The Relation of Aerobic Fitness to Stroop Task Performance in Preadolescent Children

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Abstract

BUCK, S. M., C. H. HILLMAN, and D. M. CASTELLI. The Relation of Aerobic Fitness to Stroop Task Performance in Preadolescent Children. *Med. Sci. Sports Exerc.*, Vol. 40, No. 1, pp. 166–172, 2008. **Purpose:** We investigated the relation between aerobic fitness and interference control—one component of executive control—in 74 children between 7 and 12 yr of age. **Method:** Participants completed a paper-and-pencil version of the Stroop color–word task and the *FITNESSGRAM*, a valid and reliable test measuring different components of physical fitness (i.e., aerobic, muscle, and body composition). During each condition of the Stroop task (word, color, color–word), participants were instructed to read aloud as many items as possible in 45 s. Data were also collected on IQ and personal and health demographics to account for other factors influencing the relationship between fitness and executive function. **Results:** Older children and those with higher IQ responded to more items correctly during each of the three conditions. Greater aerobic fitness was also associated with better performance on each of the three Stroop conditions independently of the other variables. **Conclusion:** These findings suggest that increased levels of fitness may be beneficial to cognition during preadolescent development. **Key Words:** PHYSICAL ACTIVITY, EXERCISE, EXECUTIVE CONTROL, DEVELOPMENT, MATURATION, COGNITION

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Physical inactivity is a major risk factor for various diseases (e.g., stroke, cardiovascular disease, diabetes), with evidence also indicating that inactivity leads to decrements in cognitive health (11,17). Although the majority of research to date relating aerobic fitness to general and selective (i.e., executive control) improvements in cognitive function has been performed using adult populations, there is a considerably smaller, yet growing, database indicating general benefits in children (16,27). No previous research with children has investigated the relationship between aerobic fitness and executive control, or otherwise effortful types of cognition.

Executive control refers to a subset of cognitive processes involved in the intentional component of environmental interaction; it includes planning, working memory, coordination, and inhibitory control, as well as other effortful processes that must occur under conscious control to avoid making an error (23). Improvement in executive control tasks during childhood has been linked to development of the frontal lobe (8). During the early stages of preadolescence, children have poor inhibitory control because of difficulty gating out irrelevant information (24). Luciana and Nelson (21) tested 4- to 8-yr-old children, using a battery of neuropsychological tests, and found that performance declined with increases in task difficulty. Further, this relationship was selectively larger for those tasks (i.e., executive control) requiring prefrontal cortex recruitment, suggesting that implementation of strategy fails because of a lack of integration of information between the prefrontal cortex and other brain structures (e.g., hippocampus (21)). However, with development comes increased efficiency of executive processes, resulting in the ability to control interference (28) and to hold two or more pieces of information in working memory while inhibiting a response tendency (9).

One task frequently used to study executive control is the Stroop color–word task, which entails multiple cognitive processes including selective attention, response inhibition, interference control, and speeded responding (1). In one version of the Stroop task, participants complete three conditions, each lasting 45 s. During the first condition, participants see color words (e.g., *red*, *green*) printed in black ink and are instructed to read the word. In the second condition, participants see neutral arrays of letter–color pairs (e.g., *XXXX* printed in green ink) and are instructed to name the color of the ink. In the final condition, participants see incongruent word–color pairs (e.g., *red* printed in green ink) and are instructed to name the color of the ink in which the word is written. The basic tenet underlying Stroop performance is that individuals must

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inhibit their prepotent response to read the word and activate a normally inhibited response to name the ink color in which the word is printed, thus resolving interference associated with reading the word (1,7,22). Accordingly, participants read fewer words during the incongruent word–color condition because of response competition. To assess interference control independent of an individual's reading or color-naming speed, the congruent condition is often subtracted from the incongruent condition (13). This measure then represents executive function related to cognitive flexibility or resistance to interference. A lower score indicates greater resistance to interference and, thus, better performance (14). Therefore, this measure provides for the comparison of general versus selective effects of experimental manipulations on Stroop task performance.

Several studies indicate that Stroop task performance improves with age (7) because of increased control of interference (15) and reaction time (RT) (15). Young children read fewer words and exhibit greater interference than older children and young adults (22). Adleman et al. (1) found a linear increase in performance between 7 and 22 yr of age for raw word, color, and color–word scores. Further, Demetriou et al. (7) observed performance improvements with age in a sample of 9-, 11-, 13-, and 15-yr-olds, proposing that structural changes and practice interacted to produce such improvements. Interference effects were found to become progressively smaller with age in a sample of 4- to 11-yr-olds and young adults, using a cross-modal, nonreading version of the Stroop task (15), whereas other research has exhibited larger interference effects during old age (22), suggesting a curvilinear relationship between age and interference control across the lifespan. RT has also been found to exhibit a marked decrease with age during the course of development (15). Taken together, these improvements in task performance likely reflect structural development of brain tissue, which mediates functions related to Stroop task performance, such as response inhibition, interference resolution, and reading ability (1,22).

With regard to development, Adleman and colleagues (1) observed reduced activation of the left PFC, ACC, and parietal cortex during Stroop task performance in 7- to 11-yr-old children relative to young adults. Further, when compared with a sample of adolescents between 12 and 16 yr of age, preadolescent children exhibited reduced activation of the parietal cortex. Adolescents also exhibited decreased left-PFC and ACC activation relative to young adults, whereas no differences were observed in the parietal cortex. Accordingly, these findings indicate that the cognitive functions needed for Stroop task performance are characterized by increased recruitment of resources in specific neural structures throughout development (1). Other research has corroborated these findings, using neuroimaging techniques during performance of different inhibitory tasks (3) or functional near-infrared spectroscopy during a Stroop task (26), indicating that protracted development of the brain structures associated with component cognitive processes involved selective attention during adolescence.

Interestingly, neuroimaging studies with adults have revealed that these same brain structures are influenced by aerobic fitness during performance on tasks that require interference control (6). Specifically, reduced interference was observed in high-fit, relative to low-fit, older adults during incongruent trials of a flanker task, which requires greater amounts of interference control similar to the incongruent condition of a Stroop task. Using fMRI measures, greater activation was also observed in high-fit older adults in brain structures associated with attentional control (e.g., PFC, parietal cortex), whereas significantly less activity was exhibited in the ACC, which is thought to mediate evaluative processes related to conflict monitoring (6). A second study used a longitudinal design, wherein previously sedentary older adults were randomly assigned to a 6-month intervention of aerobic training or stretching and toning. Consistent with the cross-sectional findings, participants in the aerobic group demonstrated significantly greater activity in brain regions associated with attentional control in the parietal cortex, and significantly reduced activity in the ACC compared with individuals in the stretching and toning group. Collectively, these findings indicate the specific neuroanatomy that is influenced by increases in aerobic training, and they suggest that cognitive functions subserved by these regions are benefited by exercise participation in older adult populations. To date, no research has examined fitness effects on cognition using neuroimaging measures during development.

Behavioral research with adults has also indicated that aerobic fitness may selectively improve performance on the Stroop task, resulting in reduced interference scores (10). Sedentary 55- to 70-yr-old adults were randomly placed into an aerobic exercise group, a strength and flexibility group, or a nonexercise group. Results indicated that those participants randomized into the aerobic training group exhibited significantly reduced interference scores when compared with baseline (10). No such effect was observed for the strength- and flexibility trained or the nonexercise groups (10). Additionally, Van Boxtel et al. (29) found that aerobic fitness was associated with increased performance on tasks requiring effortful cognitive processing. Specifically, 132 adults between 24 and 76 yr completed a submaximal cycle ergometer test to estimate maximal aerobic capacity and performed the Stroop task. A positive association was found between aerobic fitness and the interference portion of the Stroop task (29). However, this finding was mediated by age, such that fitness was associated with better Stroop performance for older adults, whereas no relation was observed for younger adults. The findings from these two studies corroborate those of Colcombe and Kramer (5) and Hillman et al. (17), who found that aerobic exercise is more beneficial for tasks or task components requiring extensive executive control. That

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is, tasks that involve planning, inhibition, and scheduling of mental procedures exhibited a disproportionately larger relationship with aerobic exercise when compared with tasks that include more basic processes, such as simple RT.

Despite this intriguing relationship observed between fitness and cognition in adult populations, the selective relation of aerobic fitness to executive control cognitive function has not been reported in children. Thus, the purpose of this study was to further investigate the general versus selective nature of aerobic fitness on cognition during preadolescent development by investigating behavioral performance on a Stroop color–word task, which requires variable amounts of executive control. On the basis of previous literature investigating the relation between fitness and executive control, it was hypothesized that there would be an increase in performance across all conditions of the Stroop task (i.e., congruent, neutral, and incongruent) with higher levels of aerobic fitness. However, despite an increasingly robust literature on older adults indicating that the strongest fitness effects are found for those tasks requiring greater amounts of executive control (5,10,29), previous research with children has not replicated this finding, instead suggesting a more general relation of fitness to cognition (4,16). Thus, it was hypothesized that increased fitness would relate to improvements in task performance across the three conditions of the Stroop task, providing evidence that the relation between fitness and cognition may differ across the lifespan.

METHOD

Participants. Seventy-four children (males = 41) between 7 and 12 yr old (mean age = 9.3 yr, SD = 1.4) were recruited from the Champaign County, IL community to participate in this study. None of the participants had individual education plan or section 504 accommodations to receive direct or indirect special education services in an educational setting (e.g., attention deficit disorder; cognitive or physical disability). Participants provided written assent, and their legal guardians provided written informed consent approved by the institutional review board at the University of Illinois. See Table 1 for participants' demographic information.

Participant characteristics. Data were collected on several factors that have been previously shown to relate to either physical activity participation or cognitive function. Specifically, the Kaufman Brief Intelligence Test (K-BIT) (20) was administered by a trained experimenter to obtain a composite IQ score using measures of crystallized (vocabulary) and fluid (analogies) thinking. In a subset of participants (N = 44), guardians completed a questionnaire regarding participants' demographic information and socioeconomic status (SES). SES was determined by creating a trichotomous index based on three variables: the highest level of education obtained by the mother and father, participation in free or reduced-price lunch program at school, and number of parents who worked full-time (2). Independent sample t-tests yielded no significant differences in participant demographics between the group in which SES data were collected and the group in which it was not ($t \leq 1.7$, $P \geq 0.09$), and a repeated-measures MANOVA between these groups indicated no significant group differences for any of the Stroop task conditions, $F(2, 71) = 1.2$, $P > 0.30$. All participants reported being free of adverse health conditions, neurological disorders, any medications that influence central nervous system function, or color-blindness, and they all had normal (or corrected to normal) vision according to the minimal 20/20 standard.

Fitness testing. The *FITNESSGRAM*, which is a valid and reliable field assessment of physical fitness for individuals ages 5 through adulthood (30), was used to assess participants' fitness. The *FITNESSGRAM* measures various facets of physical fitness, including aerobic capacity (a shuttle run called the Progressive Aerobic Cardiovascular Endurance Run (PACER)), muscle fitness (push-ups and curl-ups; sit and reach), and body composition through height and weight measures that are converted to a body mass index (BMI) score. The objective of the PACER test was to run as long as possible back and forth across a 20-m distance at a specified pace, which increased each minute. A participant's score on the PACER test was equal to the number of laps completed.

Cognitive task. Participants completed the paper-and-pencil version of the Stroop Color and Word Test Children's Version for Ages 5–14 (Stoelting Testing Co, Wood Dale, IL). During each of three conditions (word, color, incongruent

TABLE 1. Group means (SD) for participant characteristics and fitness data for child participants.

Measure	All Participants	7- to 8-yr-olds	9- to 10-yr-olds	11- to 12-yr-olds
N	74 (41 males)	22 (11 males)	39 (23 males)	13 (6 males)
Mean age (yr)	9.3 (1.4)	7.5 (0.5)	9.6 (0.5)	11.4 (0.5)
SES (N = 44)	2.8 (0.5)	2.8 (0.5)	2.8 (0.5)	—
K-BIT (IQ)	113.6 (12.2)	116.2 (12.0)	111.6 (12.3)	115.0 (11.7)
PACER (laps)	23.2 (12.2)	21.1 (10.9)	23.5 (11.7)	25.8 (15.9)
Body mass index (raw)	18.5 (3.4)	17.9 (4.1)	18.7 (3.2)	19.2 (3.1)
Stroop word score	73.9 (13.4)	68.1 (12.9)	73.9 (11.0)	84.4 (16.6)
Stroop color score	51.9 (10.2)	46.5 (10.5)	52.6 (8.3)	59.5 (11.5)
Stroop color–word score	31.5 (9.8)	25.7 (9.0)	32.2 (7.2)	39.0 (12.5)
Interference score	20.4 (9.0)	20.5 (8.7)	20.3 (7.8)	20.5 (12.9)

K-BIT is a composite score for IQ. SES, socioeconomic status. The PACER and BMI are subscales of the *FITNESSGRAM* test. Normative values for the *FITNESSGRAM* may be found in Welk GJ, Morrow JR, Falls HB. *FITNESSGRAM Reference Guide.* Dallas (TX): The Cooper Institute; 2002.

color–word pairs), participants were instructed to read aloud as many items as possible in 45 s. In the word condition, participants saw a list of color words (e.g., red, blue) written in black ink and were instructed to read aloud as many words as possible during a 45-s period. In the color condition, participants saw a list of *XXXX*s printed in different ink colors (e.g., red, blue) and were instructed to read aloud the ink color. In the incongruent color–word condition, participants saw a list of color words written in incongruent color ink relative to the printed word (e.g., the word *red* printed in blue ink). The latter condition necessitates the greatest amount of interference control because participants are required to read aloud the color of the ink and inhibit the automatic task of reading the printed word. The Stroop Color and Word Test Computerized Scoring–Children (Stoelting Testing Co, Wood Dale, IL) was enacted, which involved entering raw scores into a template on a spreadsheet that had the scoring functions embedded. An investigator calculated the raw scores by counting the total number of items correctly read aloud by the participant for the word, color, and color–word conditions. An interference score was also computed for each child by subtracting the incongruent color–word score from the color score.

Laboratory procedure. Parental informed consent forms were mailed home with a description of the study. Interested parents signed and returned the consent form by mail in an enclosed, stamped envelope. Child participants completed *FITNESSGRAM* testing and the Stroop task on separate days within the same week (SD = 1.25 d). On the first day of testing, children were familiarized with all of the *FITNESSGRAM* testing protocols and were allowed to practice each of the specified techniques. On the second day of testing, children were randomly assigned to two different groups, to complete a rotation between high-intensity (push-ups) and low-intensity (sit and reach) tests. On the final day of testing, one group was randomly selected to run first and tally the total number of laps second, and the other group ran after counting laps for his or her partner. The investigation team determined test completion and recorded scores. On a separate day before any physical activity, children provided written assent, and a trained experimenter administered the Stroop and K-BIT. Testing was conducted individually in a quiet room. Demographic and SES information was completed by a subsample (N = 44) of guardians in the laboratory.

Statistical analysis. Three-step hierarchical regression analyses were performed for each of the three conditions of the Stroop task. Initial Pearson product–moment correlation analyses were conducted on scores for the four dependent variables from the Stroop task (number of items read for the word, color, and incongruent color–word, and the interference score), age, sex (coded as 1 = male, 2 = female), composite K-BIT (IQ), SES, BMI, and PACER scores. IQ, sex, SES, and age-adjusted BMI (*z*-score) were included to identify covariates for inclusion in the regression analyses.

RESULTS

Results of the initial Pearson product–moment correlation analyses indicated that aerobic fitness was negatively associated with BMI ($P < 0.001$) and positively associated with the word, color, and incongruent color–word conditions of the Stroop task ($P = 0.001$) (Table 2). Age and IQ were also positively related to the word, color, and incongruent color–word conditions of the Stroop ($P \leq 0.025$). No variable was correlated with the Stroop interference score. Further, SES and sex were not correlated with any of the Stroop task conditions or the PACER ($P > 0.06$), and, thus, these were not included in subsequent regression analyses. Accordingly, age, IQ, and BMI were treated as covariates in the subsequent regression analyses.

A series of three-step hierarchical regression analyses were conducted. In the first step, the dependent variables from the Stroop task were regressed onto age, IQ, and BMI. In the second step, scores from the PACER test, which assesses aerobic fitness, were entered into the regression analysis. In the third step, an age × fitness interaction term (created on the basis of a product of mean-centered scores) was entered into the regression analysis to examine whether aerobic fitness effects on task performance were dependent on age.

The step 1 regression analysis on the number of items read in the word condition indicated a significant overall effect (adjusted R^2 = 0.36, $F(3, 70)$ = 14.6, $P < 0.001$). There were significant effects for age (pr = 0.50, $t(70)$ = 4.8, $P < 0.001$, β = 0.46) and IQ (pr = 0.52, $t(70)$ = 5.0, $P < 0.001$, β = 0.48), indicating that older children and higher IQ were associated with better task performance. The step 2 regression analysis was also significant (ΔR^2 = 0.09,

TABLE 2. Intercorrelations between variables for all participants.

Subscales	1	2	3	4	5	6	7	8	9	10
1. Age	—									
2. Sex	−0.002	—								
3. K-BIT	−0.14	−0.07	—							
4. SES	0.07	0.03	0.27	—						
5. BMI (*z*-score)	0.18	0.06	−0.13	−0.12	—					
6. PACER	0.11	0.06	0.09	0.09	−0.49*	—				
7. Stroop word	0.39*	−0.01	0.42*	0.19	−0.03	0.39*	—			
8. Stroop color	0.43*	0.22	0.37*	0.06	−0.13	0.37*	0.64*	—		
9. Stroop color/word	0.45*	0.12	0.26*	−0.17	−0.04	0.37*	0.52*	0.60*	—	
10. Stroop interference	−0.02	0.09	0.11	0.22	−0.11	0.04	0.14	0.45*	−0.42*	—

* $P < 0.05$.

$F(1, 69) = 11.5$, $P = 0.001$). There was a significant effect for PACER scores ($pr = 0.38$, $t(69) = 3.4$, $P = 0.001$, $\beta = 0.34$), indicating that higher levels of aerobic fitness were associated with better task performance. The step 3 regression analysis was not significant ($\Delta R^2 = 0.00$, $F(1, 68) < 0.01$, $P = 0.97$), indicating that the interaction did not add to the prediction of number of items read in the word condition (see Table 3).

The step 1 regression analysis on the number of items read in the color condition indicated a significant overall effect (adjusted $R^2 = 0.38$, $F(3, 70) = 16.0$, $P < 0.001$). There were significant effects for age ($pr = 0.53$, $t(70) = 5.3$, $P < 0.001$, $\beta = 0.49$) and IQ ($pr = 0.48$, $t(70) = 4.6$, $P < 0.001$, $\beta = 0.42$), indicating that older children and higher IQ were associated with better task performance. The step 2 regression analysis was also significant ($\Delta R^2 = 0.05$, $F(1, 69) = 5.6$, $P = 0.02$). There was a significant effect for PACER scores ($pr = 0.27$, $t(69) = 2.4$, $P = 0.02$, $\beta = 0.25$), indicating that higher levels of aerobic fitness were associated with better task performance. The step 3 regression analysis was not significant ($\Delta R^2 = 0.00$, $F(1, 68) < 0.01$, $P = 0.96$), indicating that the interaction did not add to the prediction of number of items read in the color condition (Table 3).

The step 1 regression analysis on the number of items read in the incongruent color–word condition indicated a significant overall effect (adjusted $R^2 = 0.30$, $F(3, 70) = 11.6$, $P < 0.001$). There were significant effects for age ($pr = 0.52$, $t(70) = 5.1$, $P < 0.001$, $\beta = 0.50$) and IQ ($pr = 0.37$, $t(70) = 3.3$, $P = 0.002$, $\beta = 0.33$), indicating that older children and higher IQ were associated with better task performance. The step 2 regression analysis was also significant ($\Delta R^2 = 0.07$, $F(1, 69) = 7.6$, $P < 0.01$). There was a significant effect for PACER scores ($pr = 0.31$, $t(69) = 2.8$, $P < 0.01$, $\beta = 0.30$), indicating that higher levels of aerobic fitness were associated with better task performance. The step 3 regression analysis was not significant ($\Delta R^2 = 0.00$, $F(1, 68) = 0.26$, $P = 0.61$), indicating that the interaction did not add to the prediction of number of items read in the color–word condition (Table 3).

The final analysis regressed the Stroop interference scores on the PACER scores. This analysis was not significant (adjusted $R^2 = 0.01$, $F(1, 72) = 0.9$, $P = 0.77$), indicating that the relation between fitness and task performance was not selectively greater for task components requiring greater interference control (i.e., incongruent color–words).

TABLE 3. Summary of hierarchical regression analysis for variables predicting number of items read during the word, color, and incongruent color–word condition, respectively.

	B	SE B	β
Word condition			
Step 1			
Age	4.30	0.90	0.45***
K-BIT	0.53	0.11	0.48***
BMI (*z*-score)	−1.18	1.31	−0.85
Step 2			
PACER	0.38	0.11	0.34**
Step 3			
Age × fitness	0.00	0.07	0.00
Color condition			
Step 1			
Age	3.51	0.67	0.49***
K-BIT	0.35	0.08	0.42***
BMI	−2.04	0.97	−0.19
Step 2			
PACER	0.20	0.09	0.25*
Step 3			
Age × fitness	−0.003	0.06	−0.005
Color–word condition			
Step 1			
Age	3.5	0.69	0.50***
K-BIT	0.26	0.08	0.33**
BMI	−1.28	1.0	−0.13
Step 2			
PACER	0.24	0.09	0.30**
Step 3			
Age × fitness	−0.03	0.06	−0.05

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

DISCUSSION

Aerobic fitness was related to better cognitive function in preadolescent children using a task that required variable amounts of executive control. Replicating previous research (1,22), preadolescent children, regardless of fitness level, performed progressively poorer on the color and color–word trials compared with word trials of the Stroop task, indicating that tasks requiring greater amounts of interference control are associated with decreases in task performance. Further, results indicated that age, IQ, and increased levels of aerobic fitness were beneficial to Stroop task performance during preadolescent development. Specifically, older children and those with higher IQ responded to more stimuli correctly during each of the three conditions on the Stroop color–word task. In addition, children who performed more laps on the PACER test, indicating better aerobic fitness, correctly read more stimuli during each of the three Stroop conditions relative to those children who ran fewer laps. These findings suggest that increased levels of aerobic fitness may be beneficial to cognitive function during brain development, and they suggest that fitness may provide general benefits to cognition during preadolescence.

The general relation observed for aerobic fitness and cognitive function herein has been supported by previous findings in the literature examining preadolescent children, with results indicating that higher-fit children exhibit overall better performance regardless of the amount of executive control required. This finding clearly differs from the literature base that has examined the same relationship in adult populations using similar Stroop tasks (10,29). Castelli et al. (4) examined the relation between different components of fitness (i.e., aerobic, muscle strength, body composition) and academic achievement (i.e., total achievement, mathematics, and reading) in 259 elementary school children in the third and fifth grades. After controlling for other variables (i.e., age, socioeconomic status, etc.), only aerobic fitness was positively related to academic performance, and this relation was observed across all three achievement test

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measures (4). These data suggest that higher aerobic fitness during preadolescent childhood may be associated with better academic performance, lending further support to the notion that fitness is globally associated with cognitive performance during development (4).

Additional support comes from Hillman et al. (16), who observed a global increase in neuroelectric activity (as measured via the P3 component of an event-related brain potential) for higher-fit preadolescents across target and nontarget conditions of an oddball task, which requires the allocation of attentional resources to stimulus discrimination through the manipulation of stimulus probability. These findings suggest that higher-fit, relative to lower-fit, children may be better able to recruit neural resources to improve task performance. Higher- and lower-fit young adults were tested for comparison purposes, and no such fitness-related differences were observed, likely because of the small executive control requirements involved in an oddball task. That is, higher fitness was positively associated with cognitive function related to attentional resource allocation during working memory processes, as measured by the amplitude of the P3 potential, only in preadolescent children. However, aerobic fitness, regardless of age, was positively associated with stimulus classification speed, as faster P3 latency was observed for fit compared with sedentary participants. Importantly, fitness was also associated with task performance in preadolescent participants with shorter RT for higher-fit compared to lower-fit children. Thus, these findings provide further support that fitness may be associated with general improvements in cognitive function during preadolescent development, because modulation of neuroelectric and task performance measures were observed as a function of aerobic fitness across conditions of a stimulus discrimination task with small executive control requirements. The findings herein corroborate these earlier findings and extend them to tasks requiring variable amounts of interference control.

Despite the consistency of findings across tasks and measures, there is little understanding of the underlying mechanisms that mediate fitness-related differences on preadolescent cognitive function. No prior research has provided an understanding of the relation of aerobic fitness to brain and cognition during development. Thus, the brain structures underlying the general versus selective influence of fitness on cognition that has been observed to differ across children and adults remain unresolved. However, Posner and his colleagues (12,25) developed the Attention Network Test (ANT), which has led to a greater understanding of changes in cognitive function during preadolescence. The ANT is a combination of the cued RT paradigm and the flanker task and is designed to assess the efficiency of the three attentional networks (alerting, orienting, executive control), each of which have been related to distinct brain structures through imaging research.

Research using the ANT with children has indicated that between 6 and 10 yr of age, neither the alerting nor the orienting networks exhibited significant change, suggesting that these networks mature earlier during childhood. However, the interference network showed improvement in task performance between ages 6 and 7, but little change thereafter (25), implicating the ACC and lateral PFC as structures that continue to develop during preadolescent childhood, thus leading to alterations in cognitive function. Further, Bunge and colleagues (3), using fMRI, found left-PFC activation in children compared with right-PFC activation in adults during performance of a modified flanker task that involved interference control, indicating differential cognitive strategy between adults and children, with the latter relying on fluid verbal ability to complete the task. Taken together, these data implicate the PFC and ACC as neural structures that undergo significant change during preadolescent development. As indicated above, aerobic fitness also influences these same structures in older adults and has been associated with improvements in task performance on interference tasks (6). Accordingly, one might speculate that Stroop task performance, which has been shown to activate ACC and PFC during preadolescent development, might similarly be influenced by aerobic fitness in this population and, thus, lead to improved performance. Clearly, future research needs to test this hypothesis, to better determine the nature of the relation of fitness on brain structure and function during tasks requiring the executive control of attention.

An alternate hypothesis regarding the influence of fitness on Stroop task performance may be garnered from the work of Kail (18,19), who has proposed that developmental changes in cognition are related to processing speed. That is, Kail (18,19) suggests that because distinct speeded processes develop at the same rate, a common (i.e., global) mechanism may be responsible for changes in cognitive function during development. Further, this global factor would change systematically throughout development and would not be selective to individual cognitive tasks. Support for the processing speed hypothesis stems from a meta-analytic review of 72 studies comparing adults and children, which indicates that the RT of children and adolescents was longer than the RT of adults, and that, as children aged, their RT became exponentially shorter across a variety of cognitive and motor tasks (18). The current results corroborate Kail's (18,19) findings in that both age and fitness were independently related to better performance across the three Stroop task conditions. Accordingly, despite the above discussion linking specific cognitive functions to specific brain structures, consideration for other mechanisms that have a general influence on processing speed remain. How fitness relates to the underlying mechanisms mediating processing speed is unknown, but it should continue to be examined in future research.

Several limitations of this research warrant mention. First, because this study used a cross-sectional design, the differences observed between high- and low-fit children may be attributable to another factor, such as motivation, or a

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combination of factors that were not measured herein. Although several other variables that have been found to relate to fitness or cognition were collected (e.g., IQ, SES, BMI), there is still the possibility that a selection bias occurred. Future research should include randomized control interventions to better establish a direct relationship between aerobic fitness and interference control in children. Further, the current study used a field test of aerobic capacity rather than an objective measure of aerobic fitness (e.g., $\dot{V}O_{2max}$). However, in 70% of individuals who were also tested using a $\dot{V}O_{2max}$ test, the PACER test accurately classified their fitness level (30). Thus, future research should also attempt to quantify aerobic capacity using $\dot{V}O_{2max}$ measures. Finally, it is possible that the relation between fitness and Stroop task performance observed herein was mediated by reading ability, despite the precautions taken to ensure that all children were able to read at grade level. Future research should consider using a nonreading version of the Stroop task to eliminate this possibility.

In conclusion, these findings add to the growing literature base indicating a positive relation between fitness and cognition in children. Specifically, fitness was generally associated with better performance across the three conditions (word, color, incongruent color–word) of the Stroop color–word task, which varied in their executive control requirements. Future research should be conducted to investigate the general versus selective relationship between fitness and cognition in children, to better understand the mechanisms underlying how fitness influences cognition and why this influence may differ across the human lifespan.

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