Mental Health and Physical Activity 21 (2021) 100411

Contents lists available at ScienceDirect

Mental Health and Physical Activity

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

Associations between changes in physical fitness and psychological difficulties status among Norwegian adolescents

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ARTICLE INFO

Keywords:
Physical fitness
Psychological difficulties
Mental health
Moderator
Change score
Adolescents

ABSTRACT

Objectives: To investigate the associations for one-year changes in cardiorespiratory fitness, muscular strength and body mass index, with psychological difficulties status in adolescents.

Methods: Norwegian 14-15-year-olds (n = 925) participated in data collection at two time points separated by one year. Psychological difficulties were assessed via the Strengths and Difficulties questionnaire and data from follow-up serve as the dependent variable. Cardiorespiratory fitness (the Andersen-test), muscular strength (Eurofit) and body mass index were measured. Change scores were calculated from the physical fitness variables and serve as independent variables in linear mixed effects models.

Results: There was no association between change in body mass index and psychological difficulties. Sex and socioeconomic status moderated the association between cardiorespiratory fitness and psychological difficulties. Immigrant status moderated the association between muscular strength and psychological difficulties. Subgroup results indicated inverse associations between change in cardiorespiratory fitness and psychological difficulties among boys (b = −0.009; 95% CI = −0.015 to −0.003; p = .006); change in muscular strength and psychological difficulties among immigrants (b = −1.97; 95% CI = −4.03 to 0.09; p = .061). Subgroup results also indicated an association between change in cardiorespiratory fitness and psychological difficulties among girls in the highest socioeconomic group (b = 0.014; 95% CI = 0.003 to 0.025; p = .014).

Conclusions: The associations for different fitness components were dependent on different moderators. Possibly, this indicates that associations in different subgroups are mediated by different mechanisms. Moderated associations should be addressed in future investigations.

1. Introduction

Mental health problems are the leading cause of disability among adolescents (Erskine et al., 2015), and because most adult mental disorders begin in adolescence (Jones, 2013), it is important to investigate viable methods of prevention. There is compelling evidence in favor of physical activity (PA) as a preventive measure against mental disorders in adults (Choi et al., 2019), however, evidence is more inconclusive among adolescents (Biddle, Ciaccioni, Thomas, & Vergeer, 2019).

It is unclear how PA influences mental health, however, Lubans et al. (2016) have suggested that the influence may be caused by different neurobiological-, psychosocial- or behavioral mechanisms. For instance, the neurobiological mechanism can refer to how aerobic PA can influence structures and functions in various regions of the brain (Matta Mello Portugal et al., 2013). Furthermore, the psychosocial mechanism can refer to how strength training can positively influence senses of "self" (e.g. self-esteem, self-efficacy, self-perceptions; Collins, Booth, Duncan, Fawkner, & Niven, 2019). Lastly, the behavioral mechanism can refer to how various aerobic PA may influence self-regulation skills, such as attention and concentration (Laberge, Bush, & Chagnon, 2012). In turn, the mechanisms might influence various mental health outcomes, such as depression (Nestler et al., 2002; Steiger, Allemand, Robins, & Fend, 2014) or well-being (Steinberg, 2014, p. 177). Knowledge of the mechanisms is "critical to developing effective targeted interventions to promote mental health and reduce mental disorders in youth" (Doré et al., 2020). Unfortunately, we still know little about the

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https://doi.org/10.1016/j.mhpa.2021.100411
Received 2 March 2021; Received in revised form 23 May 2021; Accepted 2 June 2021
Available online 12 June 2021

mechanisms and Biddle et al. (2019) have called on future research to focus on identifying them.

To improve our ability to identify the mechanisms, measurement precision and validity is important, considering that the mechanisms can be moderated by "frequency, intensity, time, type and context" of PA (Lubans et al., 2016). This level of detail in PA measurement can prove challenging, considering how complex and multidimensional PA behavior is (Warren et al., 2010). Physical fitness is strongly related to PA (Fogelholm, Stigman, Huisman, &) and can be divided into three health-related components: cardiorespiratory fitness (CRF), muscular strength and body composition (Caspersen, Powell, & Christenson, 1985). Although these components do not necessarily provide specific information regarding frequency, intensity, time, type and context of PA, the components can at least give some indication of some of these moderators and how they occur over time (Blair, Cheng, & Holder, 2001). Thus, physical fitness may be a more suitable measure in the effort to investigate the association between habitual PA and mental health, and the potential explanatory mechanisms of the association. Studies that argue for using physical fitness over PA have suggested that "quantification of fitness is more objective than physical activity" (Schuch et al., 2016) and that "fitness is a more relevant disease or prognostic marker" (Tacchi, Heggelund, & Scott, 2019). It has also been suggested that physical fitness itself mediates the effect of PA on mental health outcomes (Eddolls et al., 2018; Ruggero, Petrie, Sheinbein, Greenleaf, & Martin, 2015).

There is an abundance of studies examining the cross-sectional association between physical fitness and mental health among adults (Papasavvas, Bonow, Alhashemi, & ; Pereira-Miranda, Costa, Queiroz, Pereira-Santos, & Santana, 2017; Volaklis, Mamadjanov, Meisinger, & Linseisen, 2019). Longitudinal studies that examine the association over time, however, are scarce. The existing evidence suggests that having a lower body mass index (BMI) and preventing CRF from declining is prospectively associated with lower odds of depression (Bjerkeset, Romundstad, Evans, & Gunnell, 2008; Dishman et al., 2012; Shigdel, Stubbs, Sui, & Ernstsen, 2019). Regarding muscular strength, a recent study indicated that grip strength is associated with lower odds for developing depression, for females only (McDowell, Gordon, & Herring, 2018).

In the context of physical fitness and mental health research, adolescents are an understudied population. Cross-sectional studies have found positive associations between mental health outcomes and CRF (Greenleaf, Petrie, & Martin, 2010), muscular strength (Smith et al., 2014) and BMI (Eddolls et al., 2018). Longitudinal studies, however, are scarce, which should be considered a major gap in our knowledge of how physical fitness is associated with mental health over time, in the period of adolescent development. The first and only review of such longitudinal studies was published recently by Tacchi et al. (2019). The results of the review associated higher levels of physical fitness with lower incidence of mental health problems; however, the authors listed several limitations regarding the reviewed studies. For instance, there was an overweight of male participants, CRF was the only fitness component included, and studies did not control for important covariates, such as socioeconomic status (SES). Examples of categorical variables that are associated with both mental health and physical fitness include SES (Bøe, Øverland; Cleland, Ball, Magnussen, Dwyer, & Venn, 2009), sex (Fröjd et al., 2008) and immigrant status (Abebe, Lien, & Hjelde, 2014; Lämmle, Worth, & Bös, 2012). It is therefore important to control for these variables and to investigate whether they have moderating effects on the association between physical fitness and mental health.

To learn more about the possible protective properties of the health-related components of physical fitness, there is a need for more research on the prospective association between physical fitness and mental health outcomes in adolescent populations. The aim of the present paper was therefore to investigate whether one-year changes in physical fitness components were associated with psychological difficulties status among Norwegian adolescents. Secondary aims were to explore potential moderators of the association, and to explore whether an association could be attributed to specific aspects of psychological difficulties. Psychological difficulties include emotional difficulties, conduct problems, hyperactivity and peer problems; and they might provide an indication of which mechanisms that mediate potential associations.

2. Methods

2.1. Design and participants

This was a prospective cohort study that used baseline (May–August 2017) and follow-up (April–June 2018) data from the School in Motion study. Briefly, School in Motion was a multicenter cluster randomized controlled trial (RCT) that took place in four geographical regions in Norway. The primary purpose of School in Motion was to investigate whether two separate school-based PA interventions had an effect on PA levels. The secondary purpose was to investigate the effect on physical fitness, mental health, academic achievement and learning environment. Participants were ninth grade students from 29 lower secondary schools (n = 2084; age 14–15) and the schools were randomized into two intervention groups and one control group. In the present paper, all participants are treated as one cohort, but we control for school clustering and experimental group allocation in the analyses. Fig. 1 shows participant flow and missing values between baseline and follow-up. School in Motion and its procedures were approved by the Norwegian Centre for Research Data (project number 49094), and the study is in line with the Declaration of Helsinki for experiments involving humans. The study is registered in ClinicalTrials.gov ID nr: NCT03817047.

2.2. Measurements

Measurement procedures for all variables have been described in detail in the paper outlining the cross-sectional associations between physical fitness and psychological difficulties at baseline (Åvitsland et al., 2020). Therefore, a brief description is provided below.

2.2.1. Psychological difficulties

Psychological difficulties were assessed by using the self-report version of the Strengths and difficulties questionnaire (SDQ; Goodman, 1997). The SDQ consists of 25 items, divided into five subscales, each holding five items. Four of the subscales – emotional problems, conduct problems, hyperactivity and peer problems – are summed to create the Total difficulties score (TDS). The TDS ranges from 0 to 40 and a higher score indicates increased psychological difficulties. The TDS functions as a dimensional measure that indicates a general mental health state in children and adolescents, as it has been found to detect changes in psychopathology on each point of the scale (Goodman

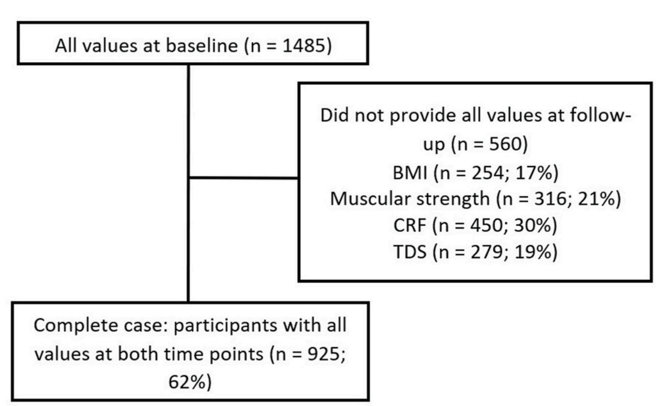

Fig. 1. Participant flow chart between baseline and follow-up. Percentages represent amount relative to 1485; BMI = body mass index; CRF = cardiorespiratory fitness; TDS = Total Difficulties Score.

& Goodman, 2009). To differentiate between groups and identify risk of mental disorders, the TDS can be divided into three levels: Scoring 0–15 is "normal", scoring 16–19 is "borderline", and scoring 20–40 is "abnormal". The abnormal range has been shown to indicate an increased risk of developing mental disorders (Goodman, Ford, Simmons, Gatward, & Meltzer, 2000). The psychometric properties of the SDQ have been validated several times in many countries, including Norway (Van Roy, Veenstra, & Clench-Aas, 2008).

2.2.2. Physical fitness

We measured CRF with a modified version of the Andersen-test (Andersen, Andersen, Andersen, & Anderssen, 2008). The modification was the test field distance, which in the standardized Andersen-test is supposed to be 20 m, but because of limited space in the gymnasiums, we used 16 m. The outcome variable for CRF in this study is the total distance run in meters (m). To assess muscular strength, the participants performed sit-ups, standing broad jump and handgrip test, as they are described in the EUROFIT test battery (Council of Europe, 1988). As an expression of body composition, we measured participants' height and weight and calculated BMI (kg/m^2). All physical fitness tests were conducted at the participants' respective schools, by trained test-personnel.

2.2.3. Covariates and subgroups

We obtained categorical data for covariates and potential moderators. Sex was noted by test-personnel. Immigrant status was self-reported in the questionnaire by asking if the participant was born in Norway. Socioeconomic status (SES) is expressed as the parent with the highest education level (Erola, Jalonen, & Lehti, 2016), which we obtained from national registries. The education level was split in four subgroups: lower secondary school or less; upper secondary school; less than four years university education; more than four years university education. Based on the "normal", "borderline" and "abnormal" TDS cutoffs, we created a categorical baseline TDS variable. Lastly, we also used the categorical data describing participants' allocation to one of the three experimental groups. To ensure the credibility of our subgroup analyses, we adhere to the three most critical criteria set forth by Sun et al. (2012): subgroup variables must be assessed at baseline, subgroup hypotheses must be specified ahead of analyses and there must be an interaction effect.

2.3. Statistical analyses

All analyses were performed in IBM SPSS Statistics 25 (IBM, Armonk, New York, USA). SDQ data were managed and organized into the predetermined scales by the syntax provided by the SDQ information web page (Youthinmind, 2018). Cronbach's alpha was employed to assess the internal consistency of TDS and its subscales. The respective alphas from baseline and follow-up were as follows: emotional problems (0.67 and 0.71), conduct problems (0.51 and 0.53), hyperactivity (0.66 and 0.68), peer problems (0.61 and 0.61) and TDS (0.62 and 0.61). We report all values from both time points with descriptive statistics as means and standard deviations (SD). Paired t-tests were conducted with all outcome variables to assess the overall changes from baseline to follow-up.

We calculated individual change scores for the physical fitness variables (follow-up - baseline), which functioned as the independent variables. The change score for muscular strength is a mean composite z-score, stratified for sex. It was constructed from the change scores for handgrip test, standing broad jump and sit-ups, which were transformed into separate z-scores and averaged.

To test the prospective association between changes in health-related components of physical fitness and psychological difficulties status, we conducted linear mixed effects models, with schools as a random effect. We assessed the potential moderating effect of sex, SES, immigrant status, TDS category at baseline (normal, borderline and abnormal) and experimental group on the association between the independent and dependent variables by creating separate models for each moderator. In each model we added the moderator as an interaction term for all three independent variables, while also controlling for the independent variables. Subsequently, we performed subgroup analyses of the categorical variables that indicated an interaction effect. Follow-up TDS was the primary dependent variable and when a model indicated results that were compatible with an association, we conducted analyses to investigate if the association could be attributed to any of the TDS subscales (emotional problems, conduct problems, hyperactivity and peer problems). All models controlled for the dependent variable's baseline result, sex, SES, immigration status and experimental group allocation. We report unstandardized regression coefficients (b) with 95% confidence intervals (CI) and exact p values (b; 95% CI; p). The b represents difference on the scale of the dependent variable for each unit increase on the scale of the independent variable.

We do not dichotomously interpret the p-values to be either significant or non-significant. Instead, we adhere to the guidelines provided by the American Statistical Association's statement on statistical significance and p-values (Wasserstein & Lazar, 2016), and more recent guidelines (Wasserstein, Schirm, & Lazar, 2019). Specifically, we interpret p-values as continuous quantities that express how compatible the observed data are with the null-hypotheses: Higher p-values indicate greater compatibility with the null-hypotheses. We interpret and present our results based on a continuous interpretation of the p-values, the size of the unstandardized regression estimates (b) and the limits of the confidence intervals (Amrhein, Greenland, & McShane, 2019; Greenland et al., 2016). Our interpretations are also influenced by prior evidence, plausibility of mechanism, study design and data quality (McShane, Gal, Gelman, Robert, & Tackett, 2019).

2.3.1. Missing values

Missing values between enrollment and baseline have been described extensively in a previous paper (Åvitsland et al., 2020) which argued that the cross-sectional associations at baseline were likely not affected by the missing values. Participation was voluntary and without reward, which may have caused participants to opt out. For example, during measurements, some students expressed their unwillingness to run the CRF test. Furthermore, missing values from the SDQ might be explained by the size and duration of the questionnaire, which consisted of several other instruments and questions. This meant that completion of the extended questionnaire could take up to 1 h. These are only potential explanations, and the missing values might have been caused by other reasons unknown to us. Of the participants with all values at baseline ($n = 1485$), 62% ($n = 925$) had all values at follow-up. A grouping variable was created, and one-way ANOVAs were used to analyze differences between the complete case group, and participants with present values at baseline but missing values at follow-up ($n = 560$).

To assess whether missing values were missing completely at random (MCAR), Little's MCAR test was conducted on the group with all values at baseline ($n = 1485$). The MCAR test of missing values for TDS, CRF, BMI and muscular strength at follow-up indicated that the missing data in this group were either missing at random (MAR) or not missing at random (MNAR; 47.401, DF = 25, $p = .004$). To investigate missing data further, we used descriptive and frequency statistics to determine the degree of missing values from each variable.

As a final measure of handling missing data, we conducted multiple imputation. With five imputations and ten iterations, missing data were imputed from TDS, CRF, muscular strength and BMI at both time points and covariates, using the automatic procedure, which allows the program to choose imputation method based on the pattern of missingness. SPSS cannot handle multiple imputation with too many variables, thus we did not impute on the SDQ subscales (Mustillo & Kwon, 2015). The linear mixed effects models that were compatible with effects on the complete case dataset, were conducted on the imputed dataset. We report results from complete case analyses and after multiple imputation, which has been recommended by Manly and Wells (2015) and Sterne et al. (2009).

3. Results

3.1. Descriptives and group differences

The complete case group included 925 participants, of which 474 (51%) were girls and 74 (8%) were immigrants. The four SES groups contained, from lowest to highest SES, 43 (5%), 246 (27%), 374 (40%) and 262 (28%) participants. Table 1 shows the means with standard deviations from both time points, and the respective mean changes (the mean results from baseline and follow-up respective to each categorical moderator subgroup is presented in Supplementary Table 1a). All variables, except conduct problems and peer problems indicated increases at follow-up.

3.2. Associations between change in fitness and psychological difficulties status

The results were compatible with an inverse association between change in CRF and follow-up TDS for all participants (b = −0.004; 95% CI = −0.008 to −0.001; p = .040). The results were not compatible with associations between follow-up TDS and change in BMI or change in muscular strength. The results from moderator analyses were compatible with three separate interaction effects for associations with follow-up TDS: sex * change CRF (p = .010); immigration status * change muscular strength (p = .110); and SES * change CRF (p = .011).

Subsequent subgroup analysis of sexes was compatible with an inverse association between change in CRF and follow-up TDS among boys only (−0.009; 95% CI = −0.015 to −0.003; p = .006). These results suggest that 100 m increase in CRF was associated with 8.5% (0.9 points) lower follow-up TDS, relative to boys' mean values. (10.5 points). Subscale analyses showed that the results could mainly be attributed to lower conduct problems (−0.002; 95% CI = −0.005 to −0.001; p = .034), hyperactivity (−0.003; 95% CI = −0.006 to −0.001; p = .011) and peer problems (−0.003; 95% CI = −0.005 to −0.001; p = .005).

The subgroup analysis of immigrants/non-immigrants was compatible with an inverse association between change in strength and TDS among immigrants only (−1.96; 95% CI = −4.03 to 0.092; p = .061). These results suggest that 1 standard deviation increase in the z-score composite of handgrip strength, standing broad jump and sit-ups, was associated with 18% (1.96 points) lower follow-up TDS, relative to the immigrant population's mean values (10.7). Subscale analyses showed that the results could mainly be attributed to lower conduct problems (−0.48; 95% CI = −1.05 to 0.08; p = .095), and hyperactivity (−0.64; 95% CI = −1.45 to 0.16; p = .113).

The subgroup analysis of SES indicated inverse associations between change in CRF and follow-up TDS in SES groups 1–3 (unstandardized coefficients between −0.007 and −0.04, p-values between .039 and .063). SES group 4 (highest levels of parental education) demonstrated an opposite tendency (b = 0.004; 95% CI = −0.004 to 0.012; p = .278). This prompted further investigation by stratifying the SES groups. The analysis stratified for SES and sex was compatible with an association between change in CRF and follow-up TDS among girls in SES group 4 (n = 135; 0.014; 95% CI = 0.003 to 0.025; p = .014). These results suggest that 100 m increase in CRF was associated with 13% (1.4 point) higher follow-up TDS, relative to girls in SES group 4's mean values (10.5). Subscale analyses showed that these results could mainly be attributed to emotional problems (0.005; 95% CI = −0.001 to 0.01; p = .076) and hyperactivity (0.007; 95% CI = 0.003 to 0.012; p = .002). No other sub-stratification of SES showed results compatible with associations that have not been described. Results from the full study sample and subgroups are presented in Table 2.

Table 1
Mean results and difference between baseline and follow-up (n = 925).

	Baseline (SD)	Follow-up (SD)	Mean change	95% CI	p
Total difficulties score (0–40)	10.1 (5.0)	10.6 (5.4)	0.5	0.2 to 0.8	.001
Emotional problems (0–10)	3.0 (2.2)	3.2 (2.4)	0.2	0.1 to 0.4	<.001
Conduct problems (0–10)	1.5 (1.4)	1.6 (1.5)	0.03	0.07 to 0.1	.535
Hyperactivity (0–10)	3.9 (2.1)	4.1 (2.2)	0.2	0.1 to 0.3	.001
Peer problems (0–10)	1.7 (1.6)	1.8 (1.7)	0.1	0.1 to 0.2	.371
Body mass index	19.8 (2.9)	20.3 (3.1)	0.5	0.5 to 0.6	<.001
Standing broad jump (cm)	174 (25)	181 (26)	7	6 to 8	<.001
Sit-ups (n/30 s)	19 (4)	20 (4)	1	0.8 to 1.2	<.001
Handgrip strength (kg)	30.5 (7)	33.3 (9)	2.8	2.4 to 3.1	<.001
Cardiorespiratory fitness (m)	909 (91)	927 (101)	18	13 to 22	<.001

3.3. Missing value analyses

Missing value analyses showed that results were compatible with some differences between the complete case group and the group with missing values (n = 560). Specifically, the complete case group displayed 6% higher SES (p < .001); 6% lower baseline TDS (0.6 points; p = .017) and 10% lower follow-up TDS (1.1 points; p = .002) and ran 1% (10 m; p = .064) farther at baseline, compared to the missing values group. The results were not compatible with any other differences. Further exploration revealed that the missingness was largely due to participants not performing the CRF-test. Between test centers, not participating in the CRF-test at follow-up caused 62%–89% of the missing values from the follow-up data collection.

After multiple imputation, linear mixed effects models showed similar associations as in the complete case results: Change in CRF was inversely associated with follow-up TDS for all participants (n = 2044; −0.005; −0.009 to 0.001; p = .062) and subgroup analyses showed the association was only present among boys (b = −0.007; −0.013 to −0.001; p = .047). However, compared to the complete case results, results after multiple imputation were much less compatible with associations between change in muscular strength and follow-up TDS among immigrants (n = 190; −0.69; −1.95 to 0.57; p = .278); and between change in CRF and follow-up TDS among girls in SES group 4 (b = 0.002; −0.006 to 0.01; p = .588). Considering that values were imputed for 55% (n = 1119) of the study sample and that an independent variable, follow-up CRF, was the main reason for missing values, the results from the multiply imputed dataset should be treated with caution (Hughes, Heron, Sterne, & Tilling, 2019). We will therefore focus our attention on the complete case results in the discussion, although we acknowledge that our results are uncertain.

4. Discussion

We aimed to investigate whether one-year changes in physical fitness components were associated with adolescent psychological difficulties status. The key findings were 1) an inverse association between change in CRF and follow-up psychological difficulties among boys; 2) an inverse association between change in muscular strength and follow-up psychological difficulties among immigrants; and 3) an association between change in CRF and psychological difficulties among girls in the highest SES group. The three findings are discussed separately.

Table 2
Associations between independent variables (change scores = follow-up - baseline) and dependent variables at follow-up.

Independent variable	Dependent variable			
	Group		Unstandardized b (95% CI)	p
Change CRF		**Follow-up TDS**		
	All participants		−0.004 (−0.008 to −0.001)	.040
	Boys		−0.009 (−0.015 to −0.003)	.006
	Girls		0.001 (−0.004 to 0.006)	.739
	Girls in SES group 1		−0.038 (−0.106 to 0.029)	.238
	Girls in SES group 2		−0.004 (−0.015 to 0.007)	.473
	Girls in SES group 3		−0.001 (−0.008 to 0.005)	.704
	Girls in SES group 4		0.014 (0.003–0.025)	.014
		Emotional problems		
	Girls in SES group 4		0.005 (−0.001 to 0.01)	.076
		Conduct problems		
	Boys		−0.002 (−0.005 to −0.001)	.034
		Hyperactivity		
	Boys		−0.003 (−0.006 to −0.001)	.011
	Girls in SES group 4		0.007 (0.003–0.012)	.002
		Peer problems		
	Boys		−0.003 (−0.005 to −0.001)	.005
Change strength		**Follow-up TDS**		
	All participants		−0.14 (−0.59 to 0.30)	.523
	Immigrants		−1.97 (−4.03 to 0.09)	.061
	Non-immigrants		−0.05 (−0.50 to 0.40)	.830
		Conduct problems		
	Immigrants		−0.48 (−1.05 to 0.086)	.095
		Hyperactivity		
	Immigrants		−0.645 (−1.45 to 0.157)	.113
Change BMI	**TDS**			
	All participants		−0.10 (−0.33 to 0.13)	.400

Note. All models included the three physical fitness variables, experimental group belonging, the dependent variable at baseline, sex, immigration and socioeconomic status, except in models where the categorical variable itself stratified the data. b = regression coefficient; CI = confidence interval; TDS = Total difficulties score; CRF = Cardiorespiratory fitness; BMI = Body mass index; SES = Socioeconomic status.

4.1. The association between change in CRF and follow-up psychological difficulties among boys

Based on interpretation of the p-values alone, the inverse association between change in CRF and follow-up psychological difficulties among boys appear quite certain. To interpret the meaningfulness of the association, we use the paper by Goodman and Goodman (2009), which showed that a one-point reduction in TDS has been associated with a 16%–23% lower likelihood of developing a mental disorder. Thus, the association may be meaningful in a clinical sense, considering that psychological difficulties in boys overall increased, while 100 m increase in CRF suggested 14%–3% lower levels than the boys' mean (10.5), according to the confidence intervals.

These results are in support of the baseline findings from the same population, which were incompatible with any associations between muscular strength and psychological difficulties, or BMI and psychological difficulties (Åvitsland et al., 2020). The results are also supported by previous cross-sectional studies that only found CRF to be associated with a mental health outcome, while controlling for at least one other measure of physical fitness (Andersen et al., 2017; Rieck, Jackson, Martin, Petrie, & Greenleaf, 2013; Yeatts, Martin, & Petrie, 2017). To the best of our knowledge, only Ruggero et al. (2015) have previously investigated the prospective association between physical fitness and mental health outcomes in a similar adolescent population. However, the present results stand in contrast to the results by Ruggero et al. (2015), which showed that baseline CRF was inversely associated with follow-up depression levels among girls, not boys. Similarly, in the cross-sectional study by Greenleaf et al. (2010), higher levels of CRF indicated lower levels of depression among girls only. Moreover, a recent cross-sectional study by Janssen et al. (2020), showed stronger associations between CRF and internalizing problems among girls than among boys. Another recent cross-sectional study showed inverse associations between CRF and internalizing problems and externalizing problems; however, sex did not moderate the association (Wheatley et al., 2020). Rieck et al. (2013) had similar findings as ours and showed that boys, but not girls, with low CRF had higher odds of elevated depression than boys classified as having high CRF. Studies have also investigated whether the effect of PA interventions on mental health is moderated by sex. A meta-analysis found that the effect on mental health outcomes was larger for boys than girls in randomized studies; the effect was opposite in non-randomized studies (Ahn & Fedewa, 2011).

Considering that adult women and men show similar favorable associations between CRF and mental health (Sui et al., 2009), the different associations in the present results may be specific to the adolescent age group. The present subscale results might provide some explanation. Firstly, conduct problems, one of the three aspects of psychological difficulties that the inverse association with TDS was attributed to, is more common among boys than girls (Button et al., 2007). This was also true for the present study population (data not shown). Lower conduct problems may be caused by an increase in self-regulation, a behavioral mechanism (Lubans et al., 2016), which has been associated with PA among adolescents (Wills, Isasi, Mendoza, & Ainette, 2007) and is more common among girls than boys (Raffaelli, Crockett, & Shen, 2005). Therefore, the potential for change in conduct problems and self-regulation is larger among boys than girls. This was demonstrated in the study by Lakes and Hoyt (2004), which also found reductions in conduct problems among boys only, and that the reduction was associated with an increase in self-regulatory skills, as a result of a martial arts program.

The inverse association between change in CRF and follow-up psychological difficulties was also attributed to hyperactivity. This may have occurred through a neurobiological mechanism (Lubans et al., 2016). According to Gapin, Labban, and Etnier (2011), there are many potential neurobiological ways that PA can influence hyperactivity, for instance by increasing blood flow to the frontal region of the brain, or by increasing the availability of dopamine and norepinephrine. This was supported in the recent review by Ng, Ho, Chan, Yong, and Yeo (2017), which concluded that "… moderately-to-intense aerobic exercise, is a beneficial and well-tolerated intervention for children and adolescents with ADHD". Furthermore, that aerobic exercise may affect hyperactivity differently for boys and girls has been observed previously (Tantillo, Kesick, Hynd, &). Unfortunately, the majority of studies investigating the effect PA may have on hyperactivity has only included a male population, which makes it difficult to evaluate potentially different associations between boys and girls (Kamp, Sperlich, & Holmberg, 2014).

Lastly, the inverse association between change in CRF and follow-up psychological difficulties among boys was also attributed to peer problems. Similar findings include Lamb and Gulliford (2011), who found lower levels of peer problems in children after an aerobic exercise program; and Sagatun, Søgaard, Bjertness, Selmer, and Heyerdahl (2007), who found an inverse association between time spent in PA and peer problems among boys. A change in peer problems may occur through a psychosocial mechanism, which specifically involves social interaction and relatedness (Lubans et al., 2016). Participation in team sports provides much opportunity for social interaction and the development of social skills (Eime, Young, Harvey, Charity, & Payne, 2013) and is therefore a potential explanation for how aerobic PA affects peer problems through the psychosocial mechanism. Lower peer problems may also be directly connected to reductions in hyperactivity and conduct problems, as adolescents who have problems in peer relationships commonly also display signs of hyperactivity (Bagwell, Molina, Pelham, & Hoza, 2001) or conduct problems (Woodward & Fergusson, 1999). The difference between boys and girls may be explained by previous results showing that, compared to girls, boys report more social support, perceived benefits, self-efficacy and fun from PA (Cardon et al., 2005).

4.2. The association between change in muscular strength and follow-up psychological difficulties among immigrant adolescents

The inverse association between change in muscular strength and follow-up psychological difficulties among immigrants is the least certain of the present findings, based on p-value and confidence interval interpretation. The p-value of the association is non-significant in the traditional sense, however, it still indicates that the data conforms more toward the association hypothesis, than the null hypothesis (Greenland et al., 2016). Furthermore, the confidence interval crosses the null value, but the limits indicate that the association with 1 SD strength increase spanned from 38% lower-to 0.9% higher follow-up TDS than the immigrant means (10.7; see Supplementary Table 1a). The upper limit is not very meaningful, while the lower limit represents an association that may be meaningful in a clinical sense (Goodman & Goodman, 2009).

The inverse association between change in muscular strength and psychological difficulties is contrary to previous cross-sectional studies, which ruled out muscular strength as being associated with mental health outcomes, when controlling for CRF (Andersen et al., 2017; Kelly et al., 2010; Rieck et al., 2013; Yeatts et al., 2017). These studies, however, did not examine whether being born in the country or having immigrated to the country, moderated the associations. Given the scarcity of research about the association between physical fitness and mental health among immigrant adolescents, we can only speculate why increased muscular strength was associated with follow-up psychological difficulties in the subgroup. The association was attributed to conduct problems and hyperactivity, which points to self-esteem as a possible explanation: A review by Smith et al. (2014) showed consistent cross-sectional associations between muscular strength and perceived physical appearance, perceived sports competence, self-worth and self-esteem. These findings have also been supported in more recent research (Collins et al., 2019). Lower self-esteem has been associated with both conduct problems (Ha, Petersen, & Sharp, 2008) and hyperactivity (Edbom, Lichtenstein, Granlund, & Larsson, 2006) and it is possible that increasing muscular strength leads to improved self-esteem, which in turn leads to less conduct problems and hyperactivity. The reason why this association was present among immigrants alone may be due to immigrants having lower self-esteem than their non-immigrant peers (Bankston & Zhou, 2002); however, we do not know whether this was true for our population. Although it is an interesting and important topic, to discuss reasons why immigrant adolescents have poorer self-esteem than their non-immigrant peers, is beyond the scope of this paper. However, this subgroup can experience racial discrimination, which can influence self-esteem-related outcomes, such as perceived physical appearance, feelings of belonging to a peer group and identity development (Virta, Sam, & Westin, 2004).

Importantly, these results are based on low-powered subgroup analyses and might be spurious; irrespectively, the associations should be investigated in future studies, as immigrant adolescents have been severely neglected in this research field. Accumulated knowledge is important and can be applied by persons working with integrating and acculturating immigrant adolescents.

4.3. The association between change in CRF and follow-up psychological difficulties among high socioeconomic status girls

The association between change in CRF and follow-up psychological difficulties among girls in the highest SES group was surprising. The p-value suggests very low compatibility with a null-hypothesis and the upper limit of the confidence interval suggests a concerning association: 100 m increase in CRF was associated with up to 24% higher follow-up psychological difficulties than the mean levels in this subgroup (10.5).

To the best of our knowledge, there is no previous research to support this association, which contradicts what we consider to be established: Aerobic PA, which is positive for CRF, is associated with improved mental health (Bailey, Hetrick, Rosenbaum, Purcell, & Parker, 2017). The association between change in CRF and psychological difficulties in the present study was attributed to hyperactivity and emotional problems. This contradicts research showing that aerobic PA has a positive effect on hyperactivity and ADHD (Ng et al., 2017), and research showing that meeting the recommended PA levels is associated with fewer emotional problems (Wiles et al., 2008). On one hand, these incongruences increase the likelihood of a spurious association. On the other hand, there may be an explanation: According to the annual report on the health and well-being of Norwegian adolescents (Bakken, 2019), stress and pressure is more often experienced by girls than boys and is also more prevalent in high SES populations. Stress has been shown to be associated with hyperactivity (Biederman et al., 1995) and emotional problems (Moksnes, Moljord, Espnes, & Byrne, 2010). Therefore, it can be hypothesized that within a female high SES group, CRF might increase as a consequence of stress and pressure from high self-expectations to exercise more often than average, and to obtain body image ideals. Furthermore, the same stress and pressure might also lead to an increase in psychological difficulties. Future studies that examine the association between change in physical fitness and the status of a mental health outcome among adolescents should include SES, to be able to substantiate, or contradict these findings.

4.4. Strengths and limitations

Strengths of the present study include a high number of participants, objective measurements of three components of physical fitness, adjusting for covariates, and the option to conduct interaction analyses and subsequent subgroup analyses. Importantly, subgroup analyses are debated as they are susceptible to arbitrary findings due to chance. However, the present subgroup findings can be considered credible, as we have fulfilled most of the credibility criteria for subgroup analyses, set by Sun et al. (2012). A strength of the SDQ is that it allows investigation into subscale associations, which can help us understand the underlying mechanisms that explain the relationship between PA or physical fitness and mental health.

The most important limitation of the present study is the large amount of missing data at both time points, which may have influenced the results. Additionally, the prospective cohort study design limits causal interpretations, and a longer study period with more tests could have provided more knowledge in that regard. Compared to the full study sample, the subgroups were relatively small, thus reducing the statistical power of the analyses. Furthermore, the present subgroups may not represent equivalent subgroups outside of the study population. It is also possible that the observed associations were caused by other variables, not measured. Using BMI as an indication of body composition could be a limiting factor, considering that the association between BMI and adiposity has been shown to be weaker for lower BMI values (Marshall, Curtis, Cavanaugh, Warren, & Levy, 2021). The mean BMI scores of the present population, however, were in the low end of the normal weight category. Another instrument limitation is the shortened length of the Andersen-test, causing the present CRF results to be incomparable to other studies using the intended field length of 20 m. Lastly, the SDQ is a self-report questionnaire, which can be considered a limitation because respondents might answer in ways they perceive to be socially desirable (Leising, Locke, Kurzius, & Zimmermann, 2016). Moreover, TDS and subscales performed poorly on the Cronbach's alpha-test, compared to the recommended cutoff point at 0.7 (Bland & Altman, 1997). A potential explanation is that, in low-risk samples, the subscales might provide inaccurate descriptions of its constructs (Goodman, Lamping, & Ploubidis, 2010). Other possible explanations include poor understanding of the questions or unwillingness to answer the questions honestly. This is another factor that may contribute uncertainty to the results, however, the relevance of Cronbach's alpha has been debated (Sijtsma, 2009). The present study could also have benefitted from using more than one measure of mental health.

5. Conclusions

This one-year prospective investigation indicated three separate associations: Increased CRF may be associated with less psychological difficulties among boys; increased muscular strength may be associated with less psychological difficulties among immigrants; and increased CRF may be associated with more psychological difficulties among high SES girls. The hypothesized mechanisms of the associations are plausible, and the results suggest that changes in physical fitness components influence mental health through different mechanisms, depending on sex, immigrant status and SES. However, the uncertainty of the present results, and the scarcity of comparable studies, highlights the need for more research on this subject. Further exploration of the potentially moderated associations is necessary to improve our understanding of how we can use PA to prevent mental health problems in different subgroups.

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.

Acknowledgements

The study was funded by grants from the Norwegian Directorate for Education and Training.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.mhpa.2021.100411.

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