorespiratory fitness = PACER laps completed; muscular fitness = sum of standardized push-up and standing long jump tests; 1 = well-being, 2 = internalizing problems, 3 = BMI z-score, 4 = cardiorespiratory fitness, 5 = muscular fitness

Regression models predicting well-being

The multi-level regression models predicting well-being explained 8% of the variance (Table 3). CRF (β = .201, p <.001) was significantly associated with well-being. After adjustment for age, sex, CRF and MF, BMI z-score (β = .063, p = .022) was also positively associated with well-being, suggesting that adolescents with higher BMI reported higher levels of well-being. The sex interaction term was statistically significant for the model predicting CRF (B = .059, p <.001), but not for the MF model (B = .863, p = .056). Separate regression models demonstrated that CRF was more strongly associated with well-being in girls (β = .257, p <.001) than boys (β = .112, p = .015). SES did not moderate the cross-sectional association between MF (B = .001, p = .783) or CRF (B = .001, p = .610) and well-being. Similarly, the weight status interaction term was not significant for MF (B = .001, p = .378) or CRF (B = .001, p = .386).

Table 3: Regression model predicting adolescent well-being

Variables	Unstandardized estimate B	Standard error of estimate B	Standardized β	*p* value
Age	.468	.507	.044	.356
Sex	-.352	.628	-.037	.575
Socio-economic status	-.011	.007	-.057	.116
BMI z-score	.288	.125	.063	.021
Cardiorespiratory fitness	.038	.007	.201	<.001
Muscular fitness	.152	.166	.058	.360
			R square	.080

Note. Sex coded as male = 1 and female = 2; BMI z-score = body mass index z-score; cardiorespiratory fitness = PACER laps completed; muscular fitness = sum of standardized push-up and standing long jump tests; B = unstandardized coefficient and β = standardized coefficient.

Regression models predicting internalizing problems

The multi-level regression models predicting internalizing problems explained 11.5% of the variance. CRF (β = -.204, p <.001) and sex (β = .116, p = .014) were significantly associated with internalizing problems (Table 4). The sex interaction term was statistically significant for the model predicting CRF (B = .059, p <.001), but not for the MF model (B = .863, p = .056). CRF was more strongly associated with internalizing problems in girls (B = -.041, p <.001), compared to boys (B = -.458, p = .086). Separate regression models demonstrated that CRF was more strongly associated with internalizing problems in girls (β = -.276, p <.001) than boys (β = -.105, p = .038). The SES interaction term was not significant for MF (B = -.001, p = .631) or CRF (B = .001, p = .828). Similarly, weight status did not moderate the cross-sectional association between MF (B = -.001, p = .227) or CRF (B = .001, p = .136) and internalizing problems.

Table 4: Regression model predicting internalizing problems

Variables	Unstandardized estimate B	Standard error of estimate B	Standardized β	*p* value
Age	-.139	.269	-.020	.605
Sex	.736	.304	.116	.014
Socio-economic status	-.009	.005	-.074	.055
BMI z-score	-.030	.109	-.010	.783
Cardiorespiratory fitness	-.026	.005	-.204	<.001
Muscular fitness	-.088	.094	-.050	.354
			R square	.115

Note. Sex coded as male = 1 and female = 2; BMI z-score = body mass index z-score; cardiorespiratory fitness = PACER laps completed; muscular fitness = sum of standardized push-up and standing long jump tests; B = unstandardized coefficient and β = standardized coefficient.

Discussion

The primary aim of our study was to determine if MF was associated with mental health (i.e., well-being and internalizing problems) independently of CRF in older adolescents. Although MF was significantly associated with both mental health outcomes in the bivariate correlations, the association was no longer statistically significant after adjusting for sex, SES, BMI and CRF. Our secondary aim was to determine if the association between fitness (both CRF and MF) and mental health was moderated by sex, SES and weight status. Notably, the strength of the association between CRF and mental health was significantly stronger in girls, compared to boys. No interaction effects were observed for SES or weight status.

We did not find an independent association between MF and mental health in our sample of older adolescents. Previous studies examining the associations between MF and mental health in adolescents have produced mixed findings [21 37 38] and none focused on older adolescents in their final years of school. For example, higher muscular strength was associated with more positive mental health outcomes, including lower level of stress and negative affect, as well as higher levels of self-esteem and optimism in a small sample of overweight children [21]. Alternatively, CRF but not MF was positively associated with all five health-related quality of life domains in Norwegian children [38]. Powerful evidence for the benefits of MF for mental health can be observed in a 24-year longitudinal study involving more than one million male adolescents (16-19 years) [39]. Muscular strength in adolescence was linked to 20-30% lower risk of death from suicide, and 15-65% less chances to be diagnosed with any psychiatric disease as an adult [39]. However, it is must be noted that this study [39] did not adjust for the potential confounding effect of CRF, and risk reductions for suicide- and substance-abuse related mortality were also found with higher CRF in this cohort [40].

Internalizing symptoms often emerge during adolescence and if untreated, may manifest as depression and anxiety. Consistent with previous literature, we observed a moderate negative association between CRF and internalizing problems[13 14]. However, the majority of research has focused on children and young adolescents. For example, Rieck and colleagues [13] reported that children with higher levels of CRF reported significantly lower levels of depression. In a longitudinal study concerning middle school students [14], CRF in sixth grade (mean age 11.6 years) was associated with less depression by seventh grade in girls, but not in boys (although the effects were in the same direction). Another longitudinal study involving middle school students (mean age 11.4 years) revealed that higher levels of physical fitness, including CRF and MF, were associated with improved mental health (i.e., lower levels of depression, peer rejection, loneliness, internalizing symptoms as well as higher levels of adaptive functioning, externalizing symptoms, self-worth, and perceived competence) [41]. To our knowledge, this is the first study to identify an inverse association between CRF and internalizing problems in older adolescents. These findings have important implications for physical activity promotion in this age group.

Sex was a significant moderator of the association between CRF and mental health in our study. This finding may be explained by the interpersonal stresses experienced by adolescent girls as well as their physical activity profiles. Consistent with previous research, girls in our study reported higher levels of psychological distress and lower levels of fitness, than boys[14 20]. In addition, evidence suggests that girls display more negative emotional responses to stressful events, in the form of anxiety and depression, compared to boys [6]. Overall, girls tend to be more "vulnerable" than boys throughout adolescence and may be more susceptible to the consequences of poor fitness. The majority of cross-sectional [15] and experimental [42] studies examining the association and impact of CRF and MF has involved younger adolescents and produced modest effect sizes. Additional studies involving older adolescents are needed and such studies may yield larger effects, particularly among girls and those with low levels of fitness and poor mental health.

Consistent with our findings, several studies have demonstrated that CRF is positively associated with various indicators of well-being in young adolescents [43 44]. For example, Riiser and colleagues [43] demonstrated that CRF was significantly associated with health-related quality of life in Norwegian adolescents. Also, CRF in girls and MF in boys, were more strongly associated with health-related quality of life dimensions in Spanish children [44]. It is perhaps worth noting that the Spanish study measured MF using a handgrip strength and the standing broad jump tests, which measure strength and power, respectively [44]. In the current study, standing long jump and push-up tests were used as a measure of muscular endurance. In the current study, the standing long jump and push-up tests were used to measure MF. It is possible that other measures of MF might produce different results. We intended to provide a proxy measure of 'overall' muscular fitness by creating a composite score encompassing both lower and upper body regions and both maximal strength/power (standing long jump) and muscular endurance (push-ups) domains. However, it remains possible that certain dimensions of MF are more strongly related to mental health than others, and the lack of association in the present study is a measurement issue. As such, future research could evaluate associations between specific MF and mental health in adolescents, using criterion measures (e.g., 1 repetition maximum testing) [45].

Interestingly, BMI z-scores were positively associated with internalizing problems in the bivariate correlations, but this association was reversed when MF and CRF were included in the regression model. It is possible that high levels of MF and CRF act as a protective barrier against internalizing problems among adolescents with high BMI z-scores. Similar findings were demonstrated in a longitudinal study involving adults, where no measure of fatness was associated with the onset of depressive symptoms after controlling for CRF [46].

However, due to the relatively small magnitude of effect in the present study, we cannot discount the possibility of type II error.

Strengths and limitations

The strengths of this study include a unique study population, field-based measures for CRF and MF, multi-level regression models adjusting for clustering of effects at the school level and validated questionnaires for different mental health outcomes. However, some limitations must be acknowledged. First, as this is a cross-sectional study, causation cannot be established. Randomized controlled trials are needed to clarify the independent effects of MF on mental health in older adolescents. Second, our study measured broad domains of mental health (i.e., well-being and internalizing problems), but did not specify the specific indicators of mental health within those domains (e.g., anxiety and depression). Evidence for the benefits of fitness for the prevention of specific mental health disorders in young people will support health promotion efforts. Third, our posterior power calculation revealed lower statistical power to detect associations for MF compared to CRF. As such, due to the relatively small magnitude of effect in the present study, we cannot discount the possibility of type II error. Finally, although the PACER is considered the most appropriate field-based measure for evaluating CRF, it is difficult to determine whether maximal effort is reached.

Conclusion

MF was not independently associated with mental health in a sample of older adolescents aged 15-17 years. It is possible that a measure of muscular strength (e.g., handgrip test) would produce a different result, as we found that our MF index was strongly correlated with CRF in the study sample. After adjustment for CRF and MF, BMI was not associated with internalizing problems and positively associated with well-being. Consistent with previous research, CRF was moderately associated with mental health in older adolescents, with stronger associations observed in girls.

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