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Factors associated with adherence to the muscle-strengthening activity guideline among adolescents

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ABSTRACT

Purpose: We aimed to explore associations between guideline-concordant muscle-strengthening activity (MSA) and demographic, biological, psychosocial, and behavioral factors among Australian adolescents.
Methods: We used baseline data from the 'Resistance Training for Teens' cluster randomized controlled trial (collected April–June 2015). Adolescents (n = 602, mean age = 14.1 ± 0.5 years, 50% female) from 16 schools in New South Wales, Australia self-reported their sex, primary language spoken at home, postal code (for socioeconomic status), resistance training (RT) self-efficacy, motivation for RT, perceived strength, moderate-to-vigorous physical activity (MVPA), screen-time, and sleep. Participants also completed tests of height, weight, cardiorespiratory and muscular fitness, flexibility, and RT skills. MSA was self-reported and participants were dichotomized as 'meeting' (3–7 days) or 'not meeting' (0–2 days) the MSA guideline. Binary logistic regression with odds ratios (OR) was used to determine associations with adolescents' MSA.
Results: Analyses for each variable group explained a small-to-moderate proportion of the variance in MSA. Sex, muscular fitness, RT self-efficacy, perceived strength, and total MVPA emerged as statistically significant factors. However, only RT self-efficacy (OR = 2.48 [1.37 to 4.50]) and total MVPA (OR = 1.48 [1.22 to 1.79]) were associated with guideline-concordant MSA in the full model, which explained 52% of the variance.
Conclusions: Our study adds to the limited understanding of adolescents' MSA behavior. RT self-efficacy and total MVPA were independently associated with guideline-concordant MSA among Australian adolescents. The findings have implications for the design and delivery of future interventions targeting adolescents' MSA behavior.

Introduction

Muscle-strengthening physical activity (MSA), including formal resistance training (RT) and certain leisure-time activities (e.g., climbing on playground equipment), contribute to the health and well-being of school-aged youth. For example, clinical studies conducted with children and adolescents have demonstrated the efficacy of resistance training (RT) for improving various health-related outcomes, including body composition, insulin sensitivity, sports-injury risk, self-esteem, and sports performance (Lloyd et al., 2014). Moreover, muscular fitness is associated with skeletal health, total and central adiposity, cardiovascular/metabolic parameters, and self-perceptions (Smith et al., 2014a). Such associations might explain why muscular fitness during adolescence predicts morbidity and mortality in adulthood (Ortega et al., 2012), and highlights the need to support youths' MSA participation.

Of note, the World Health Organization (WHO) has, since 2010, explicitly recommended youth aged 5–17 years engage in activities to strengthen muscle and bone at least three times per week (World Health Organization, 2010). First introduced in the 2008 'Physical Activity Guidelines for Americans', this recommendation has since been adopted by a number of countries, including the United Kingdom (U.K.), Canada, Australia, and 19 member states of the European Union. Despite its widespread endorsement there is surprisingly little global data describing youth participation in MSA. In particular, the proportion of youth engaging in sufficient (or guideline-concordant) MSA is largely

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unknown. Indeed, the most recent global matrix of report card grades on physical activity for children and adolescents did not mention MSA, focusing instead on participation rates for organized sports, active play, active transportation, recreational screen-time, and overall moderate-to-vigorous intensity physical activity (MVPA) (Aubert et al., 2018).

To date, representative population estimates of youth MSA participation have been confined mostly to North America. According to the 2017 Youth Risk Behavior Surveillance System (YRBSS), 51% of U.S. high school students (62% of boys and 41% of girls) engage in guideline-concordant MSA (Centers for Disease Control and Prevention, 2017). Corresponding YRBSS data indicate this is higher than in 1991 (48%) but lower than in 2011 (56%) (Centers for Disease Control and Prevention, 2017). Similar MSA prevalence has been reported in Canada, with COMPASS study data indicating 54% of adolescents (58% of boys and 50% of girls) met the MSA guideline in 2013–14 (Harvey et al., 2017). By contrast, the 2017–18 National Health Survey found only 13% (22% of boys and 8% of girls) of Australian 15–17 year olds satisfy the MSA guideline (Australian Bureau of Statistics, 2018). Yet, little is known about why some young people, in Australia or elsewhere, engage in sufficient MSA while others do not.

Identifying the correlates of youths' MSA behavior is an important first step towards designing and implementing effective interventions, but there is a distinct lack of research on MSA correlates. A recent systematic review identified a range of factors associated with adult participation in RT (e.g., education, self-efficacy, subjective norms etc.) (Rhodes, Lubans, Karunamuni, Kennedy, & Plotnikoff, 2017), but no equivalent evidence synthesis has been conducted for children and adolescents. Of the work that has been done, associations have been found between adolescents' MSA and demographic variables, including sex/gender, race/ethnicity, and socioeconomic status (SES) (Song et al., 2013; Roth et al., 2019); biological variables, such as cardiorespiratory fitness (CRF), muscular fitness (Morrow et al., 2013), and (albeit with mixed findings) body composition (Song et al., 2013; Roth et al., 2019; Morrow et al., 2013); and psychosocial variables, including perceptions/beliefs about PA, and peer/parent social support (Roth et al., 2019).

These studies provide insights into several factors that may be relevant for adolescents' MSA behavior, but as all were conducted with U.S. youth the findings may not be generalizable to young people in other parts of the world. In addition, there may be other factors meaningfully linked to MSA in this population, justifying the examination of novel variables that have not been evaluated previously (e.g. behavioral factors). For example, physical activity and sedentary behaviors seem to covary (in opposite directions) across the transition from primary to secondary school (Chong et al., 2020). In addition, meta-analytic evidence indicates a strong association between physical activity and sleep during mid-adolescence and early adulthood (d = 0.894 [0.484 to 1.305]) (Lang et al., 2016). Whether or not these associations extend to MSA remains an open question. Considering the paucity of evidence on MSA correlates within the published literature, the aim of the present study is to quantify associations between guideline-concordant MSA among a sample of Australian adolescents and a range of demographic, biological, psychosocial, and behavioral factors.

Methods

Participants and procedure

Data were drawn from participants taking part in the 'Resistance Training for Teens' (hereafter: RT for Teens) cluster randomized controlled trial (RCT). The trial was prospectively registered with the Australian and New Zealand Clinical Trials Registry (ACTRN12615000360516), and a full description of the study protocols (Lubans et al., 2016) and main findings (Kennedy et al., 2017) have been published previously. Participants (n = 607, 50% female, mean age = 14.1 ± 0.5 years) attending 16 Government secondary schools in the Hunter, Central Coast and Sydney regions of New South Wales (NSW), Australia, were enrolled and assessed at the schools by trained research assistants (April–June 2015). Eligible participants were apparently healthy Grade 9 students (third year of secondary school), without an illness or injury that would preclude them from participating in physical activity. Ethics approval for the study was obtained from the Human Research Ethics Committees of the University of Newcastle (H-2014–0312) and NSW Department of Education (SERAP: 2,012,121). All participants (and their parents/guardians) provided informed written assent/consent prior to enrolment.

Study measures

Detailed information on the administration, scoring, validity and reliability of study measures can be found elsewhere (Lubans et al., 2016).

Muscle-strengthening activity

MSA was assessed using a single-item self-report measure previously used in the YRBSS (Morrow et al., 2013). Participants were asked to report the number of days in the past week they had participated in "*exercises to strengthen or tone the muscles such as push-ups, sit-ups, or weight lifting*" (possible range = 0–7 days). Participants reporting 3–7 days were classified as meeting the WHO recommendation, whereas those reporting 0–2 days were classified as not meeting the recommendation (World Health Organization, 2010).

Demographic factors

Participants completed an online survey using electronic tablets and reported their sex, cultural background, language spoken at home, and residential postal code. Postal code was used to determine area-level SES, using the Socio-Economic Indexes For Areas (SEIFA) Index of Relative Socio-economic Disadvantage (IRSD) (Australian Bureau of Statistics, 2008). The IRSD is expressed in percentile units, with lower values indicating greater disadvantage.

Biological factors

Upper body muscular endurance was assessed using the 90° push-up test (Cooper Institute for Aerobics Research, 1999), and lower body strength/power was assessed using the standing broad jump (SBJ) test (Castro-Piñero et al., 2010a). Both tests have acceptable test-retest reliability in youth, and the SBJ demonstrates high criterion validity (Castro-Piñero et al., 2010b). Conversely, push-up performance is influenced substantially by body composition. Therefore, push-up test results were normalized for body mass using the allometric scaling parameter recommended by Jaric et al. (Jaric et al., 2005). Results for both muscular fitness tests were then standardized by sex (value–mean/SD) and summed to create a composite muscular fitness score (MFS). CRF was assessed using a submaximal step-test protocol (Francis & Feinstein, 1991). Participants were fitted with a heart rate (HR) monitor and instructed to step up and down on a portable step for 3 min, after which their HR was recorded at 5 and 15 s. HR recovery between 5 and 15 s was used to estimate $\dot{V}O_2$ max in mL/kg/min (Francis & Feinstein, 1991). Flexibility was assessed by the sit and reach test (Cooper Institute for Aerobics Research, 1999), and calculated as the sum of reach distances on left and right sides. Height and body mass were assessed in light clothing without shoes. Body mass index (BMI) was calculated using mass [kg] divided by height $[m]^2$ and converted to age- and sex-specific z-scores. International Obesity Task Force cut-offs (Cole & Lobstein, 2012) were used to determine weight status, dichotomized as 'not overweight' (i.e., thin and healthy weight) or 'overweight/obese' (i.e., overweight, obese, and morbidly obese).

Psychosocial factors

RT self-efficacy was assessed using a brief scale designed for use with adolescents (Lubans et al., 2011). Participants responded to 4-items (e.g., *I have the skill and technique to complete resistance training exercises safely*) using a 5-point Likert scale (1 = *strongly disagree* to 5 = *strongly agree*). The internal consistency of items among the study sample was acceptable (Cronbach's α = 0.79). Motivation for RT was assessed using a modified version of the Behavioral Regulations in Exercise Questionnaire-2 (Markland & Tobin, 2004), with items adapted to reflect RT participation (e.g., *I value the benefits of resistance training*). Participants responded to each item using a 5-point scale (1 = *not true for me* to 5 = *very true for me*), and a relative autonomy index (RAI) was calculated as the sum of weighted subscales: (−3 x amotivation) + (−2 x controlled) + (−1 x introjected) + (2 x identified) + (3 x intrinsic). Possible scores range from −24 to 20, with positive values indicating greater autonomous motivation for RT. The internal consistency of items for each subscale among the study sample was good (Cronbach's α > 0.80 for all). Perceived strength was assessed using a single item from the International Fitness Scale (IFIS), which has been shown to correctly rank adolescents according to objectively measured strength, and also has moderate reliability (kappa = 0.54) (Ortega et al., 2011). Participants reported perceptions of their 'muscular strength' relative to their peers using a 5-point scale (1 = *very poor* to 5 = *very good*).

Behavioral factors

Total MVPA was self-reported using a single item measure previously validated with adolescents (Scott et al., 2015). In brief, participants were asked to reflect on the past week and responded to the question: "*on how many days have you done a total of 60 min or more of physical activity, which was enough to raise your breathing rate?"* (possible range = 0 to 7). Recreational screen-time was assessed using a modified version of the Adolescent Sedentary Activity Questionnaire (ASAQ) (Hardy et al., 2007). Further detail on the modifications made to the ASAQ for this study can be found elsewhere (Smith et al., 2014b). Briefly, participants were asked to reflect on a normal week, and reported (for each day) the total time spent sitting using screens for the purposes of entertainment. Sleep duration was assessed using items from the School Sleep Habits survey (Wolfson & Carskadon, 1998), which has been previously validated against diary-reported and actigraphically-estimated sleep among high school aged youth (Wolfson et al., 2003). Participants reflected on the past two weeks and reported their usual bedtime, wake time, and time taken to get to sleep (i.e., sleep onset latency). Sleep duration was calculated as the time between bedtime and wake time minus sleep onset latency, and classified as 'sufficient' if above minimum thresholds of recommended sleep for age (Australian Government, 2019). Sleep duration below these thresholds was classified as 'insufficient'. RT skill competency was assessed using video analysis of the Resistance Training Skills Battery (RTSB), which has previously shown acceptable construct validity and test-retest reliability (ICC = 0.88) (Lubans et al., 2014), as well as inter-rater reliability (CV = 4.9%) with adolescents (Barnett et al., 2015). After watching a standardized video demonstration, participants were video recorded completing two sets of four repetitions of six foundational RT skills (i.e., squat, lunge, overhead press, suspended row, push-up, front support with chest touch). A trained research assistant with a postgraduate degree in strength and conditioning and substantial prior experience with this tool scored the video recordings, with scores for individual skills summed to create an overall RT skill score (possible range = 0 to 56).

Statistical analysis

The analytical sample comprised those who provided data for MSA participation (n = 602, 99% of full sample). Analyses were performed using the Mplus 8.3 program (Muthén & Muthén, Los Angeles, CA), with statistical significance set at $p < 0.05$. First, Pearson correlation coefficients were calculated to determine bivariate associations between study variables. Binary logistic regression models with odds ratios and their 95% confidence intervals (OR; 95% CI) were then estimated: (i) separately for each group of factors (i.e., demographic, biological, psychosocial, and behavioral), and (ii) in a full model with all variables included together. The preliminary models were tested to identify the most important predictive variables within a variable group, and to evaluate and compare the explanatory power of groups of related variables, whereas the full model was tested to evaluate the total variance explained by all study variables. For interpretation, OR's for categorical variables represent the odds of guideline-concordant MSA relative to the reference category, whereas OR's for continuous variables represent the odds of guideline-concordant MSA per unit increase in the independent variable.

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. Symmetric confidence intervals were estimated by this procedure using the adjusted standard errors. However, the p-value was inconsistent with symmetric confidence intervals. Therefore, non-symmetric confidence intervals and standard errors were estimated. All standard errors and confidence intervals were estimated using bootstrap estimates. Finally, intra-class correlation coefficients (ICC) were calculated for all variables to quantify clustering at the school-level.

Thresholds for interpreting the magnitude of effect sizes are as follows (Ferguson, 2009): correlation coefficients of 0.20, 0.50, and 0.80; R-square values of 4%, 25%, and 64%; and OR's of 2.0 (or 0.50), 3.0 (or 0.33) and 4.0 (or 0.25) each represent 'small', 'moderate' and 'strong' effects, respectively.

Results

Characteristics of the study sample are provided in Table 1. The vast majority spoke English as their primary language at home, and two-thirds identified their cultural background as 'Australian'. Two-thirds were a healthy weight, while one-fifth were overweight and 8.2% were obese. One in four participants reported zero days of MSA per week, followed by one (21%) and two (19%) days. In total, 35% met the MSA recommendation. Bivariate correlations between study variables are provided in Table 2. MSA was significantly correlated (r's ≥ ± 0.2) with muscular fitness, RT self-efficacy, motivation for RT, perceived strength, and total MVPA. The ICC's for study variables ranged from 0.00 to 0.70 (Table 3).

Logistic regression results by variable groups

Separate logistic regression models were estimated to determine the total variance in guideline-concordant MSA explained by each variable group, and to identify initially significant factors (Table 3). The total variance explained ranged from 3.1% for demographic variables to 23.3% for psychosocial variables. Female sex was associated with lower odds of guideline-concordant MSA (OR [95%CI] = 0.55 [0.34 to 0.91], effect size [ES] = small). Greater muscular fitness (OR = 1.27 [1.08 to 1.50], ES = negligible), RT self-efficacy (OR = 1.94 [1.33 to 2.82], ES = small), perceived strength (OR = 2.14 [1.59 to 2.89], ES = small), and total MVPA (OR = 1.58 [1.39 to 1.79], ES = negligible) were associated with higher odds.

Logistic regression results including all variables

The full model including all variables simultaneously explained 52% of the variance in guideline-concordant MSA (Table 4). In this model, the association for RT self-efficacy became stronger (OR = 2.48

Table 1
Characteristics of the study sample.

Characteristics[a]	All (n = 602)	Boys (n = 299)	Girls (n = 303)
Age, years	14.1 (0.5)	14.2 (0.5)	14.1 (0.4)
English language spoken at home, n (%)	547 (90.9)	270 (90.3)	277 (91.4)
Cultural background, n (%)			
Australian	396 (65.8)	194 (64.9)	202 (66.7)
European	51 (8.5)	26 (8.7)	25 (8.3)
African	5 (0.8)	1 (0.3)	4 (1.3)
Asian	74 (12.3)	41 (13.7)	33 (10.9)
Middle Eastern	9 (1.5)	5 (1.7)	4 (1.3)
Other	67 (11.1)	32 (10.7)	35 (11.6)
ATSI, n (%)	44 (7.3)	19 (6.4)	25 (8.3)
Socio-economic status, decile, n (%)			
1–2	66 (11.0)	36 (12.1)	30 (10)
3–4	136 (22.7)	68 (22.8)	68 (22.6)
5–6	233 (38.9)	98 (32.9)	135 (44.9)
7–8	27 (4.5)	17 (5.7)	10 (3.3)
9–10	137 (22.9)	79 (26.5)	58 (19.3)
Weight status, n (%)			
Thinness	24 (4.0)	12 (4.0)	12 (4.0)
Healthy Weight	410 (68.6)	202 (67.8)	208 (69.3)
Overweight	115 (19.2)	55 (18.5)	60 (20.0)
Obese	49 (8.2)	29 (9.7)	20 (6.6)
Push-ups, repetitions	11.9 (7.8)	11.7 (6.9)	12.1 (8.6)
Standing broad jump, cm	158.3 (34.7)	179.0 (29.3)	137.6 (26.4)
Cardio-respiratory fitness, mL/kg/min	48.3 (8.7)	51.4 (7.7)	45.1 (8.5)
Flexibility, cm	24.6 (7.6)	22.5 (7.0)	26.7 (7.7)
RT self-efficacy, units	3.7 (0.7)	3.7 (0.6)	3.7 (0.7)
Motivation for RT, units	3.8 (6.0)	3.1 (5.9)	4.5 (6.0)
Perceived strength, units	3.3 (0.8)	3.4 (0.8)	3.1 (0.8)
Total MVPA, days/week	3.5 (1.8)	3.8 (1.8)	3.2 (1.8)
Screen-time, minutes/day	175 (122)	162 (104)	188 (136)
RT skill competency, units	34.9 (7.3)	34.8 (7.0)	35.0 (7.6)
Sleep duration, hours/day	8.3 (1.3)	8.2 (1.3)	8.3 (1.3)
Days per week of MSA, n (%)			
0	149 (24.8)	68 (22.7)	81 (26.7)
1	129 (21.4)	47 (15.7)	82 (27.1)
2	112 (18.6)	59 (19.7)	53 (17.5)
3	97 (16.1)	56 (18.7)	41 (13.5)
4	41 (6.8)	21 (7.0)	20 (6.6)
5	32 (5.3)	21 (7.0)	11 (3.6)
6	10 (1.7)	6 (2.0)	4 (1.3)
7	32 (5.3)	21 (7.0)	11 (3.6)
Meets MSA recommendation, n (%)[b]	212 (35.2)	125 (41.8)	87 (28.7)

Note. ATSI = Aboriginal or Torres Strait Islander, MSA = muscle-strengthening activity, MVPA = moderate-to-vigorous physical activity, RT = resistance training, SD = standard deviation.
[a] Data are presented as mean (SD) unless otherwise specified.
[b] 3 days per week.

[1.37 to 4.50], ES = small), while the association for total MVPA weakened but remained statistically significant (OR = 1.48 [1.22 to 1.79], ES = negligible). While not statistically significant, there was a trend ($p < 0.10$) towards significance for SES ($p = 0.06$) and recreational screen-time ($p = 0.08$), but the corresponding effect sizes were negligible. The associations for sex, muscular fitness, and perceived strength were no longer statistically significant in the full model.

Discussion

To our knowledge, this is the first study to comprehensively examine factors associated with adolescents' adherence to the MSA guideline. Initially, sex, muscular fitness, RT self-efficacy, perceived strength, and total MVPA were significantly associated with guideline-concordant MSA. However, only RT self-efficacy and total MVPA were independent correlates in the full model. These findings provide a novel contribution to the literature, given the lack of research focused on MSA behavior among adolescents. Moreover, our study is timely in light of recent evidence showing secular declines in muscular fitness among Australian youth (Fraser et al., 2019).

A key finding from the present study was the independent association between MSA and RT self-efficacy. To our knowledge, this is the first time RT self-efficacy has been identified as a correlate of guideline-concordant MSA in adolescents. Specifically, there was 2.5-fold greater odds of meeting the MSA guideline per unit increase in RT self-efficacy. For interpretation, a one-unit difference in RT self-efficacy in the study sample equated to approximately 1.5 standard deviations. Notably, RT self-efficacy was a significant correlate in both models, but the association strengthened in the full model with all variables included. Conversely, the associations for most other variables weakened, and several were attenuated to non-significance (i.e., sex, muscular fitness, and perceived strength). Some of these variables were correlated with RT self-efficacy, suggesting their association with MSA is actually explained by this construct. Overall, this finding reinforces the importance of self-efficacy for MSA behavior in adolescents, which is consistent with systematic review findings for adults (Rhodes, Lubans, Karunamuni, Kennedy, & Plotnikoff, 2017).

It is generally accepted that self-efficacy is both a determinant and an outcome of physical activity (McAuley & Blissmer, 2000). For example, past trials have shown RT programs can improve RT self-efficacy among apparently healthy (Kennedy et al., 2017) and overweight/obese (Schranz et al., 2014) adolescents. Further, a moderate effect for RT self-efficacy was reported in a recent meta-analysis of youth RT trials (Collins et al., 2019). Alternatively, popular health behavior theories including Social Cognitive Theory (Bandura, 1986) identify self-efficacy (or analogous constructs) as important predictors of future behavior. Given most adolescents will have had little prior experience with formal RT, it is perhaps more likely that RT self-efficacy is influencing intentions to engage in MSA in the present study population (rather than MSA participation improving RT self-efficacy). It is worth noting that our RT self-efficacy measure evaluated 'task' self-efficacy, but 'barrier' self-efficacy (i.e., one's belief in their ability to overcome barriers to participation) might also be relevant for adolescents' MSA. Consequently, barrier self-efficacy should be examined as a determinant of MSA in future research.

A second key finding was the small but significant independent association between total MVPA and guideline-concordant MSA, which in the full model translated to 48% greater odds for each additional day/week of sufficient MVPA. It must be noted that MVPA and MSA were assessed using very similar measures (i.e., self-reported as days/week). In addition, the MVPA item did not require participants to distinguish between aerobic physical activity and MSA. Hence, our MVPA measure may be capturing participation in MSA to some extent. Nonetheless, MSA and MVPA were only weakly-to-moderately correlated ($r = 0.39, p < 0.01$), suggesting they are not measuring the same thing. Although the magnitude of the OR for total MVPA was negligible, this could be in part due to the sensitivity of the measure, which does not provide an estimate of overall MVPA volume (i.e., minutes/week). Future research using objective/device-based measures of MVPA (e.g., accelerometry) might provide a clearer indication of the association between MVPA and MSA. For example, the present finding could simply be the result of common method bias due to the similarity in measures used. Alternatively, our crude MVPA measure might be underestimating the positive association between MVPA and MSA.

Measurement issues aside, the persistent association for total MVPA is plausible. For example, the individual characteristics, interpersonal facilitators, and supportive environments that enable some adolescents to participate in high amounts of MVPA are probably transferrable to MSA. Alternatively, youth reporting greater MVPA may be more likely to engage in certain activities within which MSA is encouraged or explicitly taught. Prior work has identified sports participation as a consistent correlate of overall physical activity among adolescents (Van der Horst et al., 2007), emphasizing the contribution of sport to an active

Table 2
Bivariate correlations between study variables.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. MSA	-														
2. Sex	0.14**	–													
3. Language	−0.01	−0.02	–												
4. SES	−0.07	0.04	**0.31****	–											
5. MFS	**0.23****	0.01	−0.01	0.14**	–										
6. CRF	0.15**	**0.36****	−0.03	0.17**	**0.35****	–									
7. Flexibility	0.07	**−0.27****	−0.06	0.02	**0.31****	−0.00	–								
8. BMI *z*-score	−0.05	0.03	0.08	−0.13**	**−0.32****	**−0.30****	−0.02	–							
9. RT self-efficacy	**0.33****	0.03	0.03	0.02	**0.37****	**0.23****	0.14**	−0.12**	–						
10. Motivation for RT	**0.21****	−0.11**	−0.00	0.04	**0.27****	0.14**	**0.20****	−0.08	**0.45****	–					
11. Perceived strength	**0.36****	0.15**	0.04	0.01	**0.36****	**0.22****	0.14**	0.11**	**0.53****	**0.25****	–				
12. Total MVPA	**0.39****	0.16**	0.01	0.09*	**0.29****	**0.32****	0.12**	−0.08*	**0.36****	0.17**	**0.33****	–			
13. Screen-time	−0.15**	−0.11**	−0.04	−0.06	−0.13**	−0.19**	−0.04	0.06	−0.17**	−0.06	−0.10*	**−0.25****	–		
14. RT skills	0.10	−0.01	−0.01	0.19**	**0.45****	**0.30****	**0.23****	**−0.23****	**0.31****	0.19**	**0.20****	**0.20****	−0.19**	–	
15. Sleep duration	0.02	−0.01	0.04	0.09*	−0.01	0.03	−0.05	−0.09*	0.08	0.07	0.04	0.07	−0.18**	0.07	–

Note. MSA expressed in days/week; Sex coded as 0 = female, 1 = male. BMI = body mass index; CRF = cardiorespiratory fitness; MFS = muscular fitness score; MSA = muscle-strengthening activity; MVPA = moderate-to-vigorous physical activity; RT = resistance training; SES = socio-economic status. Statistically significant correlations ≥ ± 0.20 appear in bold type.
$^*p < 0.05$; $^{**}p < 0.01$.

lifestyle. Similarly, organized sport might provide an opportunity for regular MSA, whereas certain other PA contexts may not to the same extent (e.g., active transportation). Specifically, coaches might utilize MSA during the conditioning component of sports practice. Moreover, the desire to improve sports performance might lead athletic youth to pursue formal RT as a supplement to regular sports practice.

Regarding demographic factors, our data showed a clear difference in the proportion of boys and girls meeting the MSA guideline (i.e., 41.8% versus 28.7%), which is consistent with findings for MVPA (Biddle et al., 2011). Notably, the magnitude of this difference was very similar to that found among a large representative sample of Australian youth (Australian Bureau of Statistics, 2018). Sex was the only significant demographic predictor, with females demonstrating 45% lower odds of guideline-concordant MSA compared with males. Sex differences in MSA (favoring males) have previously been reported among U.S. (Centers for Disease Control and Prevention, 2017; Roth et al., 2019; Song et al., 2013) and Canadian (Harvey et al., 2017) youth, but to our knowledge there are no comparative data from other countries. Interestingly, our findings contrast with the adult literature, which find no sex differences in guideline-concordant MSA among Australian

Table 3
Logistic regression results by groups of predictors.

Predictors	ICC	Coefficient		Odds Ratio	
		Estimate	SE	Estimate	95% CI
Demographic					
Sex (ref. male)	0.05	−0.59*	0.24	0.55	0.34 to 0.91
Language at home (ref. English)	0.44	−0.13	0.33	0.88	0.46 to 1.66
SES, percentile	0.70	−0.01	0.00	0.99	0.99 to 1.00
R-square = 3.1%					
Biological					
Muscular fitness score, units	0.13	0.24*	0.08	1.27	1.08 to 1.50
CRF, mL/kg/min	0.12	0.02	0.01	1.02	1.00 to 1.05
Flexibility, cm	0.08	0.00	0.01	1.00	0.98 to 1.02
Weight status (ref. not overweight)	0.03	−0.05	0.14	0.95	0.72 to 1.26
R-square = 7.9%					
Psychosocial					
RT self-efficacy, units[a]	0.06	0.66**	0.19	1.94	1.33 to 2.82
Motivation for RT, units[b]	0.00	0.03	0.02	1.03	0.98 to 1.07
Perceived strength, units[a]	0.00	0.76***	0.15	2.14	1.59 to 2.89
R-square = 23.3%					
Behavioral					
Total MVPA, days/week[c]	0.05	0.46***	0.06	1.58	1.39 to 1.79
Screen-time, hours/day	0.07	−0.11	0.06	0.89	0.79 to 1.01
RT skill competency, units[d]	0.25	−0.01	0.02	0.99	0.94 to 1.03
Sleep duration (ref. insufficient)	0.05	0.25	0.36	1.28	0.63 to 2.60
R-square = 20.4%					

Note. CI = confidence intervals; CRF = cardiorespiratory fitness; ICC = intra-class correlation coefficient; MVPA = moderate-to-vigorous physical activity; RT = resistance training; SE = standard error. $^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.
[a] possible range = 1 to 5.
[b] possible range = −24 to 20.
[c] possible range = 0 to 7.
[d] possible range = 0 to 56.

Table 4
Logistic regression results with all predictors.

Predictors	Coefficient		Odds Ratio	
	Estimate	SE	Estimate	95% CI
Sex (ref. male)	−0.40	0.29	0.67	0.38 to 1.18
Language at home (ref. English)	0.06	0.64	1.06	0.30 to 3.73
SES, percentile	−0.01	0.01	0.99	0.98 to 1.00
Muscular fitness score, units	0.17	0.12	1.18	0.93 to 1.50
CRF, mL/kg/min	−0.01	0.02	0.99	0.96 to 1.03
Flexibility, cm	0.00	0.01	1.00	0.97 to 1.02
Weight status (ref. not overweight)	0.17	0.42	1.19	0.52 to 2.70
RT self-efficacy, units[a]	0.91**	0.30	2.48	1.37 to 4.50
Motivation for RT, units[b]	0.02	0.03	1.02	0.97 to 1.08
Perceived strength, units[a]	0.02	0.33	1.02	0.53 to 1.96
Total MVPA, days/week[c]	0.39***	0.10	1.48	1.22 to 1.79
Recreational screen-time, hours/day	−0.10	0.06	0.90	0.81 to 1.01
RT skill competency, units[d]	−0.03	0.02	0.98	0.93 to 1.02
Sleep duration (ref. insufficient)	0.13	0.31	1.14	0.62 to 2.10
R-square = 52.4%				

Note. CI = confidence intervals; CRF = cardiorespiratory fitness; MVPA = moderate-to-vigorous physical activity; RT = resistance training; SE = standard error. **p* < 0.05; ***p* < 0.01; ****p* < 0.001.

[a] possible range = 1 to 5.
[b] possible range = −24 to 20.
[c] possible range = 0 to 7.
[d] possible range = 0 to 56.

adults (Bennie et al., 2016).

Considering the above, future research exploring why adolescent girls participate in less MSA would be valuable. Participant sex was not a significant factor in the full model suggesting that other factors (related to sex) are driving the observed sex-differences in MSA. Of note, perceived strength was significantly correlated (albeit weakly) with sex, and this variable was associated with MSA in the psychosocial factors model. It could be that differences in physical self-perceptions in part explain the differential participation in MSA between boys and girls. However, it is also possible that other unmeasured factors (e.g., perceived social norms, peer/parent social support etc) underpin this finding. Future intervention studies targeting this group should also consider maturational timing, as early maturation has been linked with less physical activity among adolescent girls (mediated through negative self-concept) (Jackson et al., 2013). This may or may not extend to girls’ MSA behavior.

SES and language spoken at home were not related to adolescents' MSA, which is somewhat surprising given ‘low SES’ and ‘non-English speaking background’ have been linked with poor muscular fitness in Australian youth (Hardy et al., 2016). Biological factors were also unrelated to MSA in the full model, despite an initially significant association for muscular fitness. This was also unexpected, as participation in regular MSA should theoretically result in improved muscular fitness. However, we did not assess students' maturational stage, and variation in muscular fitness attributable to differences in maturation at this age (14–15 years) might be difficult to distinguish from variation due to MSA. Indeed, age at peak height velocity (PHV), a common marker of biological maturation, can vary from 10–15 years in girls and from 11–16 years in boys (mean age at PHV is 12 and 14 for girls and boys, respectively) (Stratton et al., 2020). Finally, RT skill competency was also non-significant in both models. This was again surprising as actual competence should theoretically be related to MSA behavior. However, it might be that perceived rather than actual competence is the more important contributor to behavior. Indeed, prior research evaluating other movement skills has shown adolescents' perceptions of their physical abilities is a better predictor of physical activity behavior than their actual abilities when assessed objectively (De Meester et al., 2016).

Strengths of the present study include the assessment of a wide range of novel factors that would not be feasible for larger population-based surveys, adjustment for school-level clustering in the analysis, and use of validated measures with acceptable measurement properties. However, there are several limitations that must be recognized. First, the study sample was smaller than some other studies of physical activity correlates. In addition, the study schools were not randomly sampled, participants were from a single school grade, and all had agreed to enroll in a school-based physical activity intervention. While the sample appears similar to the general adolescent population, we cannot discount the possibility of sampling or selection bias, and care should be taken in generalizing the findings to other groups. Second, given the cross-sectional design we cannot determine causality. Third, our findings for MVPA should be treated with caution, given the recognized limitations of self-report and potential for double counting of MSA using this specific measure. Finally, MSA was self-reported in days/week precluding a robust analysis of associations with overall MSA volume, and it is possible participants' responses were influenced by social desirability or recall bias. Also, the validity and reliability of our MSA item is currently unclear, although in adults a similar single-item self-report measure of MSA demonstrated excellent test-retest reliability (Kappa = 0.85–0.92) (Yore et al., 2007). Nevertheless, there is presently no viable alternative, given device-based measures are poor at detecting non-ambulatory physical activity, and to the authors' knowledge there are no validated instruments for evaluating youths’ MSA behavior with greater resolution (i.e., providing detail on frequency, intensity, time, or type of MSA performed).

Practical implications

The present study contributes to our understanding of MSA, but further research is required to gain a more complete picture of this behavior during adolescence. Nonetheless, there are some potential implications of our findings for practice. First, as previously noted there is a clear rationale for MSA interventions designed specifically for adolescent girls. Although beliefs about ‘gendered’ physical activities appear to be slowly changing in many countries, young girls may still perceive MSA to be a predominantly male activity. This could be tied to self-perceptions of physical strength (Lubans & Cliff, 2011), which might contribute to girls' beliefs about appropriate physical activity choices.

Second, the robust association with RT self-efficacy highlights the need for future interventions to consider strategies to support self-efficacy. Pedagogical principles for maximizing youths' engagement in, motivation for, and satisfaction with organized physical activity opportunities generally (Lubans et al., 2017), and RT specifically (Faigenbaum & McFarland, 2016), have appeared recently in the published literature. These frameworks provide useful advice for practitioners on how to support youths' self-efficacy, including: i) thoughtful exercise prescription that provides an optimal level of challenge and is matched to the participant's current abilities and experience, and ii) promotion of a mastery climate that fosters self-rather than peer-comparison of performance.

Finally, school PE might be a suitable context for adolescents to be introduced to RT, as teachers can provide proper instruction on technique, correct performance errors through the provision of appropriate feedback, educate students on the benefits of MSA for health and well-being, and provide support for students to complete MSA outside of school (e.g., by identifying suitable places for MSA in the local area, or by helping youth to develop their own tailored exercise plans and goals). All of these strategies might help to support students’ self-efficacy, which could plausibly lead to greater adoption and maintenance of MSA. High-quality teacher training/professional development might support this objective (Kennedy et al., 2019).

Conclusions

The present study contributes to our understanding of MSA behavior in adolescents, which has thus far received little attention from the public health research community. Overall, RT self-efficacy and total MVPA were significantly and independently associated with guideline-concordant MSA. Future research should examine whether these findings are reproducible in other population groups (e.g., children, older adolescents, and youth from low- and middle-income countries). In addition, the causal direction of associations should be evaluated using prospective and experimental research designs. Finally, exploration of other novel MSA correlates is warranted, given our full model explained just over half the variance in MSA guideline attainment.

Trial registration number

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CRediT authorship contribution statement

Jordan J. Smith: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft. **Thierno M.O. Diallo:** Formal analysis, Writing - review & editing. **Jason A. Bennie:** Conceptualization, Writing - review & editing. **Grant R. Tomkinson:** Writing - review & editing. **David R. Lubans:** Funding acquisition, Project administration, Conceptualization, Investigation, Writing - review & editing.

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.

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