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Aerobic Fitness, Executive Control, and Emotion Regulation
in Preadolescent Children

Mark A. Lott

A dissertation submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy

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ABSTRACT

Aerobic Fitness, Executive Control, and Emotion Regulation in Preadolescent Children

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The present study evaluated direct and indirect associations between aerobic fitness, executive control, and emotion regulation among a sample of children aged 8-12 years. To evaluate these associations, the study employed a cross-sectional design and full-information maximum likelihood (FIML) structural equation modeling. Although the hypothesized factor analytic model failed to converge, an alternative exploratory model allowed for the evaluation of associations between primary study variables. Results supported a moderate direct association between childhood aerobic fitness and executive control, a strong direct negative association between executive control and emotion regulation, and a moderate indirect association between aerobic fitness and emotion regulation through executive control. These findings provide preliminary evidence that executive control functions as a mediator between aerobic fitness and emotion regulation and may help explain the means by which aerobic exercise exerts its influence on emotional wellbeing among preadolescent children.

Keywords: aerobic fitness, executive control, emotion regulation, structural equation modeling

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Aerobic Fitness, Executive Control, and Emotion Regulation in Preadolescent Children

The effects of aerobic exercise on emotional wellbeing are both preventive and curative. A growing consensus throughout the literature suggests that aerobic exercise produces significant improvements in overall mood and substantial reductions in symptoms of depression and anxiety, independent of age, gender, or medical condition (U.S. Department of Health and Human Services, 2008). Individuals who regularly engage in aerobic exercise experience lower levels of depression, anxiety, insomnia, psychosocial stress, and fatigue, as well as higher levels of self-esteem and improved sleep quality compared to their less aerobically active peers (U.S. Department of Health and Human Services, 2008). Across randomized controlled trials among individuals with mood and anxiety disorders, aerobic exercise has generally been comparable to gold-standard pharmaceutical and psychological treatments in reducing mood and anxiety symptoms (Mead, Morley, Campbell, McMurdo, & Lawlor, 2010; Wipfli, Rethorst, & Landers, 2008). Despite these mental health benefits, an understanding of the underlying mechanisms that account for aerobic exercise's influence on emotional wellbeing remains elusive.

Recent findings from research exploring aerobic fitness-cognition associations among preadolescents could provide additional insight into underlying mechanisms by which aerobic fitness exerts its influence on emotional wellbeing. Converging lines of evidence suggest that aerobic fitness associated with regular participation in aerobic exercise has both general and selective effects on cognitive functioning, with a small effect for broad cognitive and academic abilities ($g = .32 - .48$; Colcombe & Kramer, 2003; Sibley & Etnier, 2003) and moderate effects for executive control among adult populations ($g = .68$; Colcombe & Kramer, 2003; Etnier & Chang, 2010). Although there has been relatively less research exploring the relationship

between aerobic fitness and executive abilities among children, cross-sectional and experimental studies over the past decade have provided sufficient evidence to suggest that aerobic fitness influences the development of specific executive control abilities during preadolescence (Best, 2010; Etnier & Chang, 2010; Hillman, Kamijo, & Scudder, 2011). These same differences in executive control abilities and their latent neural circuitry found among preadolescents may also support enhanced emotion regulatory abilities, and may at least partially account for the general mood benefits that result from regular aerobic exercise among children.

In order to elucidate how aerobic fitness may influence the development of emotion regulation through changes in executive control abilities, this literature review will (a) provide a working definition of executive control, emotion, and emotion regulation, (b) explicate the relationship between executive control and emotion regulation from a developmental perspective, (c) delineate the shared neural network of executive control and emotion regulation, (d) describe how regular aerobic exercise may influence this shared network in relationship to the greater literature, (e) propose an executive control model of emotion regulation, and finally, (f) present an initial effort to test this model with associated hypotheses, methods, and results.

Defining Executive Control and Emotion Regulation

Executive control. Executive control, also referred to as “effortful control,” or “executive function,” encompasses multiple distinct higher-order cognitive abilities that allow an individual to adjust and control thought and action to achieve one’s goals in the context of changing environmental demands. These abilities are generally associated with frontal lobe structure and function (Diamond, 2002). As a general construct, executive control can be defined as “the ability to voluntarily regulate behavior and attention, as seen in the inhibition of a dominant response and activation of a subdominant response” (Rothbart, Sheese, Rueda, &

Posner, 2011, p. 207). It includes the ability to monitor and update underlying processes, consciously and willfully direct and shift attentional resources, inhibit pre-potent responses, and activate a subdominant response in order to meet higher-order goals (Eisenberg, Smith, & Spinrad, 2011). Although there remains some debate surrounding which specific cognitive functions comprise executive control, three interrelated primary executive processes have been identified within both pediatric and adult populations, including (a) inhibitory control, (b) mental flexibility or set shifting, and (c) monitoring and updating of working memory representations (Diamond, 2006; Miyake et al., 2000).

Emotion and emotion regulation. Russell and Barrett (1999, p. 805) argue that “the structure of emotion concerns an essential first step in any scientific treatment of emotion: its description and assessment.” In other words, semantic clarity must precede the scientific measurement and conceptual validity of any emotional phenomena. This implication is not limited to measurement of the primitive building blocks of emotion or prototypical emotional events, but also broadly applies to more complex emotional processes such as emotion regulation. Therefore, any conceptualization of emotion regulation is dependent on an underlying definition of emotion or “what is being regulated” (Gross & Thompson, 2007, p. 4). Therefore, we attempt to provide a working definition of emotion prior to defining emotion regulation.

Over a century of research on emotion has made it clear that there remains considerable disagreement in the literature as to what constitutes an emotion. Consistent with past disagreements about the definition of emotion, contemporary definitions disagree across multiple key points, such as whether emotions are categorically or dimensionally defined, and whether the processes of emotions are simple, circumplex, or hierarchical (Russell & Barrett, 1999). In an

attempt to avoid this conceptual quagmire and avert an overly reductive definition of emotion, we adopt Gross and Thompson's (2007) prototypical definition of emotion, which rejects classical conceptions of emotion that require "necessary" and "sufficient" conditions to qualify as an emotion, but rather rely on common core features of emotion to suggest an increased probability of the presence of emotion in any given situation. Under this probabilistic and constructivist framework, emotion is defined as a meaning-bound, non-obligatory, multisystem process that involves "loosely coupled changes in subjective experience, behavior, and central and peripheral physiology" (Gross & Thomson, 2007, p. 4).

Closely related to this definition of emotion, emotion regulation is a broad construct that encompasses "processes responsible for monitoring, evaluating, and modifying emotional reactions" (Thompson, 1994, p. 27-28), including initiating or inhibiting changes in the subjective experience, physiology, and/or behavioral expression of an emotional response, dependant on one's goals in a given context (Eisenberg, Hofer, & Vaughan, 2007). Emotion regulation not only involves the modification of emotional response tendencies and is thereby integrally related to behavioral observation of emotion, but also the appraisal and awareness of underlying emotional experience.

Conceptually, emotion regulation has generally been considered distinct from emotion generation in that it involves the subsequent, top-down modification of an acute state of emotional processing in response to specific, time-bound, contextual changes. However, recent conceptual definitions challenge traditional views that hold emotion generation and regulation as ontologically separate. In contrast, they provide an alternate conceptualization in which the generation and regulation of emotion interdependently and concurrently function in concert and are ever active in some degree, and thereby, are non-dissociable (Campos, Frankel, & Camras,

2004). Similarly, empirical evidence suggests a more nuanced view in which emotion regulation and emotional wellbeing remain relatively distinct, yet reciprocally inter-related, such that acute regulation of emotion influences longitudinal mood and wellbeing, and general mood state and wellbeing influence acute regulation of emotion (Gross & John, 2003; Kring & Sloan, 2009; Larsen, 2000).

The conceptual definition of emotion regulation overlaps with definitions of executive control, and there remains considerable debate in the literature as to whether these constructs are actually distinct or fundamentally equivalent (Carlson & Wang, 2007; Zelazo & Cunningham, 2007). In acknowledging this conceptual overlap, we propose an exploration of the relationship between executive control and emotion regulation as it relates to aerobic fitness with an assumption that these constructs are distinct.

The Relationship Between Executive Control and Emotion Regulation

The relationship between executive control and emotion regulation has been supported by two broad complimentary lines of evidence that help elucidate how aerobic exercise may influence emotional processes through changes in executive control. These include a developmental perspective from behavioral and temperament research, and a cognitive neuroscience perspective exploring the structural and functional circuitry of emotion regulation and executive control.

Development. Within the first years of life and then continuing until early adulthood, there is a gradual, protracted growth in the functional skills and latent neural circuitry associated with executive control (Best & Miller, 2010; Diamond, 2006). The prolonged development of executive abilities is paralleled by and directly associated with a similar gradual increase in emotion regulatory capacities (Rothbart & Sheese, 2007; Thompson & Goodman, 2010). Both

executive abilities and emotion regulation are skills highly associated with child and adolescent academic success, psychosocial adjustment, and moral development (Castelli, Hillman, Buck, & Erwin, 2007; Eisenberg et al., 2011; Kochanska, Murray, & Harlan, 2000).

Empirical evidence also suggests that these constructs are closely interrelated. Specifically, attentional control and response inhibition, two primary executive control abilities, have been identified as essential to the regulation of emotion throughout childhood, adolescence, and early adulthood (Henderson & Fox, 2007; Posner & Rothbart, 1998; Rothbart & Bates, 1998; Taylor & Amir, 2010). Rothbart, Ahadi, Hershey, and Fisher (2001) have hypothesized that these two executive abilities (attentional and inhibitory control) represent a common constitutional temperament factor called “effortful control” (also see Rothbart & Rueda, 2005). Attentional control, also known as “executive attention,” involves the ability to shift, maintain, or focus attentional resources (Rueda, Posner, & Rothbart, 2011). A closely related construct, response inhibition, also known as “inhibitory control,” is the ability to inhibit or suppress a dominant thought process or action, thereby permitting the activation of a subdominant response (Carlson & Wang, 2007), and is directly involved in attentional control (Rueda et al., 2011).

By four months of age, infants who display greater control over their attentional faculties also display greater emotional self-regulation as evidenced by less negative affect (Johnson, Posner, & Rothbart, 1991). Among both toddlers and school-aged children, these basic executive control abilities are inversely associated with parent and self-reported negative emotions (Rothbart & Sheese, 2007). Young children who are able to shift their attention during a delay of gratification task demonstrate better regulatory capabilities as adolescents and adults, particularly better emotion regulation (Ayduk et al., 2000; Henderson & Fox, 2007; Mischel, Shoda, & Rodriguez, 1989; Shoda, Mischel, & Peake, 1990). Finally, adolescents and adults

who report greater attentional control also report experiencing fewer negative emotions (Derryberry & Rothbart, 1988; Evans & Rothbart, 2007). Overall, evidence from developmental studies suggests that executive abilities, including inhibitory and attentional control, are closely associated with individual emotional regulation beginning early in infancy and continuing across the lifespan.

Cognitive neuroscience. As further evidence of the close relationship between executive control and emotion regulation, the same neuroanatomical areas involved in the executive processes of attentional control and response inhibition have also been implicated in emotion regulation, including the anterior cingulate cortex (Bush, Luu, & Posner, 2000; Luu, Collins, & Tucker, 2000; Shackman et al., 2011) the prefrontal cortices (Damasio, 1994; Zelazo & Cunningham, 2007), and the basal ganglia (Brown, Schneider, & Lidsky, 1997; Posner & Rothbart, 1998), structures directly associated with aerobic fitness. These structures create a broad regulatory network that has been shown to support both cognitive and emotional processes (Goldsmith, Pollak, and, Davidson, 2008; Oschner & Gross, 2005), and the activation of this network is directly associated with behavioral measures of executive control (Rueda et al., 2011). Furthermore, these same neural structures are involved in the regulation of emotional processes as evidenced by corresponding variations in the amygdala and insula (Oschner & Gross, 2008) and differences in parental reports of self-regulation and emotional control (Posner & Rothbart, 1998).

Associations Between Executive Control and Aerobic Fitness

Intriguingly, these same executive abilities, attention and inhibitory control, are directly associated with preadolescent aerobic fitness (Buck, Hillman, & Castelli, 2008; Hillman, Buck, Themanson, Pontifex, & Castelli, 2009), suggesting that regular aerobic exercise may not only

contribute to the development of executive abilities (Best, 2010), but may increase emotion regulatory capacities through changes to executive control processes and associated neural circuitry in preadolescent children. In an initial cross-sectional study exploring the relationship of executive control to aerobic fitness among a group ($N = 74$) of 7 to 12 year-olds, Buck and colleagues (2008) found that greater aerobic fitness was associated with better Stroop performance, a measure of inhibitory control as well as selective attention. Multiple follow-up cross-sectional studies using a modified flanker task, another cognitive measure of attentional and inhibitory control, in combination with a variety of neuroimaging techniques demonstrated greater attentional control and response inhibition among more aerobically fit preadolescents compared to their lesser fit peers (Chaddock et al., 2012; Hillman et al., 2009; Pontifex et al., 2011; Voss et al., 2011). Finally, in a randomized controlled trial of overweight children ages 7 to 11 years old, Davis and colleagues (2011) found that differential changes in aerobic activity levels resulted in dose-response improvements in executive control and academic achievement (also see Davis et al., 2007).

Neuroimaging results from many of these same studies, using electroencephalography (EEG), magnetic resonance imaging (MRI), and functional magnetic resonance imaging (fMRI), further substantiate an aerobic fitness - executive control association. Taken together, these studies have demonstrated that aerobic fitness level among preadolescents is associated with functional and structural differences specific to brain structures associated with the executive processes of attentional control and response inhibition (for a review, see Chaddock et al., 2011; Hillman et al., 2011), including structural differences in the basal ganglia (Chaddock et al., 2010), and functional differences in the anterior cingulate and prefrontal cortices (Chaddock et al., 2012; Hillman et al., 2009; Voss et al., 2011). A preliminary pilot trial among preadolescents

supports a causal link between changes in aerobic capacity and functional differences in prefrontal activation (Davis et al., 2011). Specifically, Davis and colleagues (2011) used a small subgroup of overweight preadolescents ($N = 20$) within a randomized control trial to evaluate regional brain activation during a task of executive control. Results indicated that, compared to controls, individuals in the exercise condition exhibited increased bilateral prefrontal activity and decreased bilateral posterior parietal cortex activity (Davis et al., 2011), indicating that exercise-induced changes to executive control are paralleled by functional changes to the executive circuitry. These exercise-induced differences in executive neural circuitry not only appear to translate into greater executive control but may also contribute to increases in emotion regulation, which may account for the general mood benefits that result from regular aerobic exercise.

Although causal evidence connecting aerobic fitness and executive control remains somewhat limited among preadolescent populations, a more advanced adult and animal literature supports causal connections between aerobic activity and executive control and its latent neural circuitry (Colcombe et al., 2006; Weinstein et al., 2011). In conjunction with the few extant pediatric experimental and cross-sectional studies on this topic, this evidence justifies additional research among pediatric populations. Furthermore, this literature provides sufficient support for a potential association between preadolescent aerobic fitness and emotion regulation through changes to executive control and underlying neural circuitry.

Executive Control and Other Proposed Mechanisms of the Aerobic Exercise - Emotional Wellbeing Association

Executive control as a mechanism of action of emotion regulation compliments both psychological and physiological theory and empirical evidence within the greater exercise and

emotional wellbeing literature. While a comprehensive review of the literature is beyond the scope of this paper, a brief overview will attempt to demonstrate how an executive control and emotion regulation relationship relates to the broader aerobic fitness literature, with an emphasis on a neuroendocrinologic explanation and stress-reduction theories of the exercise-emotional wellbeing literature.

Neuroendocrinologic explanations. Aerobic exercise upregulates catecholaminergic activity in the brain, including serotonin, dopamine, and norepinephrine (McMorris, 2009), which have been shown to selectively modulate the same executive networks of the brain involved in both executive control and emotional regulation (Holroyd & Coles, 2002; Rueda et al., 2011). Significant evidence further suggests that executive networks are also selectively influenced by exercise-induced upregulation of specific neurotrophic factors (i.e., BDNF, IGF, VEGF; see Cotman, Berchtold, & Christie, 2007) and associated neurogenesis (Churchill, 2002), angiogenesis (Cotman et al., 2007), and increased cerebral blood volume (Ekkekakis, 2009) that likely account for the structural and functional differences, enhanced executive control, and improved emotional wellbeing found among more aerobically fit individuals compared to less aerobically fit controls.

Stress reduction theories. These structural and functional adaptations in the executive circuitry may equally relate to stress reduction theories of exercise and emotional wellbeing, which posit that routine aerobic exercise results in adaptation to HPA axis activity, contributing to a generalized reduction in stress and emotional responsivity to psychosocial stressors (see Sinyor, Schwartz, Peronnet, Brisson, & Seraganian, 1983). Research demonstrates that the prefrontal cortex (PFC), a brain structure closely associated with executive control, has a dynamic regulatory relationship with the hypothalamic–pituitary–adrenal (HPA) axis, such that

alterations in PFC activity modulates HPA responsivity to stressors (Diorio, Viau, & Meaney, 1993; Sullivan & Gratton, 2002). This suggests that structural and functional changes to the executive circuitry through aerobic exercise may alter individuals' stress responsivity to psychosocial stressors, and thereby may further contribute to enhanced emotion regulation (see Stranahan, Lee, & Mattson, 2008). In summary, exercise-induced changes in neuroendocrinologic and HPA dynamics provide additional support for executive control as a mediating factor in the relationship between aerobic fitness and emotion regulation.

Current Study

Consistent with previous literature, we hypothesize that the same exercise-related processes that produce changes in executive control, specifically enhanced attentional control and response inhibition, will contribute to better emotion regulation among preadolescents. We propose that the observed differences in emotional wellbeing resulting from regular aerobic exercise can be accounted for by differences in executive control and emotion regulation, and that differences in emotion regulation as a product of aerobic fitness will be mediated by executive control (See Figure 1). Executive control theories of emotion regulation are not novel to the cognitive and developmental literature (see Barkley, 1997; Bishop, Duncan, Brett, & Lawrence, 2004; Oschner & Gross, 2005; Posner & Rothbart, 1998; Zelazo & Cunningham, 2007); however, this hypothesis has never been applied to the pediatric aerobic fitness literature.

Exploring the association between aerobic fitness and executive control as they relate to emotion regulation may contribute to a broader understanding of the mechanisms that account for the influence of aerobic exercise on emotional wellbeing. Similarly, such a theory would support a novel and alternative approach to encouraging emotion regulation within a pediatric

population, as children may find aerobic activity more appealing than standard psychotherapy and exercise may have fewer side-effects and complications than pharmacologic treatments.

In an initial attempt to examine an executive control theory of aerobic fitness and emotion regulation within a pediatric sample, the present study employed a cross-sectional design and structural equation modeling (SEM) to evaluate associations between aerobic fitness, executive control, and emotion regulation among a sample of preadolescent children.

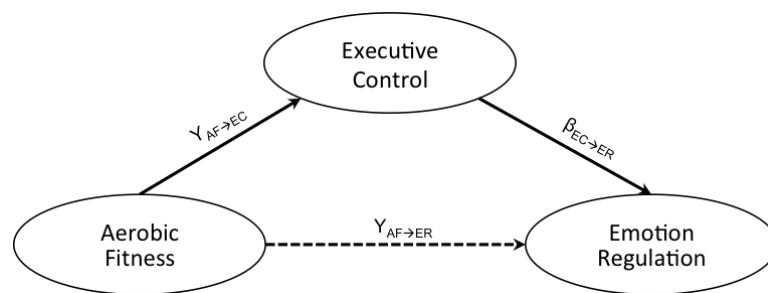


Figure 1. Proposed structural model.

Hypotheses. Consistent with previously cited literature, we hypothesized that aerobic fitness among preadolescents would be positively associated with executive control, such that greater aerobic fitness would be associated with greater executive control. We further hypothesized that a positive association would exist between executive control and emotion regulation, such that greater executive control would be associated with better emotion regulation. Finally, we posited that a positive association between aerobic fitness and emotion regulation would be mediated, or accounted for, by executive control.

Method

Participants

Three-hundred twenty-six children and their participating parent/guardian were recruited through a brief announcement and a handout provided to children during physical education classes at five public elementary schools within the Provo, UT School District. Children with a

neuropsychiatric diagnosis (i.e., ADHD, autism, epilepsy, etc.) and/or who were using medications that influence central nervous system functioning ($N = 48$) were allowed to participate. However, consistent with previous studies, these children were excluded from final analysis due to interaction effects encountered in preliminary statistical analysis. Therefore, two-hundred seventy-eight participants (133 Males) between 8 and 12 years-old (mean age = 9.73, $SD = .901$) were included in the final analyses. Parent-child dyads were eligible to participate if: (a) the participating child was between the ages of 8 – 12 years, (b) the participating child had no serious health related concerns that would preclude them from participating in physically rigorous activity (assessed using the Physical Activity Readiness Questionnaire; Warburton, Jamnik, Bredin, & Gledhill, 2010), (c) one parent/guardian participated in the study and provided informed consent, (d) the child provided written assent, and (e) the parent/guardian and child spoke English. See Table 1 for a summary of demographic and anthropometric characteristics for children who were included in the final analysis.

Table 1

Summary of Demographic and Anthropometric Data, by Grade

| | All Participants | 3 rd Grade | 4 th Grade | 5 th Grade |
|------------------------------------|------------------|-----------------------|-----------------------|-----------------------|
| <i>N</i> | 278 (133 Males) | 96 (50 Males) | 84 (32 Males) | 97 (50 Males) |
| Mean Age (<i>SD</i>) | 9.73 (.90) | 8.80 (.41) | 9.64 (.39) | 10.71 (.40) |
| BMI (<i>SD</i>) | 17.35 (2.47) | 17.02 (2.24) | 17.08 (2.55) | 17.91 (2.57) |
| Race (% of Total) | | | | |
| Caucasian | 227 (81.65%) | 75 (78.13%) | 72 (85.71%) | 79 (81.44%) |
| Hispanic | 23 (8.27%) | 10 (10.42%) | 5 (5.95%) | 8 (8.25%) |
| Pacific Islander | 5 (1.80%) | 2 (2.08%) | 1 (1.19%) | 2 (2.06%) |
| Asian American | 1 (0.36%) | - | - | 1 (1.03%) |
| Multiracial & Other | 22 (7.91%) | 9 (9.38%) | 6 (7.14%) | 7 (7.22%) |
| Monthly Gross Income (<i>SD</i>) | 6.32 (3.12) | 6.34 (3.17) | 6.16 (3.19) | 6.47 (3.25) |

Note. Monthly Gross Income was measured in \$1,000 increments such that 1 = \$0 - 999, 2 = \$1,000– 1,999, 3 = \$2,000 – 2,999, 4 = \$3,000 - \$3,999, 5 = \$4,000 – 4,999, 6 = \$5,000 – 5,999, 7 = \$6,000 – 6,999, 8 = \$7,000 – 7,999, 9 = \$8,000 – 8,999, 10 = 9,000 – 9,999, 11 = 10,000 +.

Measures

Aerobic fitness. Participant's aerobic fitness was evaluated using the Fitnessgram's Progressive Aerobic Cardiovascular Endurance Run (PACER; Welk & Meredith, 2008). The PACER is a widely used, standardized field measure of maximal oxygen consumption (VO_2Max), providing a generally reliable and valid estimate of aerobic capacity for children and adolescents (Mahar et al., 1997; Welk & Meredith, 2008). Estimates of PACER test-retest reliability for preadolescent children range from .84 to .90 and estimates of concurrent validity between gold standard treadmill tests of VO_2Max and PACER estimations range between .54 to .90 (Welk & Meredith, 2008), suggesting that the PACER has generally high test-retest reliability and moderate to high concurrent validity with a field test of aerobic capacity. The PACER consists of a 20-meter shuttle run with one-minute incremental increases in speed over the course of the test until a participant fails to complete two consecutive laps at the required pace. The total number of completed laps was used to calculate a VO_2Max estimate for each participant using Mahar et al.'s (2011) quadratic model of VO_2Max . Mahar's Model of aerobic fitness has an estimated concurrent validity of .69 to .73 (*SE* of the Estimate = 6.39 – 6.91) when compared to gold-standard treadmill tests of VO_2Max , slightly improving upon the predictive validity of previous models (Mahar, Guerieri, Hanna, & Kemble, 2011).

During the PACER, heart rate measurements were recorded using Polar FT2 portable electrocardiogram (ECG) based monitors, including sub-maximal heart rate ($HR_{Sub-max}$; Goran, Fields, Hunter, Herd, & Weinsner, 2000) and heart rate recovery (HRR; Baraldi, Cooper, Zanconato, & Armon, 1991). $HR_{Sub-max}$ is a non-invasive measure of aerobic capacity and cardiorespiratory adjustment to exercise recorded at one minute into an exercise protocol at a pace below VO_2Max . Although reliability estimates have not been established, sub-maximal

heart rate has often been used to evaluate individual aerobic capacity and has been shown to distinguish aerobically fit from less aerobically fit individuals (Goran et al., 2000; Jones & Carter, 2000; Spina, 1999).

HRR is a non-invasive measure of cardiorespiratory adjustment following exercise with high test-retest reliability estimates ($ICC = 0.70$, $SEM = 10.1s$; Buchheit et al., 2008) and is calculated by taking the absolute difference between HR_{Max} during exercise and the heart rate at one minute post-exercise during passive recovery (Buchheit, Papelier, Laursen, & Ahmaidi, 2007; Ohuchi et al., 2000; Shetler et al., 2001). Although it is closely related to level of aerobic capacity in both children and adults (i.e., higher aerobic capacity (VO_2Max) is associated with faster post-exercise recovery; see Darr, Bassett, Morgan, & Thomas, 1988), HRR provides a distinct indicator of aerobic fitness in addition to measures of VO_2Max , as it represent post-exercise parasympathetic reactivation during recovery (Baraldi et al., 1991; Hagberg, Hickson, Ehsani, & Holloszy, 1980; Ohuchi et al., 2000).

In addition to these heart rate measures, Body Mass Index Percentile for age and sex (BMI%) was calculated for each participant. BMI% is a moderately reliable indicator of body fat percentage (Mei et al., 2002), and has a moderate inverse relationship with measures of cardiovascular fitness, such that individuals with a higher BMI% are less likely to be aerobically fit (Chen, Unnithan, Kennedy, & Yeh, 2008; Joshi, Bryan, & Howat, 2012). BMI was calculated using a standardized formula ($BMI = [weight (kg)]/[height (m)]^2$; Keys et al., 1972), and was then converted to an age- and sex-adjusted percentile score using the Center for Disease Control and Prevention (CDC) BMI percentile calculator (CDC, 2010).

Executive control. Consistent with the reviewed literature, executive control was evaluated using the Stroop Test (Golden version for children ages 5 – 14; Golden, Freshwater, &

Golden, 2003) and Rothbart's parent-report Early Adolescent Temperament Questionnaire-Revised (EATQ-R; Ellis & Rothbart, 2001). The Stroop Test and the EATQ-R were selected in order to strengthen the internal and ecological validity of the executive control construct by including a direct behavioral measure and a well-validated parent-report measure of attentional control and response inhibition.

The Stroop Test is a standardized behavioral measure of response inhibition and attentional control, consisting of the following three 45-second conditions: *Word-condition*, *Color condition*, and *Incongruent Color-Word condition* (Strauss, Sherman, & Spreen, 2006). First, during the Word condition, participants were presented with a sheet of 100 color words (i.e., red, green, blue) printed in black ink and were required to read aloud the color words down each column as quickly as they could within the time limit. During the Color condition, participants were presented with a sheet of 100 XXXXX's printed in red, green, or blue ink and were required to name aloud the ink color of the XXXXX's down each column as quickly as they could within the time limit. Finally, during the Incongruent Color-Word condition, participants were presented with a sheet of 100 words from the first page printed in incongruent colors from the second page (i.e., the word "red" printed in green ink or the word "blue" printed in red ink). These three subtests produced three scores based on the number of items answered correctly within the time limit, and these three were combined to produce a composite interference score (Chafetz & Matthews, 2004). In theory, the Stroop Test measures an individual's ability to resolve Stroop incongruency by inhibiting their prepotent response to read the word, and instead activating a subdominant response to name the ink color. The measures modestly correlate ($r = .31 - .56$) with other measures of attentional control and response

inhibition, suggesting moderate concurrent validity, and test-retest reliability has been reported between .73 - .86 for the three different subtests (Strauss et al., 2006).

The EATQ-R is a 103-item parent-report questionnaire that measures multiple aspects of a child's (age 9 – 16) temperament and social-emotional functioning including effortful control, surgency, affiliativeness, and negative affect (Ellis & Rothbart, 2001; Putnam, Ellis, & Rothbart, 2001). The 26-items that constitute the effortful control scale were used as a measure of executive control. Effortful control is made-up of three sub-factors which were independently added to the statistical model, including: *inhibitory control* (11 items, $\alpha = .77$; the capacity to suppress inappropriate responses), *attention* (6 items, $\alpha = .65$; the capacity to focus and shift attention), and *activation control* (7 items, $\alpha = .73$; the capacity to perform an action when there is a strong tendency to avoid it); (Capaldi & Rothbart, 1992; Ellis & Rothbart, 2001). Parent report measures of effortful control have been strongly associated with laboratory measures of conflict resolution similar to the Stroop Test and with anterior cingulate activity (Posner & Rothbart, 1998). An evaluation of internal reliability coefficient for executive control scales for the present study suggests that most scales fell above the threshold for good internal consistency ($\alpha \geq 0.70$; Bland & Altman, 1997). However, the internal consistency for the EATQ-R Inhibitory Control scale fell well below previous estimates ($\alpha = .51$).

Emotion regulation. Preadolescent emotion regulation was evaluated using the Emotion Regulation Checklist (ERC; Shields & Cicchetti, 1997) and appropriate subscales from the EATQ-R (Ellis & Rothbart, 2001). The ERC is a 24-item parent-report measure of child emotion regulation (Shields & Cicchetti, 1997). Parents were asked to rate how characteristic each item is of their child by using a 4-point Likert scale (1 = Rarely/Never, 2 = Sometimes, 3 = Often, 4 = Almost Always). Sample items include “Is easily frustrated”, “Is prone to angry

outbursts”, “Is prone to disruptive outbursts of energy and exuberance”, “can modulate excitement”, and “Is whiny or clingy with adults.” The ERC has a high composite internal consistency ($\alpha = .89$) and was designed to target processes central to emotion regulation, including affective lability, intensity, valence, flexibility, and situational appropriateness of emotional expression (Shields & Cicchetti, 1997). The measure was initially validated using a sample of 513 children, ages 6 – 12 years old, and a factor-analysis identified two main factors of *emotion regulation* ($\alpha = .83$) and *lability/negativity* ($\alpha = .96$; Shields & Cicchetti, 1997).

In addition to the two factors from the ERC, three EATQ parent report sub-factors (17-items) that constitute the negative affect scale were used as a measure of emotion regulation in the present study. The three negative affect sub-scales derived through previous factor analyses include: *aggression* (7 items, $\alpha = .71$; aggressive behavior marked by hostile reactivity), *depressive mood* (5 items, $\alpha = .76$; negative affect related to loss of enjoyment and depressed mood), and *frustration* (6 items, $\alpha = .74$; negative affect related to goal interruption or impediment; Capaldi & Rothbart, 1992; Ellis & Rothbart, 2001). The internal reliability coefficients for the emotion regulation scales for this study were generally above the threshold for good internal consistency ($\alpha \geq 0.70$; Bland & Altman, 1997). However, reliability estimates for the ERC Emotion Regulation scale fell below previous estimates ($\alpha = .65$).

Covariates. Because previous research suggests that age, gender, and familial socioeconomic status (SES) may be associated with primary study variables (Diamond, 2006; Hackman & Farah, 2009; Thompson & Goodman, 2010), these were evaluated and included as covariates in study analysis. In accordance with past research demonstrating that SES is multidimensional and best represented by multiple indicators (Braveman et al., 2005), monthly gross income and parent education levels were independently used as measures of family SES.

Procedures

Approval was obtained from the Brigham Young University Institutional Review Board, from the Provo School District, and from each of the five participating elementary schools. Prior to each child's participation in the study, a parent or legal guardian provided written informed consent. The parent who provided informed consent then completed a basic demographic assessment, a brief child health history, the Physical Activity Readiness Questionnaire (PAR-Q; Thomas, Reading, & Shephard, 1992), the EATQ-R, and the ERC through an online survey using online survey software (Qualtrics, Provo, UT). The PAR-Q is a 7-item screening measure that was used to identify potential contraindications to engaging in physically rigorous activity (Warburton et al., 2010); children whose parents endorsed any of the items on the PAR-Q were not allowed to participate. After parents completed the online survey, each child was evaluated on a single occasion at their elementary school.

During the testing session, each child was given measures in a standardized order in order to eliminate acute effects of exercise on cognitive measures. First, each child was administered the Stroop Test by a trained experimenter according to a standardized protocol. Second, prior to beginning aerobic fitness testing, each child's height and weight was measured, he/she was equipped with a Polar FT2 Heart Rate Monitor, and they were introduced to the PACER. Each child was allowed to listen to audio-recorded instructions for the PACER, listen to the actual PACER audio recording, and then participate in at least one practice trial prior to examination according to the standardized protocol. Finally, each child was administered the PACER in groups of two to five participants while heart rate was measured. Trained experimenters recorded laps for each child, noting failures to complete each lap in the required time and recording sub-maximal heart rate at 1 minute into the aerobic fitness tasks. As indicated

previously, after each child failed to complete two laps at the required pace, the PACER was completed, and the experimenter recorded the child's total number of laps completed, maximum heart rate (HR_{Max}), and heart rate at 1 minute post-exercise during passive recovery.

Data Analytic Procedure

Structural equation modeling. Structural equation modeling (SEM) was used to evaluate structural and measurement models (see Figure 2) using Mplus 7.0 (Muthén & Muthén, 2012). SEM provides a dynamic and powerful statistical approach that allows for the evaluation of both measurement and structural models, and is often described as an integration and extension of multiple regression (MR) and confirmatory factor analysis (CFA; Hoyle, 2012). Although not dissimilar to other multivariate statistical methods, SEM confers several key advantages over these methods. First, SEM allows for the concurrent evaluation of both (a) the relationship between observed indicators and latent variables (measurement model) and (b) the relationship between latent variables within the same model (structural model). Second, SEM allows for the simultaneous evaluation of each latent variable as both a predictor and an outcome variable; which makes this statistical approach ideal for the evaluation of mediation. Third, because structural and measurement models were evaluated concurrently within the same overall model, error and disturbances are controlled for and partitioned systematically across observed and latent variables. Finally, SEM allows for control of measurement dependencies in the model due to cluster-level effects, thereby providing more precise estimates of model fit and standard errors.

SEM was used to estimate model parameters, confirm model fit, generate alternative models, and evaluate the hypothesized direct and indirect associations between latent constructs. The analysis followed a general SEM framework, involving the following steps: (a) model

specification, (b) parameter estimation, (c) evaluation of model fit, and (d) interpretation and comparison of model parameters (Hoyle, 2012).

Model specification. Consistent with guidelines for conducting statistical analyses using SEM (Brown, 2006), the analysis began with a confirmatory factor analysis (CFA) that included measures of interest. Subscales from the EATQ-R and ERC parent-report measure were loaded onto their respective latent constructs consistent with previous validation studies (Ellis & Rothbart, 2001; Shields & Cicchetti, 1997). Specifically, five manifest indicators (represented by previously established EATQ-R and ERC scales) were loaded onto the latent construct of emotion regulation (*EATQ-R Frustration* , *EATQ-R Depressive Mood* , *EATQ-R Aggression* , *ERC Lability/Negativity* , and *ERC Emotion Regulation*) and four manifest indicators were loaded onto the latent construct of executive control (*EATQ-R Attention* , *EATQ-R Activation Control* , *EATQ-R Inhibitory Control* , and the Stroop Interference Score). The PACER, HR_{submax}, HRR, and BMI% represented independent manifest indicators of the aerobic fitness latent construct. Although the PACER, HR_{submax}, HRR, and BMI% have independently been shown to relate to the latent construct of aerobic fitness, these manifest indicators have not previously been shown to load on a common latent construct through factor analysis. Therefore, the present factor analysis allowed for an initial evaluation of the factor structure of our proposed aerobic fitness latent construct. The confirmatory factor analysis model is displayed graphically in Figure 2.

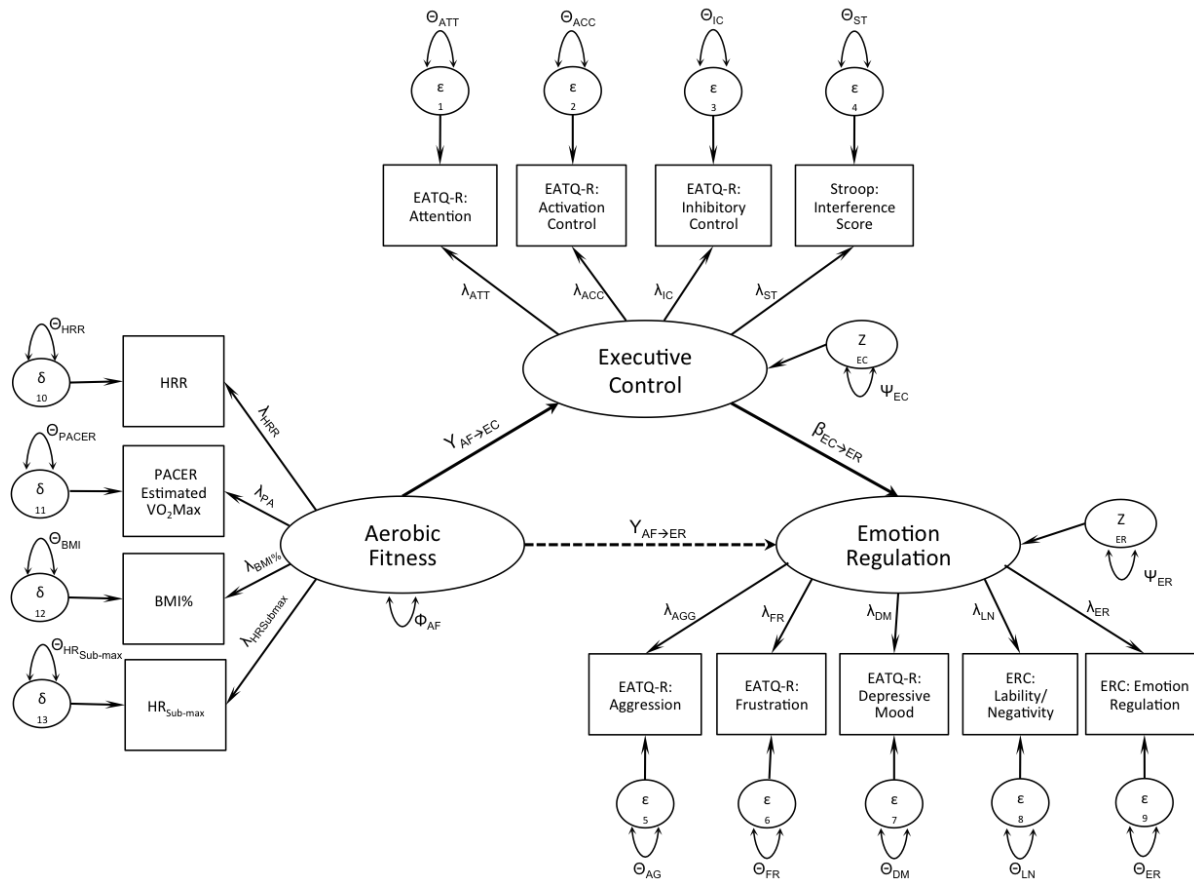


Figure 2. Proposed structural & measurement model. BMI% = Body Mass Index Percentile; EATQ-R= Early Adolescent Temperament Questionnaire - Revised; ERC = Emotion Regulation Checklist; HRR = Heart Rate Recovery; HR_{Sub-Max} = Sub-maximal Heart Rate; PACER Estimated VO₂Max = Progressive Aerobic Cardiovascular Endurance Run (Mahar et al., 2011); Stroop: Interference Score (Chafetz & Matthews, 2004)). Note. Covariates of age, gender, and familial socioeconomic status are not displayed.

Model estimation. Model parameters were evaluated using full-information maximum likelihood (FIML; Lei & Wu, 2012) estimation with robust standard errors (Asparouhov & Muthén, 2005). FIML estimation with robust standard errors has been shown to provide relatively unbiased parameter estimates when models are correctly specified, allows for accurate handling of missing data when data is missing at random (MAR; Enders & Bandalos, 2001; Shafer & Graham, 2002), and is relatively robust to non-normality and non-independence of observations (Lei & Wu, 2012; Muthén & Muthén, 2012).

Evaluation of model fit. Model fit was evaluated for all CFA and SEM analysis and acceptability of models were determined based on the following three criteria: (a) global goodness of fit measures, (b) localized strain indices, and (c) the size, direction, and statistical significance of the model's parameter estimates (Brown & Moore, 2012).

Global model fit was evaluated using the root mean square error of approximation (RMSEA), the comparative fit index (CFI), and the non-normed fit index (NNFI; also known as the Tucker-Lewis Index (TLI)). In combination, these fit indices provide a relatively accurate estimate of global model fit compared to the often used χ^2 fit index, which is overly sensitive to sample size, resulting in a higher rejection of true models in small samples and a higher acceptance of false models in large samples (West, Taylor, & Wu, 2012). Consistent with Hu and Bentler's (1999) guidelines for an acceptable model fit, model fit estimates close to an $RMSEA \leq .06$, an $NNFI \geq .95$, and $CFI \geq .95$ were used as criteria for good model fit.

Localized model strain was evaluated by an examination of normalized residuals and modification indices (Brown & Moore, 2012). Normalized residuals greater than 1.96 (Muthén & Muthén, 2007) and modification indices greater than 10.0 with a standardized expected parameter change greater than 0.2 (Saris, Satorra, & van der Veld, 2009; Whittaker, 2012) were identified and evaluated. Adjustments to model specification based on localized strain indices were made only when empirically and conceptually justified (Brown & Moore, 2012).

Finally, the size, direction, and statistical significance of factor loadings and standardized factor coefficients were evaluated. Indicators with small ($\lambda < .50$) and/or non-significant ($p > .05$) factor loadings were removed from the model, unless retaining the indicator was deemed to add unique information to the model. Because large standardized inter-factor coefficients may suggest a more parsimonious factor structure, factors with standardized inter-factor coefficients \geq

.80 were respecified by collapsing the associated factors into a single factor, fit indices were recalculated, and single and multi-factorial model solutions were compared using a chi-square difference test.

In order to account for alternative explanations of the observed data, competing nested models were compared using a chi-square difference test adjusted by robust scaling (Brown & Moore, 2012). The best fitting model was selected as a baseline model for evaluating structural associations between latent factors.

Mediation analysis. To test the hypothesis that the relationship between aerobic fitness and emotion regulation was mediated by executive control, a decomposition of effects into direct and indirect effects was conducted using the product of coefficients method ($\alpha\beta$; MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002). This approach provides a relatively accurate Type I error rate and improved power to detect indirect effects when regression coefficients α and β are non-zero when compared to alternative causal step methods of mediational analysis (i.e., Baron & Kenny Method; see MacKinnon et al., 2002). The product of coefficients method involves dividing the estimate of the intervening variable effect, $\alpha\beta$, by its standard error and comparing the value to a normal $\alpha\beta$ distribution to determine significance. Following the calculation of effects, standard errors of specific effects were calculated to establish 90% confidence intervals using the first-order multivariate delta method (Cheong & MacKinnon, 2012).

Interpretation and reporting of results. After model fit had been established and a mediational analysis completed, path parameters and estimates of indirect effects were used to evaluate the aforementioned hypotheses. Consistent with previous literature, we proposed that greater levels of aerobic fitness among preadolescents would be associated with greater levels of

emotion regulation, and lower levels of aerobic fitness would be associated with lower levels of executive control and emotion regulation. When placed within a mediation paradigm, we hypothesized that the level of executive control would account for the shared covariance between aerobic fitness and emotion regulation. In other words, when executive control was placed within the structural model, the relationship between aerobic fitness and emotion regulation would become non-significant.

Power analysis. *A priori* power analyses were conducted to determine the probability of detecting good and not-good overall model fit and to estimate appropriate sample size using a SAS program created by MacCallum, Brown, and Sugawara (1996). These tests employ root-mean-square error of approximation (RMSEA) values as indicators of model fit. In both analyses, alpha was set to .05, degrees of freedom were 41, and sample size was calculated at both 250 and 300. For the test of close model fit, the root-mean-square error of approximation (RMSEA) value for the null hypothesis was $\varepsilon_0 = .05$ and the RMSEA for the alternative hypothesis was $\varepsilon_a = .08$. Generally, power estimates of .80 or above are considered sufficient (Muthén & Muthén, 2002). Results of the analyses suggest an 80.5% ($N=250$) and 87.92% ($N=300$) chance of detecting close model fit respectively given the aforementioned parameters ($\alpha = .05$, $df = 41$, $\varepsilon_0 = .05$, and $\varepsilon_a = .08$), suggesting a high probability of confirming a good-fitting model if one exists in the data. On the other hand, the likelihood of confirming not-good fit was also examined. This approach allows one to determine power necessary for a direct test of the null hypothesis and, if the null hypothesis is rejected, provides additional evidence of good model fit. For this test, RMSEA was set to $\varepsilon_0 = .05$ for the null hypothesis and $\varepsilon_a = 0.01$ for the alternative hypothesis. Results of the analyses suggest a 67.86% ($N=250$) and 79.68% ($N=300$) chance respectively of detecting not-good model fit given the aforementioned parameters ($\alpha =$

.05, $df = 41$, $\varepsilon_0 = .05$, and $\varepsilon_a = .01$). This suggests that the power to detect poor model fit was slightly lower than power to detect good fit but approaches an adequate level of power. Given these results, it is highly likely that both a good model fit and a not-good model fit will be detected if present with a sample of greater than 250 participants.

Results

Data Screening

Prior to analysis of the data, all variables were inspected for accuracy of data, missing values, and conformity of variable distributions to the assumptions of multivariate statistical analysis using SPSS Version 21. The credibility of values for each variable was determined by an inspection of univariate descriptive statistics, including the minimum and maximum values, means, and standard deviations for each variable.

Variables were then inspected for missing values, and a missing values analysis was conducted using Little's Missing Completely at Random (MCAR) Test and Separate Variance Tests for all variables with greater than 5% cases missing. The Little's MCAR Test was not significant ($\chi^2 = 1090.987$, $df = 1,118$, $p = .713$), and missing values were not significantly related to the dependent variables; therefore, missing at random (MAR) was assumed. As noted above, full-information maximum likelihood (FIML) methods were used to handle missing data during parameter estimation (Shafer & Graham, 2002). Monte Carlo simulations have demonstrated that FIML methods outperform pairwise and listwise deletion in SEM with up to 25% of missing data (Enders & Bandolos, 2001).

Bivariate scatterplots and normal probability plots were checked for departures from linearity and homoscedasticity. No departures were noted. Subsequently, variables were evaluated for univariate outliers through an evaluation of box plots and histograms. Univariate

outliers were noted on several of the variables of interest, including on measures of heart rate, PACER, BMI, ERC, and EATQ-R. Outliers were fenced to their median +/- two interquartile ranges (IQR) to reduce outliers' influence on their respective distributions.

Variable distributions were then checked for normality through an examination of histograms, as well as measures of skewness and kurtosis. All study variables were normally distributed. Finally, distributions were evaluated for multivariate outliers using Mahalanobis distance at $p = .001$. No multivariate outliers were noted at or above $\chi^2(16) = 39.252$. Prior to parameter estimation and evaluation of model fit, covariates were evaluated for multicollinearity through an examination of sample correlation matrix in Mplus 7.0 (Muthén & Muthén, 2012).

Factor Analyses

A confirmatory factor analysis (CFA) was conducted to evaluate the acceptability and validity of the proposed measurement model. See Table 2 for descriptive statistics, including mean and standard deviations, for primary study variables. Because the study involved children nested within schools, the hierarchical nature of the sample data was first evaluated to determine the type of analysis to be used through 1) an examination of the intraclass correlations (*ICC*), 2) a calculation of design effects (*DEFF*), and 3) an examination of cluster level variances during a preliminary two-level CFA.

An examination of indicator intraclass correlations indicated generally small *ICC*'s ($ICC < .05$; Tabachnick & Fidell, 2007) with only three indicators exhibiting moderate *ICC*'s (EATQ-R Activation Control, $ICC = .091$; EATQ-R Attention, $ICC = .064$; and HRR, $ICC = .058$). An additional calculation of *DEFF*, which takes into account average cluster size when evaluating between level variance, indicated low *DEFF* for all indicators ($DEFF < 2$; Muthén, 1999). A further examination of between level variance during a preliminary two-level CFA, indicated

small and insignificant cluster level variance between factors and indicators consistent with previous findings of low *ICC*'s and *DEFF* among indicators. Because of the small cluster level variance, we determined to use a complex single-level analysis (Muthén & Muthén, 2012), which allowed for the estimation of individual measurement and regression effects while controlling for non-independence of observations due to clustering within classrooms.

Table 2

Means and Standard Deviations of Primary Study Variables, by Grade

| | All Participants | 3 rd Grade | 4 th Grade | 5 th Grade | |
|-----------------------------|---|-----------------------|-----------------------|-----------------------|----------------|
| PACER (laps) | 19.23 (8.84) | 16.13 (7.17) | 18.32 (7.81) | 23.16 (9.78) | |
| Max Heart Rate (HRMax) | 198.89 (9.54) | 198.10 (9.51) | 200.16 (10.34) | 198.72 (8.84) | |
| Aerobic Fitness Measures | PACER Estimated VO ₂ Max | 40.94 (5.09) | 39.91 (4.20) | 40.40 (4.58) | 42.41 (5.97) |
| | BMI Percentile | 53.16 (29.11) | 56.64 (28.27) | 49.25 (29.43) | 53.28 (29.55) |
| | Submax Heart Rate (HR _{Submax}) | 185.17 (13.65) | 187.4 (13.42) | 184.75 (15.69) | 183.62 (11.79) |
| | Heart Rate Recovery (HRR) | 56.80 (15.35) | 58.17 (15.38) | 57.79 (16.12) | 54.52 (14.61) |
| Executive Control Measures | Stroop: Interference Score | -6.99 (5.49) | -7.68 (5.21) | -7.39 (5.20) | -5.84 (5.85) |
| | EATQ-R – Inhibitory Control | 18.95 (2.56) | 18.40 (2.69) | 19.12 (2.16) | 19.36 (2.68) |
| | EATQ-R – Attention | 20.55 (3.93) | 19.97 (4.15) | 20.36 (3.99) | 21.35 (3.55) |
| | EATQ-R – Activation Control | 23.72 (5.13) | 23.27 (5.35) | 23.55 (4.85) | 24.38 (5.14) |
| Emotion Regulation Measures | EATQ-R – Depressed Mood | 10.93 (3.18) | 11.25 (3.27) | 10.66 (2.97) | 10.82 (3.28) |
| | EATQ-R – Aggression | 15.80 (4.59) | 16.23 (4.43) | 15.62 (4.52) | 15.47 (4.82) |
| | EATQ-R – Frustration | 14.16 (3.46) | 14.40 (3.49) | 13.98 (3.49) | 14.05 (3.45) |
| | ERC – Lability/Negativity | 23.85 (4.89) | 24.53 (4.49) | 23.32 (4.28) | 23.56 (5.64) |
| | ERC – Emotion Regulation | 26.69 (2.87) | 26.17 (2.79) | 27.30 (2.80) | 26.70 (2.95) |

Model 1. An initial evaluation of the proposed measurement model failed to converge and no parameter estimates were provided. An evaluation of the sample correlation matrix indicated relatively small associations between aerobic fitness indicators, and a preliminary CFA

using a two-level analysis with saturated variance at the cluster level demonstrated extremely low factor loadings for two of the indicators loading on the aerobic fitness factor ($\lambda_{HRSubmax} = -.199, p < .01$; $\lambda_{HRR} = .134, p = .06$). As a result, the model was re-specified by eliminating the indicators of Submaximal Heart Rate and Heart Rate Recovery.

Model 2. Model fit was re-evaluated upon respecification. Although the model converged during this second attempt, the overall fit of the factor analytic model was poor (see Model 2 in Table 3). The child BMI percentile indicator displayed high normalized residuals and exhibited a poor factor loading on the latent aerobic fitness factor ($\lambda_{BMI\%} = -.125, p = .584$), suggesting a failure to identify a common latent factor for aerobic fitness. Because the aerobic fitness latent factor failed to converge, indicating poor support of our hypothesized model, the confirmatory intent of the analysis was suspended, and we determined to explore alternative models based on the aforementioned respecification criteria.

Model 3. The model was re-specified to include a single manifest indicator for aerobic fitness (PACER Estimated VO₂Max) and model fit was evaluated. The overall fit of the CFA was poor and remained below our fit threshold (See Model 3 of Table 3). Measures of localized strain indicated three high normalized residuals and modification indices suggested that model fit could be improved if EATQ-R Attention and EATQ-R Activation Control were allowed to freely covary (M.I. = 47.363, SEPC = 1.708).

An additional evaluation of the literature indicated that the constructs of attention (the ability to switch and sustain attention) and activation control (the ability to initiate and persist in an undesirable task) are not only closely related in a common process called effortful control, but work in concert in guiding and maintaining goal directed behavior (Eisenberg, Smith, & Spinrad, 2011). In fact, many developmental researchers do not distinguish between these two constructs

(Eisenberg, Smith, & Spinrad, 2011; also see Barkley, 1997). Consistent with this conceptualization, a recent principal components analysis (PCA) of the self-report version of the EATQ-R, suggested that the attention and activation control loaded on a similar underlying component (Muris & Meesters, 2009). Therefore, based on measures of localized strain and underlying theoretical assumptions between attention and activation control, subsequent models were re-specified to include a covariance between the indicators of EATQ-R Attention and EATQ-R Activation Control.

Model 4. The factor analytic model was re-specified, adding a covariance between EATQ-R Attention and Activation Control and model fit was evaluated. The overall fit of the factor analytic model improved substantially from previous models, meeting criteria for good model fit (See Model 4 of Table 3). Measures of localized strain indicated no high normalized residuals and no modification indices were identified. Factor loadings on the executive control factor ($\lambda_{Stroop\ Interference\ Score} = .180, p < .05$) and emotion regulation factor ($\lambda_{ERC\ Emotion\ Regulation} = .453, p < .001$) were small, but were retained because both indicators were determined to provide unique information to the model. A high and significant standardized inter-factor coefficient between emotion regulation and executive control was identified above the .80 threshold ($\beta_{EC, ER} = -.877, p < .001$), suggesting that these two latent constructs may represent a single self-regulation factor. Convergence between these latent factors is consistent with recent executive control theories of emotion regulation, which posit that the control of emotion is not only dependent on executive control, but that these two constructs are isomorphic (Zelazo & Cunningham, 2007). In contrast, other theorists maintain that emotion regulation and executive control represent overlapping but distinct constructs (Calkins & Marcovitch, 2010; Ferrier,

Bassett, & Denham, 2014). Given the significant debate regarding the orthogonality of these constructs, an additional evaluation of a single self-regulation factor was justified.

Model 5. To evaluate the independence of latent constructs of executive control and emotion regulation and to determine whether a two factor or one factor model best fit the data, the emotion regulation and executive control factors were collapsed into a single self-regulation factor and model fit was evaluated. The overall fit of the factor analytic model declined significantly, falling below the fit threshold (See Model 5 of Table 3). See Table 3 for a summary of factor analytic models.

Table 3

Summary of Confirmatory and Exploratory Factor Analytic Models

| Model | Model Modification | χ^2 | df | RMSEA (90% C.I.) | CFI | NNFI |
|-------|---|----------|----|-----------------------|-------|-------|
| 1 | Did Not Converge | - | - | - | - | - |
| 2 | Removal of HR _{Submax} & HRR | 192.12 | 81 | 0.070 (0.057 - 0.083) | 0.909 | 0.877 |
| 3 | Removal of BMI Percentile | 161.79 | 68 | 0.070 (0.057 - 0.084) | 0.902 | 0.870 |
| 4 | Covariance between EATQ-R Attention & Activation Control Allowed | 108.48 | 67 | 0.047 (0.030 - 0.063) | 0.957 | 0.942 |
| 5 | Executive Control & Emotion Regulation Factors Collapsed Into a Single Self-Regulation Factor | 139.76 | 74 | 0.057 (0.042 - 0.071) | 0.931 | 0.916 |

Note. In Models 3 – 6 childhood aerobic fitness was represented by a single manifest indicator (PACER Estimated VO₂Max).

A Satorra-Bentler scaled χ^2 difference test (Satorra & Bentler, 1999) was conducted to further evaluate whether a two-factor (Executive Control and Emotion Regulation) or a single-factor (Self-Regulation) model best fit the sample data. The scaled χ^2 difference test indicated a significant difference between the two models, $\chi^2 \Delta (7) = 30.94$ ($\chi^2_{Critical} (7) = 18.475, p = .01$), suggesting that a two-factor model with separate factors for executive control and emotion regulation provided a better fit to the data compared to a model with the single self-regulation factor. Because the two-factor model met all model fit criteria and exhibited overall better fit

than a one-factor model, the two-factor model (Model 4) was utilized as the basis for path analyses and no other adjustments were made to the factor analytic model. A graphical representation of the final factor analytic model is displayed in Figure 3.

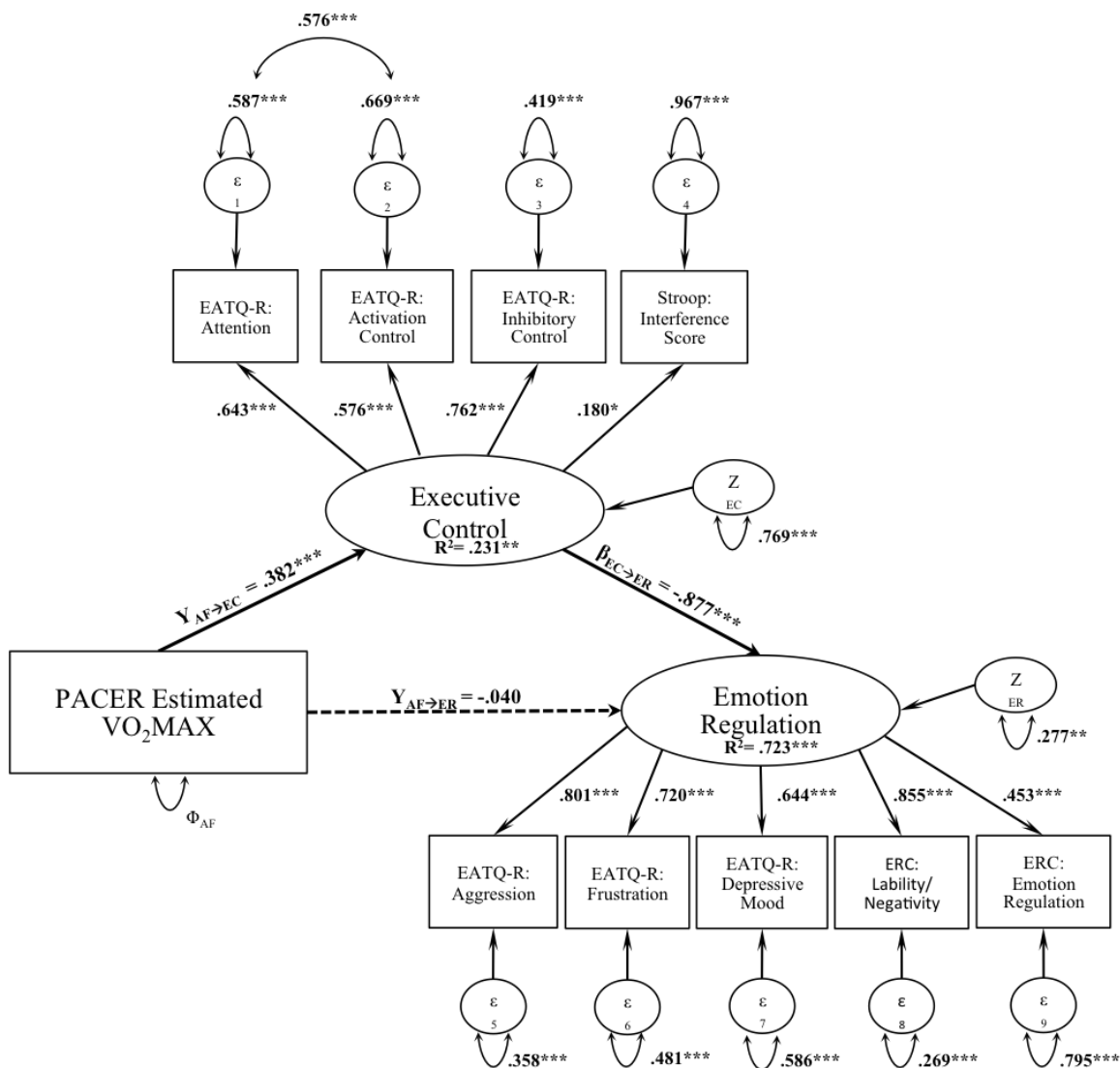


Figure 3. Final factor analytic model (See Model 4). Manifest Variables: EATQ-R = *Early Adolescent Temperament Questionnaire - Revised*; ERC = *Emotion Regulation Checklist (ERC)*; Stroop: Interference Score (Chafetz & Matthews, 2004); PACER Estimated VO₂Max (Mahar et al., 2011). Note. Covariates of age, gender, and familial socioeconomic status are not displayed. All coefficients are standardized. * $p < .05$, ** $p < .01$, *** $p < .001$

Post-hoc Power Analysis

In order to re-evaluate power to detect good model fit and not-good model fit prior to conducting final SEM analysis, a post-hoc power analysis was conducted based on the actual degrees of freedom and sample size using methods detailed in the a priori power analysis (see MacCallum, Brown, and Sugawara, 1996). Results of the analyses suggest an 84.27% chance of detecting close model fit ($\alpha = .05$, $df = 40$, $\varepsilon_0 = .05$, and $\varepsilon_a = .08$) and a 73.92% chance of detecting not-good model fit ($\alpha = .05$, $df = 40$, $\varepsilon_0 = .05$, and $\varepsilon_a = .01$). This suggests that the final factor analysis had sufficient power to detect close model fit with slightly less power to detect not-good model fit based on the final measurement model.

Structural Equation Model

Upon completion of measurement model estimation and respecification through an iterative and exploratory CFA process, structural coefficients between latent factors were evaluated. See Figure 4 and 5 for details regarding the structural model used to evaluate latent associations.

Direct effects. Consistent with our hypothesis that greater aerobic fitness would be related to higher levels of executive abilities among preadolescents, aerobic fitness exhibited a moderate positive association with executive control ($\gamma_{AF, EC} = .382$, $SE = 0.105$, $p < .001$) while controlling for age, sex, parental education, and income. Similarly, consistent with our hypothesis that higher levels of executive control would be related to greater emotional regulation among preadolescents, executive control exhibited a large negative association with emotion regulation ($\beta_{EC, ER} = -.877$, $SE = 0.080$, $p < .001$) while controlling for age, sex, parental education, and income (Note: A negative association between emotion regulation and other latent factors indicates better emotion regulation because higher values on measures of emotion

regulation indicate poorer emotion regulation). There was no direct association between aerobic fitness and emotion regulation when executive control was included in the model ($\gamma_{AF, ER} = -.040, SE = 0.077, p = .601$). The model accounted for 23.1% of the variation in executive control and 72.3% of the variation in emotion regulation.

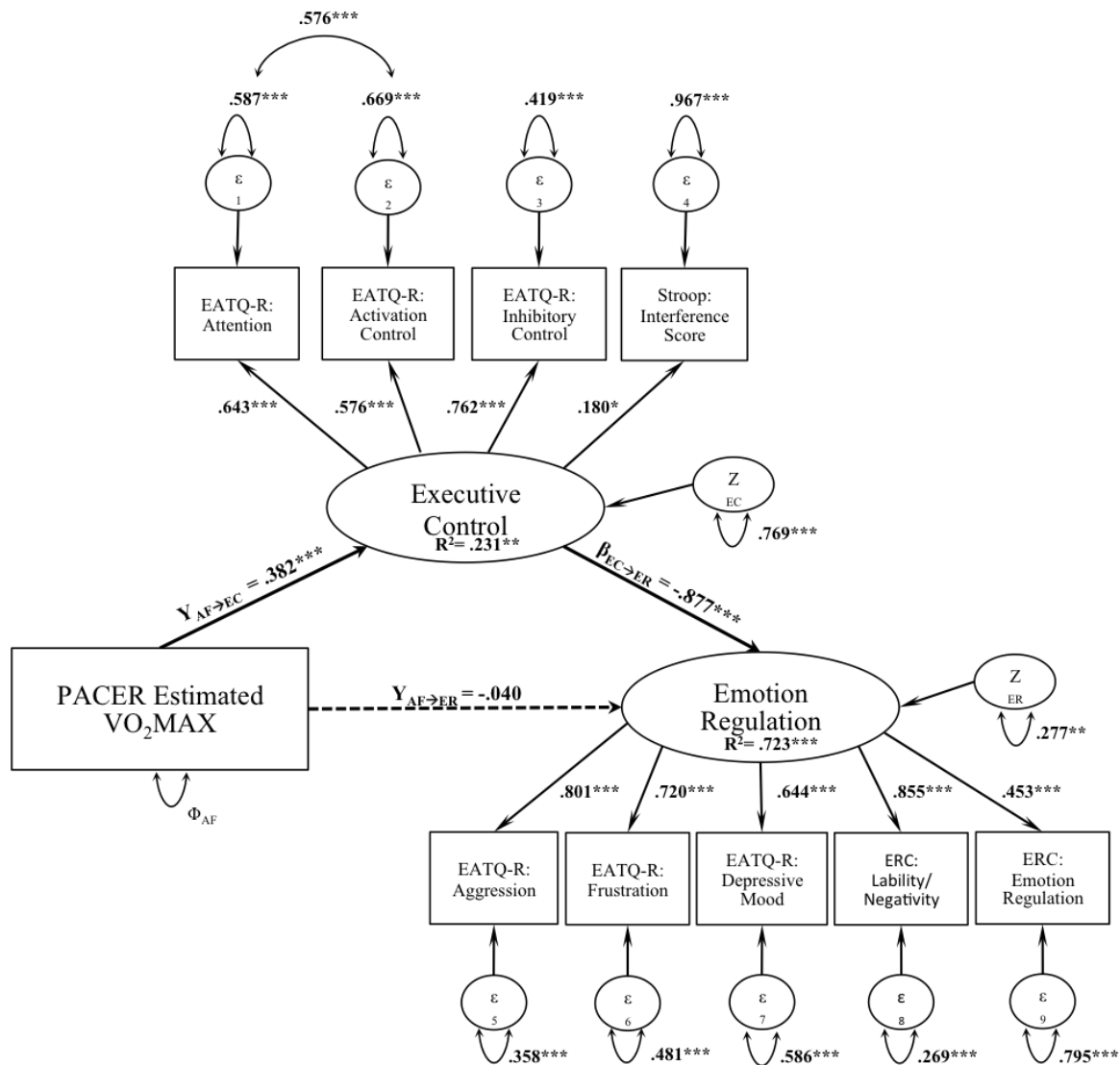


Figure 4. Final structural model, direct effects. Manifest Variables: EATQ-R = *Early Adolescent Temperament Questionnaire - Revised*; ERC = *Emotion Regulation Checklist (ERC)*; Stroop: *Interference Score (Chafetz & Matthews, 2004)*; PACER Estimated VO₂Max (*Mahar et al., 2011*). Note: covariates of age, gender, and familial socioeconomic status are not displayed. All coefficients are standardized.

* $p < .05$, ** $p < .01$, *** $p < .001$

An evaluation of covariate relationships with estimated VO₂Max indicated statistically significant associations between age ($\rho = .238, p < .001$), sex ($\rho = .587, p < .001$), maternal education ($\rho = .118, p < .05$), and income ($\rho = .241, p < .001$). This suggests that children who are older, male, and come from enriched socioeconomic backgrounds are more likely to display greater aerobic capacities. An evaluation of covariate relationships with executive control indicated a statistically significant associations between sex ($\rho = -.404, p < .001$) and executive control, suggesting greater executive abilities among female compared to male participants. There were no statistically significant associations between covariates and the latent factor of emotion regulation.

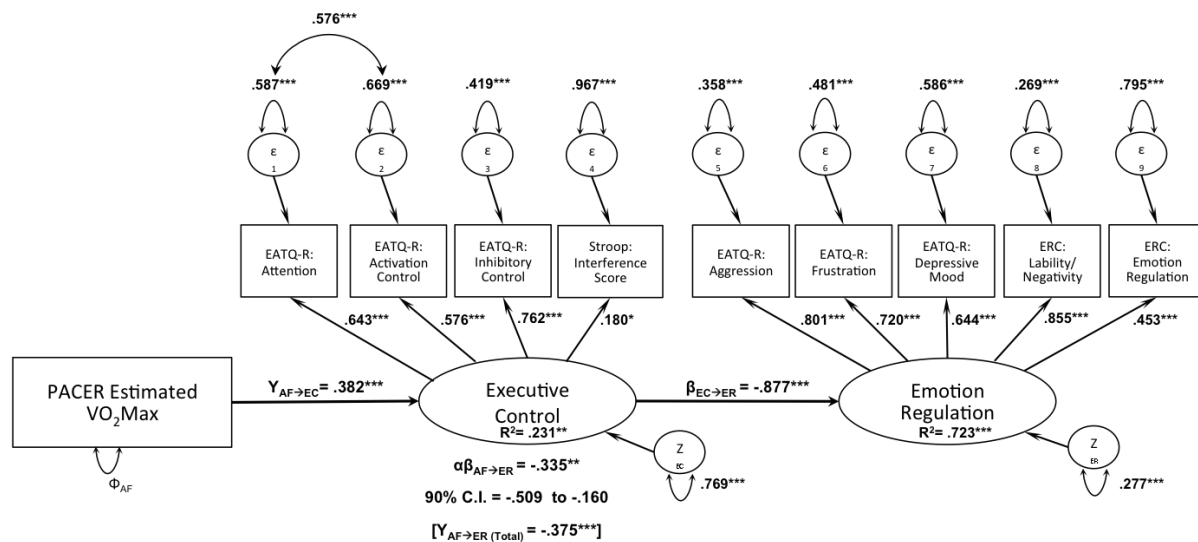


Figure 5: Final structural model, direct, indirect, and total effects. EATQ-R = *Early Adolescent Temperament Questionnaire - Revised*; ERC = *Emotion Regulation Checklist (ERC)*; Stroop: Interference Score (Chafetz & Matthews, 2004); PACER Estimated VO₂Max (Mahar et al., 2011). Note. a) Because the direct effect between the PACER Estimated VO₂Max and Emotion Regulation was small and failed to reach significance, it is not displayed and b) covariates of age, gender, and familial socioeconomic status are not displayed. All coefficients are standardized.

* $p < .05$, ** $p < .01$, *** $p < .001$

Total and indirect effects. Because aerobic fitness displayed a moderate association with executive control, and executive control displayed a large association with emotion regulation, a mediational analysis using the product of coefficients method was conducted to

evaluate the total and indirect effects between aerobic fitness and emotion regulation. Consistent with our initial hypothesis that executive control would mediate the relationship between aerobic fitness and emotion regulation, there was a moderate negative total effect ($\gamma_{AF, ER (Total)} = -.374$, $SE = .091$, $p < .001$) and a moderate indirect effect ($\alpha\beta = -0.334$, $SE = .106$; 90% CI: -0.509 – -0.159) between aerobic fitness and emotion regulation while controlling for age, sex, parental education, and income. This suggests that greater aerobic fitness is indirectly associated with greater levels of emotion regulation among preadolescents through executive control and accounts for the majority of the total effect. In other words, the relationship between aerobic fitness and emotion regulation was mediated (accounted for) by executive control.

Discussion

The present study proposed a plausible and testable theoretical model for evaluating associations between aerobic fitness, executive control, and emotion regulation among a relatively large sample of preadolescent children. Results from this cross-sectional study provide preliminary evidence supporting our hypothesis that executive control functions as a mediator of the association between aerobic fitness and emotion regulation. Specifically, a moderate negative indirect association was found between aerobic fitness and emotion regulation that accounted for most of the total effect, suggesting that executive control, involving an individual's attentional and inhibitory control, may be a mechanism by which aerobic fitness relates to preadolescent emotional wellbeing. Future studies should continue to evaluate executive control as an intervening mechanism that may account for aerobic fitness's influence on emotional regulation because this could provide a better understanding of the mechanisms that account for the emotional benefits that result from regular aerobic exercise.

Consistent with previous studies that support an association between preadolescent aerobic fitness and attentional and inhibitory control (i.e., Chaddock et al., 2012; Hillman et al., 2009; Pontifex et al., 2011; Voss et al., 2011), the results of our study provide evidence for a moderate direct association between aerobic fitness and executive control. This finding is consonant with results from a past meta-analysis that supports a moderate general association between children's overall cognitive abilities and their aerobic fitness level (Sibley & Etnier, 2003). Furthermore, our findings are consistent with other studies that support selective moderate effects between childhood aerobic fitness and academic achievement, cognitive abilities, and brain structure and function (Chaddock, Pontifex, Hillman, & Kramer, 2011).

The results from our study support a very large direct association between executive control and emotion regulation, suggesting that children who possess greater attention and inhibitory control abilities also display better overall control of their emotions. While the direction of this association is consistent with previous developmental and cognitive neuroscience studies, the size of the association in the present study ($\beta_{EC, ER} = -.877, p < .001$) was much larger than anticipated. Given the ongoing debate surrounding the overlap between constructs of emotion regulation and executive control, this finding calls into question the discriminate validity between these constructs and suggests that these factors are likely not wholly distinct, but represent overlapping regulatory mechanisms. This bolsters general executive control theories of emotion regulation (Ochsner & Gross, 2005; Zelazo & Cunningham, 2007) and supports recent neuroimaging findings that suggest that the regulation of cognitive and emotional processes are dependent upon a common broad regulatory network (Luu, Collins, & Tucker, 2000; Ochsner & Gross, 2008; Shackman et al., 2011). This finding is in contrast to past cognitive neuroscience theory that divides emotional and cognitive processes

into distinct substrates (Bush, Luu, & Posner, 2000). However, the results from this study's factor analyses suggests that a two-factor model with separate factors for executive control and emotion regulation provided a better fit to the data compared to a model with the single self-regulation factor, indicating some distinct variance between the two factors. Future studies should evaluate associations between executive control and emotional regulation, and may need to re-conceptualize these constructs to better identify unique variance. Because the broad construct of executive control represents multiple distinct higher-order cognitive abilities (Diamond, 2006; Miyake et al., 2000), it may be valuable to further evaluate which executive abilities (e.g., inhibitory control, mental flexibility, attention, working memory) are necessary for emotional regulation.

Despite the ongoing conceptual and empirical debate about the mechanism by which emotion regulation occurs, results from this study indicate that preadolescents who display greater executive abilities also exhibit greater emotional control. This finding is encouraging because it suggests that the long-term emotional benefits correlated with regular aerobic exercise may be due to general improvements in executive control. It is possible that childhood emotional development may be enhanced by similar aerobic fitness related mechanisms that account for improvements in childhood cognitive and academic functioning (Chaddock et al., 2011), and this line of investigation could provide evidence for an alternative and/or supplemental approach to promoting the development of emotion regulation within a pediatric population. Future studies should evaluate whether changes in aerobic fitness lead to dose-response changes in emotion regulation among preadolescents similar to Davis et al.'s (2011) recent randomized control trial that found a dose-response increase in executive control associated with differences in the amount of aerobic exercise among children.

Study Strengths

This study has several strengths including (a) the recruitment of a relatively large and representative sample of preadolescent children and (b) the use of SEM, a state-of-the-art data analytic technique.

The study sample was composed of a group of regionally representative preadolescents, which strengthens the external validity of the study findings (U.S. Census Bureau, 2010). Specifically, 81.7% of the sample was Caucasian, 8.3% was Hispanic, 7.9% was multi-racial/other, 1.8% was Pacific Islander, and 0.4% was Asian American. In addition, participants came from households with monthly gross income levels ranging from less than \$1,000 to \$10,000 or more per month. Although results come from a relatively representative sample, the generalizability of results depends on future replications, because sample demographics (i.e., ethnicity) do not adequately reflect recent US census data (see U.S. Census Bureau, 2011).

The present study used SEM with robust full-information maximum likelihood (FIML; Asparouhov & Muthén, 2005; Lei & Wu, 2012). This state-of-the-art data analytic technique allowed us to simultaneously evaluate proposed measurement and structural models while accurately handling missing data, systematically controlling for disturbances, and correcting for measurement error due to cluster-level dependencies (Enders & Bandalos, 2001; Shafer & Graham, 2002). This approach provided more precise model fit statistics, path estimates, and standard errors compared to other less advanced techniques (Hoyle, 2012).

Study Weaknesses

Unfortunately, the present study failed to support our proposed latent factor of aerobic fitness and there remains limited published data on the factor structure of various estimates of aerobic fitness (i.e., Marsh, 1993). In the final model of this study, aerobic fitness was

represented by a single manifest estimate of VO₂Max, based on each child's PACER performance, due to poor convergence between items and extremely low and/or insignificant factor loadings from anthropometric (BMI%) and physiological (HR_{Submax} and HRR) measures of aerobic fitness. Poor convergence and low factor loadings between items suggest that field-based performance measures of aerobic fitness (i.e., PACER Estimated VO₂Max) are distinct from other physiological and anthropomorphic measures of aerobic fitness. The items' failure to converge in a common factor is somewhat surprising because these fitness measures have all been shown to relate to laboratory measurement of VO₂Max (Darr et al., 1988; Goran et al., 2000; Joshi et al., 2012). However, these items have not previously been shown to load on a common latent construct through factor analysis, and reliability estimates for HR_{Submax} has not been established. The failure to identify a common aerobic fitness factor within this study limited our ability to remove measurement error for this construct through latent factor analysis. Future studies should attempt to establish the construct validity of aerobic fitness measures through an evaluation of the convergent validity of commonly used measures of aerobic fitness. Despite the poor convergence between aerobic fitness measures used in this study, findings from the present study suggest that the PACER provides reliable estimates of childhood aerobic fitness, allowing for the evaluation of a relatively large number of children without the cost and inconvenience of laboratory testing.

In this study, the construct validity of the executive control factor was limited due to the poor loading of the Stroop interference score ($\lambda_{\text{Stroop}} = .180$). This suggests that parent report measures of executive control from the EATQ-R that largely made up the executive control latent factor likely represent a distinct construct than what is represented by the Stroop interference score, a direct behavioral measure of attentional and inhibitory control. This

finding is consistent with past evaluations comparing parent report and behavioral measures of executive control, which generally exhibit small and/or insignificant associations between the two measurement methods (see Anderson, Anderson, Northam, Jacobs & Mikiewicz, 2002). However, the Stroop interference score indicator was retained in the model because it was believed to provide unique information about child executive control beyond parent report measures of attention and inhibitory control obtained from the EATQ-R. Because the Stroop Color-Word Test is not only based on an individual's selective attention and inhibitory control but reading abilities, future research should include other well-validated behavioral measures of executive control, such as the Trails A & B, COWAT, or Ruff Figural Fluency test (Strauss et al., 2006), which do not rely on reading ability to better estimate underlying executive abilities.

Similarly, the construct validity of the emotion regulation factor was limited due to the poor loading of the ERC Emotion Regulation indicator ($\lambda_{ERC\ Emotion\ Regulation} = .453, p < .001$). However, this measure was retained because it provided unique information beyond other parent-report measures of emotion regulation. Specifically, an evaluation of items comprising the ERC Emotion Regulation indicator suggests that this measure assesses direct regulation and situational appropriateness of emotion. This is in contrast to other indicators of emotion regulation from the EATQ-R and ERC that do not directly represent the degree of control a child has over emotional expression.

Study Limitations

Several limitations to the present study deserve mention. First, considering the cross-sectional nature of this study, causality and direction of influence may only be inferred in as much as previous, well-designed experimental studies support such effects due to the lack of temporal precedence between variables of interest within this study. Additional studies should

continue to evaluate the causal relationships assumed in the present model while attempting to rule out plausible alternative models through the use of randomized experimental design. Similarly, the inability to establish causality further limits our ability to firmly conclude that executive control is a mediator (as opposed to a confounding variable) despite the statistical degree and significance of the study results. In sum, only through careful experimental manipulation of aerobic fitness can executive control be established as a clear mediator between preadolescent aerobic fitness abilities and emotion regulation.

Second, emotion regulation was measured using two parent-report measures (ERC and EATQ-R), which introduced mono-method measurement bias that constrains the construct validity of the emotion regulation construct. Future research should address this limitation through direct behavioral measurement and/or the use of neurophysiological measures of emotion regulation. The use of a cognitive and emotion regulation paradigm while monitoring event-related potentials (i.e., N2 and frontal P3) may provide an alternative approach to evaluate the relationship between aerobic fitness, executive control, and emotion regulation (i.e. Lewis, Lamm, Segalowitz, Stieben, & Zelazo, 2006).

Implications

The present study provides preliminary evidence indicating that executive control represents a mechanism of action (mediator) accounting for the association between aerobic fitness and emotion regulation in preadolescent children. Moreover, this finding elucidates a plausible mechanism by which aerobic exercise contributes to individual emotional wellbeing. This finding is complimentary to neuroendocrinologic and stress reduction theories of exercise and emotional wellbeing and is consistent with past research findings on aerobic exercise and emotional functioning.

Furthermore, study results provide preliminary evidence supporting an alternative or supplementary approach to encouraging emotion regulation among pediatric populations. Specifically, because results support an indirect relationship between aerobic fitness and emotion regulation, it is plausible that changes in aerobic fitness through regular aerobic activity could result in improved emotion regulation. Therefore, efforts to promote physical fitness among preadolescent children may have salutary effects on their emotion regulation abilities. Future experimental studies will be necessary to confirm that increased aerobic fitness results in improved emotion regulation among preadolescent children.

Conclusion

The present study evaluated direct and indirect associations between aerobic fitness, executive control, and emotion regulation within a relatively large and representative sample of preadolescents. Although our hypothesized factor analytic model failed to converge due to poor identification of the latent factor of aerobic fitness, an alternative exploratory model was identified, allowing for evaluation of our study hypotheses. Consistent with our hypotheses, results from this cross-sectional analysis supported a moderate direct association between childhood aerobic fitness and executive control and a strong direct negative association between executive control and emotion regulation. A mediational analysis using the product of coefficients method revealed a moderate indirect association (accounted for by executive control) between aerobic fitness and emotion regulation. Results provide preliminary evidence indicating that executive control represents a plausible mediator of the association between preadolescent aerobic fitness and emotion regulation.

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