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The benefits of chronic sport participation and acute exercise on mental health and executive functioning in adolescents

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Adolescents are experiencing a growing mental health crisis, with one in seven afflicted by conditions such as depression and anxiety. This crisis is compounded by insufficient physical activity, as over 80% of adolescents fail to meet the World Health Organization's recommendation of at least 60 min of daily exercise. This combination of rising mental health disorders and sedentary behavior presents a serious public health challenge, increasing the risk of long-term cognitive and emotional impairments. While both chronic and acute exercise improve mental health and executive functioning, there is a significant gap in the literature exploring these effects within the same study, particularly among adolescents. Moreover, limited research has assessed how different types of sports differentially impact mental and cognitive health outcomes. This study uniquely addresses these gaps by investigating the effects of chronic sports participation (strategic vs. self-paced) and a single bout of acute exercise (physical education class) on mental health and executive functioning in adolescent athletes (n = 44) and non-athletes (n = 19). Our findings demonstrate that chronic participation in strategic sports significantly reduces stress, while self-paced sports enhance cognitive flexibility. Additionally, across all groups, a single session of acute exercise led to marked improvements in stress, anxiety, depression, and processing speed. These results highlight the importance of both chronic and acute physical activity in adolescent health and underscore the differential cognitive and emotional benefits of sport type. This study advances the literature by showing that physical education and sport participation, in school settings, are critical to fostering mental and cognitive health in adolescents, providing a novel understanding of exercise interventions.

Keywords Sports, Aerobic exercise, Adolescence, Executive function, Mental health

Over 80% of adolescents (ages 11 to 17) worldwide fail to meet the global physical activity recommendation of at least one hour of physical activity per day[1], with this population experiencing on average 7.7 h of daily sedentary behavior[2,3]. Such sedentary behavior is driven by increased time spent watching TV, playing video games, using computers or smartphones, and engaging with social media platforms. These virtual behaviors limit opportunities for physical exercise, which is known to have significant positive impacts on physical, mental, and cognitive health. Sedentary behavior increases the risk for obesity, Type 2 diabetes, high blood pressure, cancer, stroke, anxiety, depression, executive dysfunction, and other mental health issues[4–7]. Due to these sedentary behaviors and the associated health impairments, it is expected that this generation of children may be the first to experience a decline in life expectancy[8,9]. Despite extensive research highlighting the importance of regular exercise, adolescent physical activity levels continue to decline, raising concerns about the long-term health implications for this age group.

Along with the decrease in physical activity, a concurrent increase in mental health issues among adolescents is occurring, with 1 in 7 experiencing a mental disorder including anxiety disorders, depressive disorders, bipolar disorder, eating disorders, attention-deficit/hyperactivity disorder, and schizophrenia; these statistics

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are even more severe for BIPOC (Black, Indigenous, People of Color) and LGBTQ+ (lesbian, gay, bisexual, transgender, queer) communities[10]. Unfortunately, mental health challenges are the leading cause of disability and poor life outcomes in adolescents, with suicide being the 2nd leading cause of death in this population[11]. The consequences of neglecting adolescent mental health are significant, leading to heightened risks of physical and mental health impairments in adulthood and diminishing the potential for fulfilling and productive lives.

Unsurprisingly, the decline in physical activity is closely tied to the increase in mental health issues observed in this adolescent population[12]. Sedentary behaviors, such as excessive screen time, have been linked to impairments in executive functioning[13,14], which encompasses essential cognitive processes like memory, impulse control, and decision-making. When executive functioning is compromised, it can intensify stress, anxiety, and depression, making it more challenging for adolescents to regulate their emotions and make rational decisions. The strong connection between reduced physical activity and the increase in mental health disorders underscores the urgent need to explore alternative strategies for encouraging exercise among adolescents, with the goal of counteracting the cognitive and emotional effects of sedentary lifestyles[9,15–17].

Exercise, which is defined as planned and purposeful physical activity that aims to improve aspects of physical fitness[18], can be a promising and direct solution to increase physical activity, reduce sedentary time, and improve cognitive and mental health[19–24]. Exercise can be broken down into two categories—acute and chronic. Acute exercise is defined as a singular, bout of exercise, whereas chronic exercise is defined as repetitive bouts of physical activity over a long duration of time. While both types instill benefits to one's mental and cognitive health, the longevity of these effects vary[19,21]. Both acute and chronic exercise are associated with improvements in mental and social health including decreases in stress, depression, and anxiety, as well as improvements in cognitive functioning such as short- and long-term memory, inhibitory control, cognitive flexibility or task switching, attention, and processing speed[19,25–29]. Additionally, physical activity in adolescents is associated with improvements in academic performance and focus in school settings[23,24].

In terms of the adolescent period, high school gym classes and sports participation serve as opportunities for students to increase exercise habits. Previous research has compared the effects of various sport types on cognitive functioning and mental health, specifically regarding strategic sports (e.g., football, baseball, basketball, soccer, lacrosse) and individual self-paced sports (e.g., track, cross-country, tennis, golf)[30]. Strategic sports demand a high level of cognitive engagement, requiring athletes to make quick decisions, adapt to opponents, and employ complex tactics to succeed[31]. In contrast, individual self-paced sports involve less immediate decision-making, allowing athletes to control their own pace and focus more on personal execution and precision rather than reacting to external variables[31]. Several studies have compared these sport types, finding that as the intensity and cognitive demand of the sport increases, so do the cognitive and mental benefits[21,31].

While previous studies have investigated the chronic and acute effects of exercise on adolescent mental and cognitive health[9,15–17], limited evidence exists examining the effects of both chronic and acute within the same study. Additionally, it is unclear whether the benefits of exercise differ between chronic exercisers (i.e., athletes) versus more sedentary individuals (i.e., non-athletes). Furthermore, there is a paucity of research utilizing a school-based approach to deliver chronic and acute exercise to improve cognitive and emotional health in adolescents. Examining within-school administration of exercise is especially vital, as adolescents spend a great deal of time in this environment. Therefore, this study aimed to assess the effects of chronic versus acute exercise on both athlete and non-athlete adolescents. For chronic exercise, we compared strategic and self-paced sports athletes to a non-athlete control group, hypothesizing that the strategic group would demonstrate the largest gains in mental and cognitive health, as other research has shown similar outcomes in adult populations[32,33]. For acute exercise, we examined the effect of a single bout of exercise (i.e., gym class) on similar outcomes, hypothesizing that the non-athletes would demonstrate the largest gains, as the acute effects of exercise are influenced by an individual's level of aerobic fitness[19,34,35].

Results

Demographic information

A total of 63 participants were recruited for the study, comprising 29 strategic athletes, 15 self-paced athletes, and 19 non-athletes. Of the 63 participants recruited, 58 completed demographic information. Across all groups, participants were predominantly male (68.96%) and white (50%). The control group contained the greatest female population (18.96%) compared to the strategic (10.34%) and self-paced (1.72%) cohorts. The strategic group had the greatest mean age (16.13), with the self-paced group having the lowest (15.64) (Table 1).

Physical activity habits

Participants self-reported their physical activity habits for the week prior to study initiation. Mean activity scores were used to determine leisure, physical education class, lunch, after school, evening, weekend, and free time physical activity exertion. The highest amount of physical activity was conducted during after school hours (4.16 h/week, averaged across groups) whereas the lowest amount was conducted during lunch time (1.16 h/week, averaged across groups) (Table 2). Strategic sports athletes reported the highest levels of physical activity habits, followed by self-paced athletes, followed by non-athletes.

The effects of chronic sports engagement on depression, anxiety, and stress

Median stress change scores were significantly different between groups ($\chi^2(2) = 7.136$, $p = 0.028$). Post-hoc analyses revealed differences between the strategic and self-paced groups ($p = 0.030$), but not between the strategic and control ($p = 0.210$) or self-paced and control groups ($p = 1.000$) (Fig. 1). No significant differences were found for median total DASS change scores ($\chi^2(2) = 5.386$, $p = 0.068$), depression change scores ($\chi^2(2) = 2.385$, $p = 0.304$), or anxiety change scores ($\chi^2(2) = 0.883$, $p = 0.643$).

Groups	Strategic		Self-paced		Control		Total	χ^2/F	p
	n	%	*n*	%	*n*	%	*n*/%		
Grade									
12th	7	12.07	1	1.72	3	5.17	11/18.96	10.451	0.107
11th	11	18.97	5	8.62	13	22.4	29/49.99		
10th	3	5.17	7	12.07	5	8.62	15/25.86		
9th	2	3.45	1	1.72	0	0	3/5.17		
Sex									
Male	17	29.31	13	22.41	10	17.24	40/68.96	8.467	0.014
Female	6	10.34	1	1.72	11	18.97	18/31.03		
Race									
White	12	20.69	6	10.34	11	18.97	29/50	9.806	0.279
Asian	3	5.17	4	6.90	3	5.17	10/17.24		
Black/African	6	10.34	1	1.72	1	1.72	8/13.78		
Multiracial	1	1.72	0	0	2	3.45	3/5.17		
Other	1	1.72	3	5.17	4	6.90	8/13.79		
Ethnicity									
Hispanic	11	18.97	4	6.90	9	15.52	24/41.39	2.836	0.242
Non-Hispanic	12	20.69	10	17.24	12	20.69	34/58.62		
	Mean	± SD	Mean	± SD	Mean	± SD	Mean/SD		
Age	16.13	1.01	15.64	0.93	16.10	0.94	15.96/0.97	1.292	0.283
Weight (lbs.)	153.70	37.41	140.81	23.29	132.99	25.90	142.5/30.53	2.577	0.085
Height (in.)	67.52	3.78	67.57	3.34	65.98	3.99	67.02/3.76	1.152	0.324
B.M.I	23.70	4.04	21.68	2.89	20.48	2.42	21.95/3.26	5.469	0.007

Table 1. Demographic Information.

Groups	Strategic	Self-paced	Control		
Population	n = 24	n = 15	n = 18		
Item	Mean (± SD) (h/week)	Mean (± SD) (h/week)	Mean (± SD) (h/week)	F	p
(1) Spare time	2.00 (1.21)	1.54 (1.12)	1.37 (0.88)	1.879	0.163
(2) PE classes	2.25 (1.36)	2.07 (1.44)	2.61 (0.92)	0.807	0.452
(3) Lunch time	1.29 (0.46)	1.07 (0.26)	1.11 (0.32)	1.997	0.146
(4) After school	4.83 (0.56)	4.53 (0.74)	3.11 (1.57)	15.473	p < 0.001
(5) In the evening	3.83 (1.49)	4.27 (1.03)	3.44 (1.20)	1.684	0.195
(6) On weekends	2.79 (1.28)	3.20 (1.42)	2.67 (1.37)	0.690	0.506
(7) Free time exertion	3.71 (1.12)	3.27 (1.16)	3.06 (1.00)	1.934	0.154
(8) Frequency	3.96 (1.36)	3.64 (1.16)	2.94 (1.37)	3.141	0.051

Table 2. Physical activity questionnaire distribution.

The effects of acute exercise on depression, anxiety, and stress

In regard to the acute effect of exercise (acute minus post, all groups included), median change scores for total DASS ($\chi^2(2) = 2.043$, $p = 0.360$), depression ($\chi^2(2) = 5.663$, $p = 0.059$), anxiety ($\chi^2(2) = 1.581$, $p = 0.454$), and stress ($\chi^2(2) = 0.826$, $p = 0.662$) were not significantly different between groups. However, across all groups, acute exercise elicited a significant median decrease in total DASS ($z = -3.605$, $p < 0.001$), depression ($z = -2.350$, $p = 0.019$), anxiety ($z = -2.499$, $p = 0.012$), and stress ($z = -3.671$, $p < 0.001$) (Fig. 2).

The effects of chronic sports engagement on executive functioning

In regard to the Trail Making Test, median Trail 2 time change scores were statistically different between groups ($\chi^2(2) = 7.121$, $p = 0.028$). Post-hoc analyses revealed significant differences between strategic and self-paced ($p = 0.026$), but no significant differences were found between strategic and control ($p = 0.290$) or self-paced and control ($p = 0.768$) (Fig. 3). Median change scores for all other variables including Trail 1 errors ($\chi^2(2) = 1.042$, $p = 0.594$), Trail 2 errors ($\chi^2(2) = 1.608$, $p = 0.448$), combined errors ($\chi^2(2) = 1.969$, $p = 0.374$), Trail 1 time ($\chi^2(2) = 0.107$, $p = 0.948$), or combined time ($\chi^2(2) = 1.999$, $p = 0.368$) were not significant between groups.

In regard to the Stroop Color Word Test, median change scores for overall proportion correct ($\chi^2(2) = 0.127$, $p = 0.939$), overall reaction time ($\chi^2(2) = 1.827$, $p = 0.401$), congruent proportion correct ($\chi^2(2) = 0.431$, $p = 0.806$), congruent reaction time ($\chi^2(2) = 1.334$, $p = 0.513$), incongruent proportion correct ($\chi^2(2) = 1.433$, $p = 0.489$),

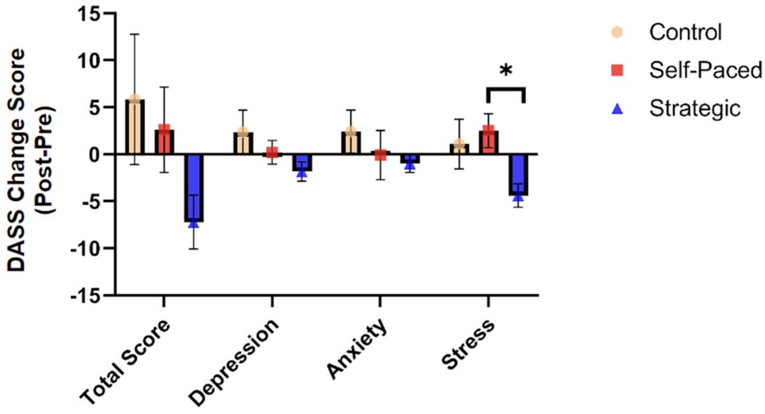

Fig. 1. The change in overall mental health (total score), depression, anxiety, and stress from before to after the sports season/semester (change scores = post-test – pre-test). Strategic sports showed the largest benefits in mental health, with the strategic sports group compared to the self-paced sports group demonstrating significant decreases in stress. *DASS* Depression, Anxiety, and Stress Scale.

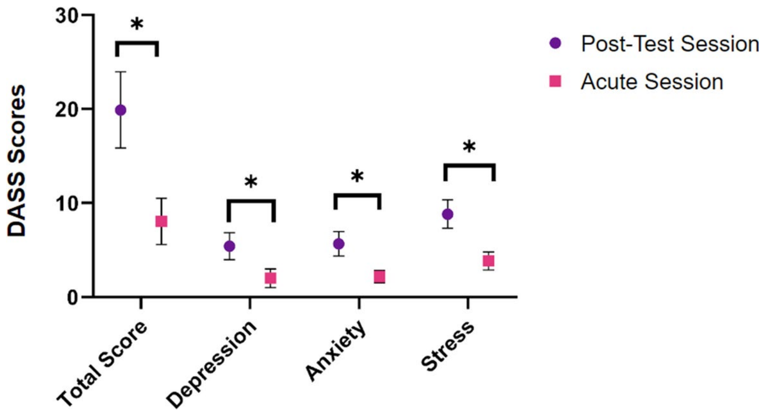

Fig. 2. The acute change in overall mental health (total score), depression, anxiety, and stress from a single bout of exercise (i.e., physical education class) (from post-test to acute-test sessions). Though no significant effects were seen between groups, when averaged, all groups demonstrated significant decreases in total mood disturbance, depression, anxiety, and stress. *DASS* Depression, Anxiety, and Stress Scale.

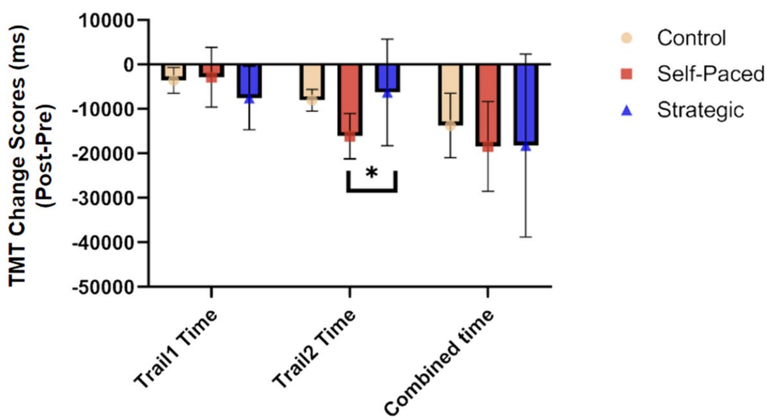

Fig. 3. The chronic change in response time for the trail making test, an executive function task that assesses visual attention and task switching, from before to after the sports season/semester (changes scores = post-test – pre-test). Self-paced sports showed the largest benefits in executive functioning, with the self-paced sports group compared to the strategic sports group demonstrating a significant improvement in task switching reaction time (Trail 2 Time). *TMT* Trail Making Test.

incongruent reaction time ($\chi^2(2) = 0.592$, $p = 0.744$), control proportion correct ($\chi^2(2) = 4.093$, $p = 0.129$), and control reaction time ($\chi^2(2) = 1.935$, $p = 0.380$) were not significant between groups.

The effects of acute exercise on executive functioning

In regard to the acute effect of exercise (acute minus post) on the Trail Making Test, median change scores for all variables including Trail 1 errors ($\chi^2(2) = 0.743$, $p = 0.690$), Trail 2 errors ($\chi^2(2) = 1.948$, $p = 0.378$), combined errors ($\chi^2(2) = 0.198$, $p = 0.906$), Trail 1 time ($\chi^2(2) = 0.768$, $p = 0.681$), Trail 2 time ($\chi^2(2) = 1.753$, $p = 0.416$), and combined time ($\chi^2(2) = 0.583$, $p = 0.747$) were not statistically significant between groups. However, across all groups, acute exercise elicited a statistically significant median decrease for Trail 1 Time ($z = -2.522$, $p = 0.012$*) (Fig. 4). No other additional significant effects were found across groups for Trail 1 errors ($z = -0.111$, $p = 0.911$), Trail 2 errors ($z = -0.178$, $p = 0.859$), combined errors ($z = -0.414$, $p = 0.679$), Trail 2 time ($z = -0.487$, $p = 0.626$), or combined time ($z = -1.855$, $p = 0.064$).

In regard to the effect of acute exercise (acute minus post) on the Stroop Color Word Test, median change scores for overall proportion correct ($\chi^2(2) = 0.745$, $p = 0.689$), overall reaction time ($\chi^2(2) = 0.648$, $p = 0.723$), congruent proportion correct ($\chi^2(2) = 1.585$, $p = 0.453$), congruent reaction time ($\chi^2(2) = 2.618$, $p = 0.270$), incongruent proportion correct ($\chi^2(2) = 0.790$, $p = 0.674$), incongruent reaction time ($\chi^2(2) = 1.694$, $p = 0.429$), control proportion correct ($\chi^2(2)2.853$, $p = 0.240$), and control reaction time ($\chi^2(2) = 0.370$, $p = 0.831$) were not statistically significant between groups. Additionally, across all groups, no significant median effects were found for overall proportion correct ($z = -0.184$, $p = 0.854$), overall reaction time ($z = -1.563$, $p = 0.118$), congruent proportion correct ($z = -0.709$, $p = 0.478$), congruent reaction time ($z = -0.438$, $p = 0.662$), incongruent proportion correct ($z = -0.081$, $p = 0.935$), incongruent reaction time ($z = -1.742$, $p = 0.081$), control proportion correct ($z = -0.487$, $p = 0.626$), and control reaction time ($z = -1.796$, $p = 0.073$).

Relationships between outcomes

Significant positive correlations were seen between the change in time for Trail Making (Part A) and total mood disturbance (Fig. 5A, $r_s = 0.450$, $p = 0.012$), change in time for Trail Making (Part A) and stress (Fig. 5B, $r_s = 0.488$, $p = 0.006$) as well as the change in time for Trail Making (Part A) and anxiety (Fig. 5C, $r_s = 0.475$, $p = 0.008$).

Discussion

This study employed a nonrandomized controlled design to examine the effects of a single bout of acute exercise and chronic sport participation on executive functioning and mental health, specifically, depression, anxiety, and stress, in an adolescent population. To our knowledge, it is one of the first causal studies in this age group to compare the impacts of strategic sports, self-paced sports, and acute exercise. The findings suggest that participation in strategic sports may be particularly effective for reducing stress, while self-paced sports appear to have a greater impact on enhancing executive functioning. Acute exercise, meanwhile, was shown to provide similar benefits across all groups, positively influencing both executive functioning and mental health outcomes.

The results of this study indicate that chronic strategic sport participation is beneficial for improving mental health, with the greatest benefits seen in terms of stress reduction. Interestingly, self-paced chronic sport participation did not elicit the same benefits to mental health. We hypothesize that this divergence in the impact of sport type on mental health may stem from the stronger social dynamics found in strategic team sports, while self-paced athletes in individual sports may experience increased pressure or competition. These findings correspond to cross-sectional data in the literature demonstrating that adolescent sports participation

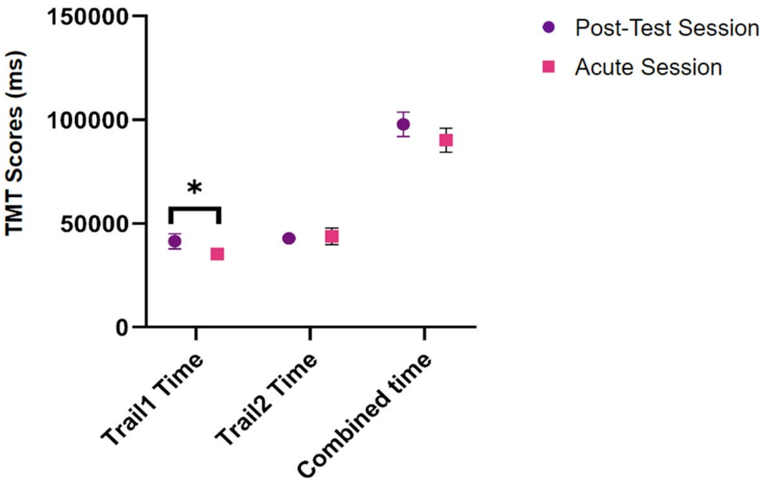

Fig. 4. The acute change in response time for the trail making test, an executive function task that assesses visual attention and task switching, from a single bout of exercise (i.e., physical education class) (from post-test to acute-test sessions). Though no significant effects were seen between groups, when averaged, all groups demonstrated a significant improvement in visual attention reaction time (Trail 1 Time). *TMT* Trail Making Test.

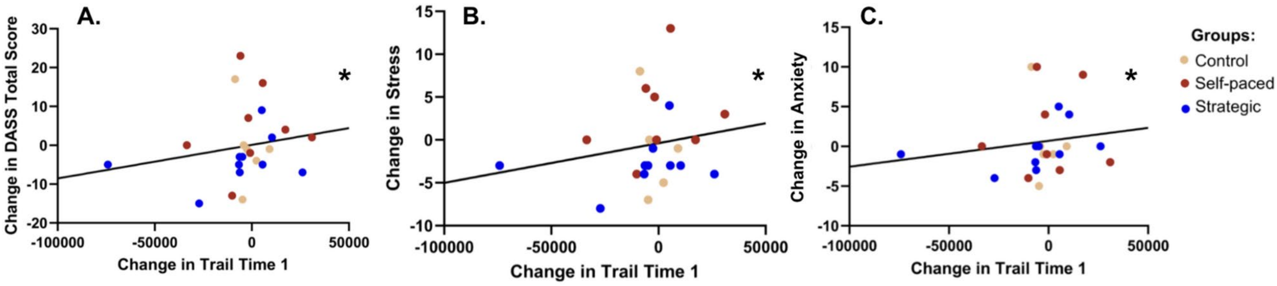

Fig. 5. The relationship between the long-term cognitive and mental health effects of sports participation. The change in visual attention reaction time (Trail 1 Time) was significantly and positively correlated with the change in (**A**) total mood disturbance; (**B**) stress; and (**C**) anxiety, such that the largest improvements in processing speed were associated with the largest gains in mental health. *DASS* Depression, Anxiety, and Stress Scale.

may be protective of mental health issues[36,37], with team sports having the most benefits, especially in the areas of depression, anxiety, and social connection[38–41]. Our findings build on existing cross-sectional data, showing that even a single season of team sport participation can positively impact adolescent mental health. The social support inherent in team sports may serve as a psychological buffer against stress, contributing to enhanced overall stress resilience. In line with our findings, a recent systematic review in adults found that sports participation was related to improved mental health, including increased psychological well-being (e.g., self-esteem, life satisfaction), decreased psychological ill-being (e.g., depression, anxiety, stress), and improved social health (e.g., pro-social behavior, sense of belonging), with those in team sports having more favorable outcomes than those in individual sports[42]. The authors propose a Mental Health through Sport Model, which proposes that the physical and social aspects of sport provide independent, yet likely synergistic contributions to the influence on mental health[42]. Other aspects that impact the effects of sports on mental health include sport type (team versus individual), intensity, frequency, context, environment (indoor versus outdoor), and level of competition (elite versus amateur). Additionally, a recent study using the National Sports and Society Survey found that adults who continually played organized youth sports had fewer depressive and anxiety symptoms compared to those who dropped out or never played sports in youth[43].

Regardless of chronic sport participation, acute exercise for adolescents as administered through a physical education class significantly improved mental health in terms of decreasing depression, anxiety, stress, and overall mood disturbance. Acute exercise is one of the most effective behavioral techniques for improving mental health and specifically for self-regulation of mood in healthy populations[19,44]. Acute exercise both increases positive mood states and decreases negative mood states, with the effect occurring immediately and lasting up to 24-h post-exercise cessation[19]. Surprisingly, little has been done to examine the effects of acute exercise in the adolescent population. One study examining the effects of acute exercise on mood in untrained adolescent boys found no significant impact[45]; however, the study used high-intensity exercise bouts, which, in some research, have been shown to negatively affect mental health[46]. Overall, the literature clearly demonstrates that physical education is an important aspect of the educational curriculum, with benefits demonstrated through reductions in depression and anxiety and improvements in positive affect, self-concept, social behaviors, goal orientation, and self-efficacy[47]. This study adds to the literature demonstrating that on a daily basis, physical education classes may provide acute positive impacts on mental health.

At a cognitive level, we found that chronic sport participation elicited improvements in executive functioning skills, measured by the Trail Making Task, specifically in the realm of task switching or cognitive flexibility. However, this same impact was not seen among strategic sport athletes, indicating that self-paced sports may provide a greater benefit to cognitive function. The benefits of chronic sports engagement across the lifespan are well documented with beneficial effects seen across a range of cognitive skills including learning and memory, attention, and other executive functions, with these benefits directly related to cardiopulmonary fitness levels (i.e., VO_2 max)[48]. For children and adolescents, in particular, physical activity can benefit similar cognitive functions, including problem-solving and decision-making as well as academic performance[49,50]. Research has shown that the type of sport can differentially influence cognitive function, with varying and often conflicting results throughout the literature. Some have suggested that athletes participating in strategic sports demonstrate superior performance on certain executive functioning tasks including cognitive flexibility, working memory, visual attention, and inhibitory control[32,51–53], whereas others have found no differences[54]. Our study is unique in that rather than taking a cross-sectional approach or evaluating athletes at a singular pre-season time point, it assessed cognitive performance both before and after a sports season, providing a more dynamic view of cognitive function over time. Additionally, our study included football players, a group at higher risk for concussions, which may have negatively impacted cognitive performance and contributed to the differing results[55]. These factors highlight key differences in study design that may explain the divergence in findings.

Acute exercise was also found to improve executive functioning, specifically in the realm of visual attention, regardless of chronic sport participation. This finding is in line with literature demonstrating that acute exercise is especially beneficial for executive functions dependent on the prefrontal cortex[19,25]. A recent systematic review and meta-analysis found that acute exercise in children and adolescents was beneficial for executive functions, with improvements seen in working memory, inhibitory control, and cognitive flexibility, with small to moderate effect sizes[30]. Similar results were found for a population of children and adolescents with attention-deficit hyperactivity disorder (ADHD), demonstrating that acute exercise can enhance attentional processes[56]. The majority of these studies have been conducted using a specific exercise intervention such as stationary bicycling, treadmill walking, or circuit training[28]. Ours is unique in that we examined the effects of a single physical education class, which was already part of the daily course curriculum.

We speculate that the differing mental health and executive function benefits observed between various types of sports participation may stem from the inherent nature of these activities. Self-paced and strategic sports diverge in how athletes control the timing of their actions and in their reliance on planning and adaptability. In self-paced sports, such as golf, archery, bowling, or track and field, athletes dictate the pace of their movements, performing without the direct external pressures of opponents or time constraints[57]. Success in these sports typically depends on the consistent execution of repeatable skills under stable conditions. In contrast, strategic sports like soccer, basketball, tennis, and football require athletes to continuously react to opponents and adjust strategies based on evolving game situations. These sports demand quick decision-making, effective communication, teamwork, and heightened situational awareness[58]. Athletes must anticipate their opponents' actions and adapt strategies mid-game. Given these differences, we speculate that individuals participating in self-paced sports may experience greater improvements in executive function, while those engaged in strategic sports may gain more pronounced mental health benefits, particularly due to the social and teamwork-oriented nature of these activities.

Finally, the findings of this study reveal a significant correlation between improvements in executive function and enhancements in mental health, specifically reductions in stress, anxiety, and total mood disturbance. We hypothesize that exercise may be driving enhanced top-down cognitive control processes. This likely enables individuals to better regulate their emotional responses, promoting a greater sense of control in stressful situations and contributing to overall improvements in mental well-being, which is especially crucial during the critical period of adolescence[59].

This study has several limitations that warrant consideration. First, while we hypothesized that the strategic sports group would show the greatest improvements in both mental health and cognitive functioning, we did not account for common sports injuries, such as concussions or traumatic brain injuries, which are more prevalent in strategic compared to self-paced sports and may have impacted our results. Additionally, we did not measure changes in cardiopulmonary fitness over the season, nor did we assess the intensity or physical exertion during the acute exercise sessions (i.e., physical education class). Including these variables in our statistical models would have provided a clearer understanding of potential correlations between fitness gains, exercise intensity, and the observed mental and cognitive health benefits. Furthermore, this study did not assess social connection, which may have been a key factor driving mental health improvements, as is suggested by our previous research[60,61]. To strengthen the present conclusions, future research should incorporate a larger and more diverse sample and account for head injuries or other sports-related injuries as covariates. This facet is important as various demographic variables are known to impact physical and cognitive health. Importantly, the lack of statistically significant differences between the sports and control groups may stem from the limited sample size, which can reduce the statistical power of the study and increase the likelihood of Type II errors. Alternatively, the academic extracurricular activities in which the control group participated may have significantly influenced their mood and cognition. Engagement in such activities has been associated with enhanced academic performance, improved time-management and leadership skills, and positive social development. Investigating the neural mechanisms underlying the psychological and cognitive benefits of both acute and chronic sports participation would also be valuable, utilizing methods such as electroencephalography (EEG) or functional magnetic resonance imaging (fMRI). Additionally, measuring neurochemical markers—such as endogenous opioids, endocannabinoids, and oxytocin—via saliva or blood could provide insight into the biological processes linking sports participation to mental and cognitive health outcomes.

In conclusion, this study adds to the growing body of literature on the effects of sports participation and exercise on mental health and executive function in adolescents. Both chronic and acute exercise proved effective in enhancing mental health and cognitive function in this population. Notably, strategic sports were associated with greater benefits for mental health, while self-paced sports yielded more pronounced improvements in executive functioning. Additionally, acute exercise demonstrated positive effects on both mental health and executive function, regardless of an individual's chronic sport participation. Adolescent athletes showed reductions in negative mental health states and improvements in cognitive function from pre- to post-season, while acute exercise enhanced these outcomes across all groups. These findings provide evidence that vigorous, sustained participation in sports can reduce mood disturbance and improve executive functioning in adolescents. Given the increasing prevalence of mental health challenges in this age group, sports participation offers a safe and effective intervention to combat these issues. Furthermore, regular acute exercise through physical education classes benefits both athletes and non-athletes by enhancing executive functioning and reducing negative mental health states. These results underscore the importance of maintaining physical education as a core component of the school curriculum to support attentional focus, mood regulation, and overall success during the school day. This study highlights the broad and significant benefits of physical activity across various forms, intensities, and frequencies, promoting both sports participation and acute exercise as essential tools for improving adolescent mental health and cognitive function.

Methods

Recruitment and experimental design

N = 63 adolescents (age 14 to 18 years) were recruited from a public high school in suburban New York (Ossining, NY) via email and school sports team meetings. All study methods and procedures were approved

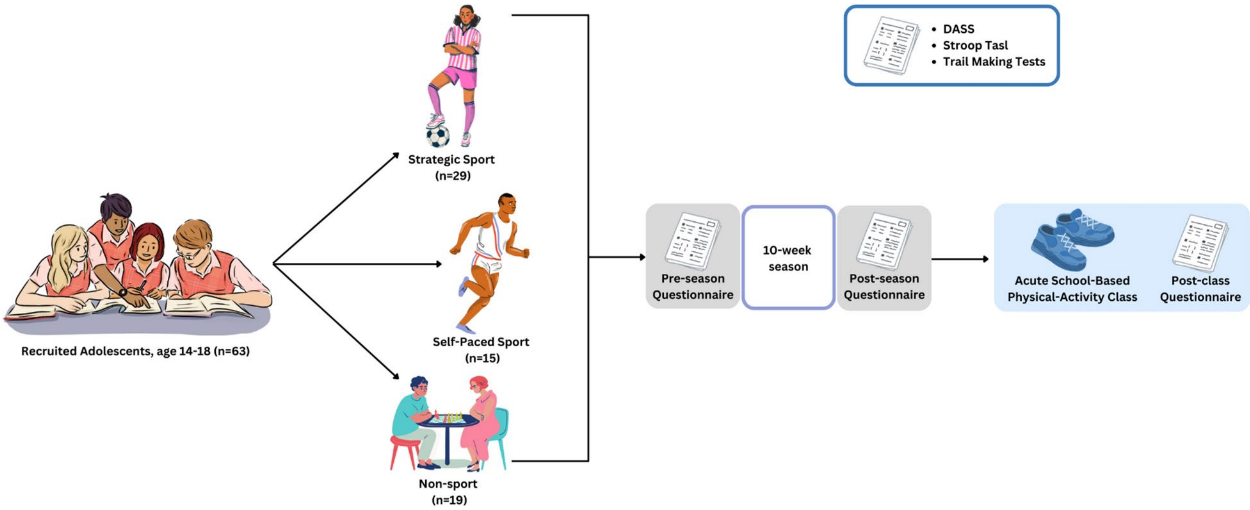

Fig. 6. Diagram of study timeline, denoting participant grouping, questionnaire timepoints, and acute exercise participation.

by the Ossining High School Institutional Review Board, and all research was performed in accordance with relevant guidelines and regulations. Because individuals were minors, all participants and their legal guardians provided written informed consent prior to beginning the study.

This study utilized a non-randomized pre/post test study design. Specifically, participants were recruited based on their sports participation—strategic sport (n = 29), individual self-paced sport (n = 15), or non-sport (n = 19). Both strategic and self-paced sports groups participated in their sport for a 10-week season. Strategic sports included varsity or junior football, flag football, lacrosse, or softball, with an emphasis on cognitively demanding, team sports. Individual self-paced sports included cross-country, tennis, or golf, with an emphasis on individual control and precision. The control group consisted of non-sport individuals in the National Honor Society, engineering club, or business/finance clubs. The control cohort did not participate in any sports activities during the same 10-week period. Participants completed behavioral and cognitive questionnaires at three time points throughout the study—pre-season, post-season, and immediately following an acute standard physical education class. During each testing period, participants completed the Depression Anxiety Stress Scales (DASS), Trail Making Test (TMT), and Stroop Test (Fig. 6). If participants failed to complete any one of these tasks during a specific time point, their data was excluded from that day.

Measures

Demographics & physical activity

Participants completed a demographic questionnaire, which included age, race, current grade level, height, gender, weight, and ethnicity. Weekly physical activity and sport participation was determined using the Physical Activity Questionnaire for Adolescents[62].

Mental health

Mental health status was assessed using the 42-item Depression, Anxiety, and Stress Scale (DASS)[63]. DASS is a widely used psychometric tool designed to measure the emotional states of depression, anxiety, and stress as well as an overall total mood disturbance score (total score). Each item is scored on a 4-point Likert scale, ranging from 0 ("Did not apply to me at all") to 3 ("Applied to me very much or most of the time"), with higher scores indicating greater severity of symptoms. The DASS exhibits high internal consistency for each of its subscales (depression, anxiety, and stress), with Cronbach's alpha values typically above 0.90 for the full scale and 0.80 or higher for individual subscales. Each subscale consists of 14 item that are summed together for a unique depression, anxiety, or stress score. All items are summed together for a DASS total score, representing total mood disturbance. DASS also has good test–retest reliability and strong construct, convergent, and divergent validity.

Executive function

Executive function was assessed via two cognitive tasks, The Trail Making Test (TMT)[64] and the Stroop Color Word Test[65], which were administered using Inquisit Web (Millisecond, Seattle, WA), precision testing software for online and mobile psychological research.

The TMT measures visual attention and task switching by asking participants to connect circles placed in a fixed order in either ascending numeric value (Trail 1, visual attention) or numerical-alphabetical order (Trail 2, task switching) by drawing a line using a mouse or touchpad on a computer. Participants are asked to move the mouse in specific, predetermined sequences from node to node. The time it took each participant to complete the test was gathered in milliseconds. A lower score on the TMT indicated a faster reaction time and thus higher executive functioning. The task took approximately 5 min to complete. For each trail, the number of errors was recorded to assess accuracy (Trail 1 Errors), while the time taken to complete each trail, measured in milliseconds (Trail 1 Time), was recorded to evaluate processing speed. To provide a comprehensive overview of performance, combined metrics were calculated: Combined Errors represented the total number of errors across all trails, and Combined Trail Time aggregated the total time spent on all trails. These combined measures offered an overall assessment of the participant's performance, integrating both accuracy and speed across different components of the TMT.

The Stroop Color Word Test evaluates an individual's ability to manage cognitive interference, which occurs when the processing of one stimulus is disrupted by the presence of a conflicting stimulus. Participants are given color words written in color (red, green, blue, and black) and are asked to indicate the color of the word (not its meaning) by key press (D, F, J, K) as fast as they can without making too many errors. Participants are provided congruent stimuli (the color of the word matching the word), incongruent stimuli (a word color not matching the word), and control trials. The correctness of the response and the response latency (in milliseconds) is measured from the onset of the stimulus. Eighty-four trials are presented in total. The following outcomes are calculated: overall proportion correct of all trials; overall mean latency of all correct trials; proportion correct of congruent trials, incongruent trials, and control trials, reported independently; and the mean latency of of all correct congruent trials, incongruent trials, and control trials, reported independently. The task took approximately 2 min to complete.

Statistical analysis
Data analysis was conducted in SPSS 29.0 (IBM Corp, Armonk, NY)[66]. We used chi-square tests of independence to assess differences between experimental groups for categorical demographic variables such as grade, sex, race, and ethnicity. For continuous demographic variables like age, weight, height, and BMI as well as the Physical Activity Questionnaire data, we conducted a one-way analysis of variance (ANOVA). Chronic exercise change scores were calculated by subtracting pre-test scores from post-test scores. Acute exercise change scores were calculated by subtracting post-test scores from acute scores. Change score differences between cohorts and pre/post/acute were calculated using the non-parametric Kruskal–Wallis H test. Distributions of DASS scores, TMT scores, and Stroop Color Word Test scores were similar for all groups. For post-hoc analyses, pairwise comparisons were performed using Dunn's procedure with a Bonferroni correction for multiple comparisons. Adjusted p-values are presented. Limited between-group differences regarding acute effects were found; thus, the nonparametric Wilcoxon signed-rank test was used to determine the effect of acute exercise across all groups. To examine relationships between change scores, the two-tailed Spearman's Rank Order Correlation was used.

Data availability
Data is available upon request. To request data, please contact Dr. Julia C. Basso at jbasso@vt.edu.

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Author contributions
JCB and LP conceived and designed the study. AP and VH provided mentoring and oversight for the study. LP conducted all experiments and collected the data. JCB, LP, MA and NT conducted data analysis, created figures, and contributed to the writing and revision of the manuscript. All authors reviewed and approved the final manuscript.

Declarations

Competing interests
The authors declare no competing interests.

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