Dorsolateral prefrontal cortical hemodynamics, cognitive inhibition, and affective responses to exercise among children: Implications for pediatric exercise prescription

by

Matthew Aaron Ladwig

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Program of Study Committee:
Panteleimon Ekkekakis, Major Professor
Ralf Brand
Lorraine Lanningham-Foster
E. Andrew Pitchford
Spyridoula Vazou
Gregory J. Welk

Iowa State University

Ames, Iowa

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DEDICATION

This manuscript is dedicated to my grandfather and the man who inspired me to pursue an academic career, Professor James Cloghessy. Though you’re not here to see it come to pass, I know that you’ll always be with me.

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ABSTRACT

Preliminary evidence suggests that children may report decreasing pleasure throughout incremental exercise tests. This pattern of affective responses might be related to the deviation of incremental and prolonged patterns of exercise from the innate propensity of children for intermittent movement. Furthermore, the self-regulation of affective responses during exercise may require cognitive strategies underpinned by cortical networks still under development during childhood. Consequently, the purpose of this study was to examine (1) whether dorsolateral prefrontal cortical (dlPFC) activity is associated with affective responses during an incremental cycling exercise test, and (2) whether theoretically relevant covariates moderate affective responses and dlPFC activation during exercise. Secondary outcomes of interest included (3) whether affective responses, dlPFC activation, and time spent exercising at intensities above ventilatory threshold (VT) are associated with lower postexercise scores on the inhibition component of executive function as assessed by a pediatric adaptation of the Eriksen Flanker Task. Fifty-six healthy girls (n = 27) and boys (n = 29) aged 7-9 years participated in the study. There was a positive association between left dlPFC activity and affective responses above VT to the end of exercise, whereby dlPFC activity declined concurrently with affective responses. Age and body mass index (BMI) moderated the slopes of change in right dlPFC activity below VT, while age moderated the slope of affective responses and BMI moderated the slope of left dlPFC activity below VT. There were no moderators of affective responses or dlPFC activity from VT to the end of exercise. These results suggest that children experience declines in pleasure that accelerate during incremental exercise and that these declines may reflect

unsuccessful prefrontally mediated efforts to self-regulate affect. Children may not yet be able to effectively self-regulate affective responses during exercise without additional biological maturation and/or deliberate practice

CHAPTER 1. INTRODUCTION

In the most recent update to the *Physical Activity Guidelines for Americans* (Piercy et al., 2018), experts continue to recommend that children and adolescents engage daily in at least one hour of physical activity (PA), with most of this activity spent at moderate-to-vigorous intensities. Although these guidelines have been widely disseminated by both private foundations (e.g., NFL PLAY 60©) and public agencies (U.S. Department of Health and Human Services, 2018), rates of PA among children and adolescents remain mostly stagnant (Centers for Disease Control, CDC; 2007, 2017). Moreover, accumulating evidence suggests that PA begins to decrease around late childhood, with the rate of change increasing during adolescence (Caspersen, Pereira, & Curran, 2000; Troiano et al., 2008; Van Mechelen, Twisk, Post, Snel, & Kemper, 2000). However, recent data collected among contemporary children indicate this reduction may emerge earlier, at around the age of seven years (Farooq et al., 2018), suggesting that the situation may be more dire than previously thought. It remains unclear what factors may explain this drastic reduction in PA, but it is becoming apparent that interventions designed to mitigate it need to be initiated early, preferably before the onset of the decline. Given the clear dose-response relationship between PA and health (Elosua et al., 2013; Manson et al., 2002; Williams, 2013), even modest successes in increasing PA (or modest attenuation in the rate of decline) during childhood and adolescence could have significant long-term societal-level implications for disease prevention and weight maintenance.

For nearly five decades, the field of exercise psychology has attempted to confront the challenge of physical inactivity but, as has also been the case in other domains of applied psychology, experiences have shown that human behavior is highly resistant to change (CDC, 2011, 2017). It is possible that, as in other areas of biological and psychological development, early intervention during childhood may help to change PA behavior. However, despite numerous attempts to promote PA and reduce sedentary time among children and adolescents, the needle continues to move mostly in the opposite direction (Corder, Winpenny, Love, Brown, White, & van Sluijs, 2019). Some of the most widely adopted interventions are within school physical education (PE) and sport, as most children attend school daily. Furthermore, without these in-school opportunities, many children may not engage in or have familial support for PA outside of school. Hence, researchers assume that targeting the school environment will maximize the potential for large-scale or even societal-level changes to PA behavior. Consequently, the Society of Health and Physical Educators (SHAPE) contends that PE should be designed in a way that allows children "to gain the necessary *skills and knowledge* [emphasis added] for lifelong participation in physical activity" (Evans & Sims, 2016, p. 24). Similarly, some sport associations are beginning to recognize the importance of outcomes beyond simply winning or losing. Consequently, the overarching theoretical framework (and focus of most of youth PA interventions) is to impart knowledge about the benefits of a physically active lifestyle and to increase PA self-efficacy through improvements in movement skill competencies (Hulteen, Morgan, Barnett, Stodden, & Lubans, 2018; Stodden et al., 2008).

Although not always explicitly stated, the knowledge and movement skill competency-fostering approaches adopted by many youth PA interventions are grounded on several theoretical models, including the Health Belief Model (HBM; Becker, 1974), Theory of Planned Behavior (TPB; Ajzen, 1985), Social Cognitive Theory (SCT; Bandura, 1986), and Self-Determination Theory (SDT; Ryan & Deci, 2000). These theories emerged following the cognitive revolution of the late 1950s in psychology (Chomsky, 1959), and to this day remain some of the most influential, and popular, models of human behavior. Because these theories share a similar genesis, they all rely on the same fundamental assumption, namely that humans are inherently rational. According to these models, if interventions provide compelling information describing the benefits of behavior change or information that bolsters behavioral self-efficacy, then behavior change should follow (Ajzen & Fishbein, 2005). However, while humans *do* have the capacity to engage in mindful, logical, and rational decision making, and despite their best intentions, they often pursue mindless, illogical, and irrational behavior (Tversky & Kahneman, 1974). For example, despite the known risks associated with excessive sedentary behavior (Patterson et al., 2018), Americans spend more than eleven hours per day interacting with digital media, with around five hours devoted to television viewing and another four engaging with a smartphone (The Nielsen Company, 2018). Even with increasing exposure to sex education, a survey (Dovey, 2017) of around 2,000 Americans reported that 65% of respondents had had unprotected sex at some point, while 30% responded that they did so "every single time". In addition, the average American ingests over 100 pounds of sugar per year (U.S. Department of Agriculture, 2009), despite its established association with the risk of type 2 diabetes and excess weight gain (Stanhope, 2016). Interestingly, though these behaviors differ qualitatively, one commonality between them is that it is difficult to discourage people from engaging in them. Therefore, it is possible that the mechanisms that explain the difficulty avoiding these behaviors could be leveraged to increase PA, a behavior that, for most, is difficult to adopt and maintain (Dishman, 1988; Linke, Gallo, & Norman, 2011). Because the previously mentioned *cognitivist* theoretical approaches have largely failed in producing meaningful and lasting changes to PA behavior, the time is ripe to search for additional perspectives beyond the prevailing paradigm.

Perhaps unsurprisingly, within the fields of exercise psychology and health promotion, the predominant cognitivist paradigm has entered a "crisis" - a term coined by Kuhn (1962) to describe how novel ideas infiltrate and eventually begin to shift the current paradigm. "Crises" lasting for extended periods often precede the emergence of novel dominant paradigms. Within exercise psychology, data collected from adult samples have contributed to an emerging "crisis" by increasing the attention given to the consequences of affective (i.e., pleasant-unpleasant) experiences before, during, and after exercise and PA. Such studies (Ekkekakis & Petruzzello, 1999; Ekkekakis, Parfitt, & Petruzzello, 2011) have revealed, for example, that exercise intensity is strongly associated with pleasure and that pleasure experienced *during* exercise, as opposed to afterwards (e.g., the postexercise "feel good" effect), may be more strongly related to continued participation (Ekkekakis & Dafermos, 2012; Rhodes & Kates, 2015). It follows that the affective associations (or memories) encoded during PA could be important possible determinants of PA (Williams, Dunsiger, Ciccolo, Lewis, Albrecht, & Marcus, 2008). The implications of this novel line of research are important, as an estimated 50% of individuals drop out of exercise programs within the first six months (Dishman, 1988) and solutions to chronic inactivity remain elusive.

Because this growing line of evidence suggests that PA preferences and behaviors could be influenced by affective associations formed for the stimulus-concept of PA (Antoniewicz & Brand, 2014; Brand & Ekkekakis, 2018; Chevance, Caudroit, Romain, & Boiché, 2017), the mechanisms underlying this relationship (i.e., how and why do affective experiences influence preferences and behaviors?) demand further investigation. Accordingly, the recent integration of cognitivist models into dual-process theories of behavior may help to explain these relationships. Dual-process theories first emerged during the late 19th century (James, 1890), and modern iterations theorize that human behavior is regulated through two parallel systems, often termed *automatic* and *reflective*. Automatic processes are posited to be fast and unconscious, with little cognitive mediation. One way to illustrate an automatic process is when individuals make behavioral decisions based on their affective association, or "gut feeling" (Wen Tay, Ryan, & Ryan, 2016, p. e98). On the other hand, reflective processes necessitate substantially more effort and cognitive mediation, and, therefore, are slower and more deliberate. Although, historically, reflective processes have garnered the most attention from researchers, recent evidence suggests that automatic processes may frequently dominate decision making, especially in instances of reduced self-control and/or self-regulatory resources (e.g., accumulation of fatigue and/or stress; Brand & Schweizer, 2015; Brand & Ekkekakis, 2018). When individuals are unable to fully utilize their self-control resources, behavior is more likely to be driven by faster and more efficient automatic processes, as opposed to slower and more resource-intensive reflective processes (Friese, Hofmann, & Schmitt, 2009). Many individuals from industrialized nations are repeatedly exposed to stressful situations and are chronically fatigued (Keyes, Maslowsky, Hamilton, & Schulenberg, 2015). Therefore, to maximize the likelihood of PA behavior, it is critical that pleasant automatic affective associations are elicited, particularly when in these states of self-control depletion.

Automatic affective associations for PA may be developed to a large extent during childhood and adolescence. Consequently, modifying these associations *ex post facto* during adulthood may be difficult, if not impossible. Therefore, like other physiological and psychological developmental phases, childhood and adolescence may constitute "critical periods" (Siegler, Saffran, Eisenberg, DeLoache, & Gershoff, 2017) during which physical activities come to be automatically associated with pleasure or displeasure. Considering that children and adolescents spend nearly a third of their waking hours in school, the pleasant and unpleasant PA experiences (i.e., PE quality, in-class activity breaks, school sports) that children are exposed to during school may influence their automatic affective associations for PA. Unfortunately, for many, it appears that the experiences during PA in school, particularly those during PE, are not optimal (Cardinal, Yan, & Cardinal, 2013, Ladwig, Vazou, & Ekkekakis, 2018).

For example, data from 1028 adult participants (Ladwig et al., 2018) suggested that retrospectively reported enjoyment of PE was associated (weakly, but significantly) with present-day (i.e., adult) sedentary behavior, as well as with present attitudes toward and intentions for PA. Some of the most compelling data from this study were qualitative responses, in which participants provided descriptions of their best and worst memories of PE. Specifically, the most common negative memory was being embarrassed in some form during PE, whereas the most common positive memories were related to performing well in front of peers. Although, in some respects, PE pedagogy has evolved over the past few decades (e.g., introduction of movement skill competency as a primary goal; SHAPE America, 2013), the results from this survey suggested that there were no appreciable differences in PE enjoyment between those younger and older than 30 years of age at the time of survey administration (i.e., 2018). Interestingly, the grade levels in which adults recalled their worst memories peaked between the 5th to 9th grade, coinciding with other data indicating both increasingly negative PE attitudes (Bernstein, Phillips, & Silverman, 2011; Säfvenbom, Haugen, & Bulie, 2014) and reduced PA (Pearson, Haycraft, Johnston, & Atkin, 2017).

A recurring theme in the qualitative responses collected by Ladwig and colleagues (2018) was embarrassment and lack of enjoyment during physical fitness testing. Fitness tests have been and continue to be a source of controversy and debate among professionals and researchers alike

(Cale, Harris, & Chen, 2007; Corbin, Pangrazi, & Welk, 1995; Pate, 1988; Rowland, 1995; Welk, 2008). As far back as the 1980s, Pate (1988) wrote that

> …if the [fitness] test is administered in an appropriate psychological environment, enhanced appreciation of physical fitness should result. *Admittedly there is little research upon which to base this conclusion, and currently we know little about the optimal ways in which to conduct the fitness testing process*. (emphasis added; p. 291)

Despite these concerns, until recently (Vazou, Mischo, Ladwig, Ekkekakis, & Welk, 2019), little attention had been given to the factors that may impact the experience of fitness testing. Although empirical data are scant, one study examined changes in affective valence (pleasure – displeasure) during incremental exercise (i.e., exercise that resembles tests of maximal aerobic capacity in PE) among children (Benjamin, Rowlands, & Parfitt, 2012). This investigation revealed that during incremental exercise to volitional termination on a treadmill, children reported reduced pleasure, or increased displeasure, from the beginning to the end of the exercise test. These data contrast with those collected in healthy adolescent and adult samples (Ekkekakis, Hall, & Petruzzello, 2005a; Hamlyn-Williams, Freeman, & Parfitt, 2014). Specifically, during exercise below the gas-exchange ventilatory threshold (VT; the point at which blood lactate begins to accumulate more rapidly than can be cleared and carbon dioxide (VCO_2) production begins to exceed oxygen consumption (VO_2)), where exercise is still manageable, adolescents and adults usually report stable or even increasing pleasure. At intensities near VT and beyond, affective responses become variable, with some individuals reporting feeling better and others worse. However, when intensities reach the respiratory compensation point (RCP; at which lactate can no longer achieve steady-state and the rate of VCO_2 production increases further in relation to VO_2 consumption), nearly all adolescents and adults report feeling worse.

Researchers such as Ekkekakis (2009b) have theorized that, among adults, these patterns of affective responses to exercise may be explained by both cognitive (e.g., self-efficacy, past experiences with exercise or sport) and interoceptive factors (e.g., increasing blood H^+ ions, ventilation rate). At intensities that are manageable with little or no cognitive intercession (i.e., below the VT), these factors likely play little part in how one feels. However, at and beyond VT, they become more influential. Some participants who report increased pleasure at intensities above VT may do so not because exercise *literally* feels good, but because they have come to associate vigorous-intensity exercise (along with the mounting discomfort and difficulty) as positive. These positive attitudes that some individuals endorse for high-intensity exercise are likely associated with factors such as sport experience, habitual exercise volume, and individual-difference traits such as their preference for and tolerance of exercise intensity (Ekkekakis, Hall, & Petruzzello, 2005) and ego achievement-goal orientation (i.e., perceived success being associated with demonstrating dominance during interpersonal competition; Duda, 1989). On the other hand, individuals who report displeasure when exercise becomes difficult may be negatively influenced by anthropometric factors, such as body mass index (BMI) and body fat percentage (Welch, Hulley, Ferguson, & Beauchamp, 2007), as well as personality traits like a task goal-orientation (i.e., success in exercise being defined by enjoyment and personal growth, rather than competition). However, as exercise intensity approaches the limit of human tolerance (i.e., at intensities proximal to and above RCP), variability largely dissipates and most individuals feel worse, likely driven by interoceptive factors that are beyond cognitive influence. The intense feelings of displeasure that compel exercise termination at near-maximal intensities are theorized to be an evolutionary protective mechanism (Ekkekakis et al., 2005a), as, if exercisers truly could persevere to their true maximal capacity, the chances of injury, or even death, would increase substantially.

Theoretical work by Ekkekakis (2009a) suggested that the interplay between the prefrontal cortex and the amygdala could provide an additional mechanistic explanation for adult patterns of affective responses to exercise. Specifically, during moderate-intensity exercise (i.e., below VT), activity in the dorsolateral right and left prefrontal cortices (dlPFC) increase, whereas activation from RCP to exercise termination decreases (Bhambhani, Malik, & Mookerjee, 2007; Rupp & Perrey, 2008). Interestingly, the activity of the dlPFC is also associated with affective and emotional self-regulation in contexts other than exercise (Kelley, Gallucci, Riva, Romero Lauro, & Schmeichel, 2019). Moreover, the strength of connectivity between the prefrontal cortex and amygdala may be related to the extent to which one can cognitively attenuate negative affective and emotional responses. This suggests that during exercise, increased activation of the dlPFC below and proximal to VT may indicate attempts to cognitively self-regulate affective responses, while decreased activity at near-maximal intensities may represent a self-protective mechanism that evolved to reduce the chances of injury by reducing the capacity of the individual to cognitively self-regulate negative affective responses. That is, when the dlPFC is no longer receiving the “fuel” (i.e., oxygenated hemoglobin) necessary to exert cognitive control over the action of the amygdala, negative affective responses driven by interoceptive factors begin to dominate consciousness, eventually impelling exercise termination.

It is plausible that these same cognitive and interoceptive factors influence affective responses while children exercise. For instance, children may lack the experiences with sport and exercise that could bolster their ability to cognitively self-regulate affect during exercise. In addition, children exhibit a lack of prefrontal cortical development relative to adolescents and adults (Lebel & Beaulieu, 2009; Lebel & Beaulieu, 2011). It is this lack of development that has been theorized to be related to the tendency for children to experience difficulty inhibiting prepotent (i.e., strong or automatic) responses (Diamond, 2013; Rimm-Kaufman, Pianta, & Cox, 2000) and self-regulating their emotions, whereas adults typically have developed the cognitive necessary strategies and brain infrastructure to do so. Therefore, due to these developmental and experiential deficits, exercise intensities that approach and exceed VT (i.e., where cognitive intervention may become necessary to self-regulate affective responses) may present situations where declining pleasure (or increased displeasure) is inescapable for most children.

Statement of Purpose

The primary purpose of this study was to examine the relationship between affective responses and dorsolateral prefrontal cortical (dlPFC) function at intensities below and beyond the ventilatory threshold (VT) during incremental cycling exercise among children.

The second purpose was to investigate whether theoretically relevant covariates moderate affective responses and dlPFC activation during exercise. Specifically, the emotionally relevant covariates affective lability and goal-orientation were examined. Additionally, cognitive developmental, biological, and experiential factors may influence the ability to recruit the dlPFC to self-regulate affective responses. Therefore, age, sex, body mass index (BMI), cognitive inhibition (Eriksen Flanker Task), total PA, and sport experience were also examined as covariates.

Finally, because activity of the dlPFC may be involved with inhibitory control during both exercise affective self-regulation and general executive functions, the final purpose of the present study was to examine whether the recruitment of dlPFC resources to self-regulate affective responses during exercise would be related to subsequent tests of inhibition.

Research Hypotheses

The following hypotheses were examined.

Hypothesis 1

At intensities below VT, dlPFC activity would be negatively associated with affective responses (i.e., affective responses would decline, and dlPFC activity would increase), while at intensities above VT, they would be positively associated (i.e., both affective responses and dlPFC activity would decline concurrently).

1a. Below VT, the slopes of affective responses and dlPFC activation would be moderated by age, sex, BMI, affective lability, goal orientation, total PA, total sport experience, and cognitive inhibition prior to exercise.

1b. While exercising at intensities above VT, these covariates would not moderate the slopes of the relationship between dlPFC activity and affective responses.

To test hypothesis 1, multivariate multilevel growth models were used to examine the slopes and slope covariances between affective valence and dlPFC activation at intensities below and above VT. Hypotheses 1a and 1b were examined using separate linear growth models with the addition of the hypothesized covariates at intensities below and above VT.

Hypothesis 2

Affective valence, dlPFC activity, and time spent at intensities above VT would be negatively associated with postexercise inhibition scores.

Hypothesis 2 was examined by regressing postexercise inhibition scores on affective valence, dlPFC activity, and time spent at intensities above VT.

CHAPTER 2. LITERATURE REVIEW

Over the past two decades, exercise psychology has begun to embrace novel paradigmatic approaches to PA promotion. A growing number of researchers are beginning to appreciate that, because PA is a relatively complex behavior, modifying it likely requires approaches different from those used successfully for other health-related behaviors, such as smoking cessation or teeth brushing (Ekkekakis et al., 2011). Until recently, most PA interventions have been overwhelmingly grounded on information-processing, or cognitivist theories (Ekkekakis & Zenko, 2016), according to which human behavior is assumed to be rational and highly amenable to cognitive influences (e.g., because people understand that exercise is good for them, the rational behavior is to participate in exercise). However, contemporary models of PA have approached the issue from both a hedonic (pleasure-displeasure; Ekkekakis, 2009b) and a dual-process perspective (Brand & Ekkekakis, 2017). These models posit that both automatic and reflective (i.e., cognitive) processes underpin decision-making. Although, under certain conditions, humans are gifted with a high capacity for deliberate and rational thought, often, the most meaningful influence on behavior is simply the automatic affective association or "gut reaction" that signals whether the activity brings pleasure (i.e., signals utility) or displeasure (i.e., signals potential danger). Because recent research suggests that adults may have already-established automatic affective associations for PA (Antoniewicz & Brand, 2014; Brand & Ekkekakis, 2018; Chevance et al, 2017), early affective experiences during PA may play a critical role in shaping affective associations that may prompt subsequent behavior (Ladwig et al., 2018; Vazou et al., 2019).

The link between exercise intensity and affective responses has been clarified and is reliably observed among healthy adults (Ekkekakis et al., 2011). Specifically, affective responses during exercise are nearly homogeneously pleasant at intensities below the gas-exchange VT, with response heterogeneity proximal to the VT, and ending with homogeneous declines in pleasure above the respiratory compensation point (RCP). Theoretically, this intense displeasure is experienced above the RCP to compel exercise termination before potentially fatal homeostatic perturbations occur. The changes in affective responses that accompany increasing exercise intensities are hypothesized to be driven by two factors, cognitive (e.g., exercise self-efficacy, self-talk) and interoceptive (e.g., muscular pain and fatigue). Below the VT, neither factor particularly influences affect, as the exercise intensity has not yet reached a level where cognitive strategies are necessary to persevere. However, as intensities approach VT, cognitive factors account for most of the heterogeneity in affective responses. At this point, breathing becomes labored, and metabolic byproducts begin to accumulate (e.g., hydrogen ions) more rapidly than they can be expelled. As these metabolites accumulate and are accompanied by increased perceptions of discomfort and fatigue, factors such as previous exercise experiences (i.e., self-efficacy; Bandura, 1986), and other cognitive strategies (i.e., attentional dissociation, cognitive reframing of the displeasure) may be engaged to self-regulate how one feels. However, without these cognitive strategies, exercisers may have difficulty controlling their affective responses, which may lead to increasing displeasure. Finally, once intensity surpasses the RCP, affective responses are influenced predominantly by interoceptive cues. When individuals reach these intensities, both those with and without exercise experience generally report increasing feelings of displeasure.

Despite hypotheses having been put forward, the mechanisms underlying affective responses to exercise have yet to be elucidated. One hypothesized mechanism (Ekkekakis, 2009a) focuses on the action of the dorsolateral prefrontal cortex (dlPFC), a brain region that is reliably shown in neuroimaging studies to be involved in the downregulation of negative affective responses, exhibiting an inverse relationship with activity of the amygdala (i.e., presumably, a top-down inhibitory effect). Recent work during exercise, using near-infrared spectroscopy (NIRS) has revealed that at intensities above the RCP, the dlPFC undergoes rapid deoxygenation, especially among untrained individuals (Ekkekakis, 2009a). Some speculate that this decreasing dlPFC oxygenation near the limit of human tolerance reduces the ability to engage top-down cognitive strategies to self-regulate affective responses. Subsequently, displeasure increases sharply during the minutes preceding volitional exhaustion, eventually leading to exercise termination. However, whether these cognitive and hemodynamic mechanisms function similarly in children and adolescents remains unknown.

Affective Responses during Exercise among Adolescents

Data collected during incremental exercise tests among adolescents have revealed dose-response patterns of affective responses to exercise that closely resemble those collected from adults. However, in contrast to the multitude of studies among adult samples, only three studies, published by the same laboratory, have investigated affective responses to incremental exercise among adolescents. Data collected from two studies (Sheppard & Parfitt, 2008; Stych & Parfitt, 2011) reported stable or increasing ratings of pleasure at intensities below VT and rapidly declining valence above VT. However, a subsequent study (Hamlyn-Williams et al,, 2014) with only girls showed that pleasure declined consistently throughout incremental exercise. However, in each study, self-selection of intensity improved affective responses, despite no significant differences in intensity between the prescribed and self-selected exercises (i.e., adolescents appear to self-select intensities that meet established recommendations for health). These results are consistent with the literature relating to the influence of self-selected intensity on affective responses among overweight adults (Ekkekakis & Lind, 2006). However, it is plausible that adolescent girls may experience incremental exercise differently than do boys, making it crucial that subsequent studies examine individual as well as group-level differences.

Affective Responses during Exercise among Children

Although PA during early childhood can, at times, appear to be ubiquitous and instinctual, around the transition from childhood to adolescence, the number of children failing to meet minimum PA recommendations increases sharply (Caspersen et al., 2000; Farooq et al., 2018; Troiano et al., 2008; Van Mechelen et al., 2000). The explanations for these decreases in PA are multifactorial, making promoting sustainable exercise and PA among children one of the most challenging issues with which exercise science must contend. Many groups, including the American College of Sports Medicine (ACSM) and the United States Department of Health and Human Services (USDHHS), recommend that children "accumulate a minimum of 60 minutes of physical activity daily" and that the activities should be a combination of moderate and vigorous intensity.

Although a handful of studies have examined affective responses to PA among adolescents, investigations with children are very limited. The only extant data suggest that affective responses to exercise among children differ markedly from data collected among adolescents and adults. Specifically, Benjamin and colleagues (2012) demonstrated that children reported less pleasure (or increasing displeasure) from the beginning of an incremental treadmill exercise test. In addition, the children elected to terminate the tests prematurely, while physiological parameters were still well below levels that would have indicated maximal aerobic capacity. Earlier studies have also reported this phenomenon, suggesting that children often do not persevere to their true maximal capacity during exercise testing (Washington, van Gundy, Cohen, Sondheimer, & Wolfe, 1988). One factor that may explain the pattern of responses reported by Benjamin and colleagues (2012) is that children might have limited capacity to cognitively self-regulate their affective responses. Specifically, children may experience an absence of dlPFC oxygenation or an earlier onset of dlPFC deoxygenation (e.g., at or near the VT) that could be manifested through reduced self-regulatory capacity.

Another potential explanation for these results is that incremental and/or continuous physical activities do not match the movement patterns in which children naturally engage. For instance, studies investigating the patterning of PA using direct observation have revealed that children gravitate toward intermittent PA that is mostly of a light-to-moderate intensity, spending only very short bursts (i.e., ~6s) at vigorous intensities (e.g., when playing tag; Bailey et al., 1995). Consequently, some of the physical activities in which children are required to participate, such as fitness testing during PE, may be incompatible with their innate movement propensities, and, therefore, might be experienced as less pleasant. These activities may engender repeated negative affective and emotional experiences (e.g., displeasure, embarrassment) that could ultimately lead to reluctance to engage in PA later in life. Despite accumulating evidence suggesting that some children intensely dislike fitness testing, even going so far as requesting doctors' notes or being absent to avoid them (Ladwig et al., 2018; Packham & Street, 2018), fitness tests continue to be largely mandated with official scoring of aerobic fitness beginning at age 10 (Welk, Saint-Maurice, Laurson, & Brown, 2011). Although there are no aerobic fitness norms for children under 10 years of age, the Cooper Institute (2007) suggests that children between the ages of 5 to 9 years complete the tests as practice. Many arguments have been put forward in support of continued fitness testing in schools, however, some of the most common relate to their use as an educational tool that represents part of the "process" leading to the "outcome" of fitness (Wiersma & Sherman, 2008, p. 174). Therefore, it is assumed that, if children are taught to understand the *value* of fitness, then they will come to enjoy the *process* involved in attaining it. Furthermore, PE programs that fail to instill these values may be considered failing to meet educational objectives, and PE teachers in these "failing" programs may be evaluated unfavorably. However, the evidence reviewed in the previous paragraphs begs the question as to whether these tests, designed to elicit near-maximal aerobic output, can be made to be "pleasantly experienced" or "perceived as enjoyable" for most children.

The following pages are devoted to exploring these questions and to offering explanations for the apparent differences in affective responses during PA among children, adolescents, and adults. To that end, these questions were approached from three distinct but tightly interwoven perspectives, namely, evolutionary psychology, developmental psychology, and affective neuroscience.

On the Role of Evolutionary Adaptation

Not long after birth, children become mobile creatures. Especially during developmental periods such as toddlerhood, parents may have difficulty keeping pace with their child's propensity for movement. These ostensibly innate PA behaviors may have been influenced by an evolutionary adaptation through the process of natural selection. For example, play behaviors, such as tag, are theorized to be vestigial remnants from our ancestors, among whom the ability to dodge, chase, and flee were integral for survival (Fagen, 1981). Those without these capabilities may not have survived to biological maturity and, with it, the chance to reproduce. Perhaps it is not surprising, then, that play is observed in nearly all higher-order animal species (Aldis, 1975; Fagen, 1981). Because of its utility for survival, play, just as with other basic survival behaviors, such as eating, drinking, and sexual activity, came to be reinforced through the rewards of pleasure and perceptions of enjoyment (Lee, Emerson, & Williams, 2016). Hence, modern humans may continue to engage in play as "practice" for behaviors rendered by modern life as mostly unnecessary, such as chasing prey and fleeing predators.

So, what mechanisms implore children to gravitate toward intermittent low-to-moderate-intensity PA? Why might they report displeasure during incremental PA? Would it not be more utilitarian to practice these forms of PA for more effective fleeing and chasing? Answering these questions requires considering the processes of evolutionary adaptation. Specifically, for adaptation to occur, a persistent challenge for survival needs to exist (Tooby & Cosmides, 2008). Some of the challenges to survival that accompany sustained periods of vigorous-or-near-maximal-intensity PA include energy exhaustion and homeostatic perturbation (i.e., disturbed physiological steady-state). These challenges could lead to injury or death if no mechanism were in place to compel PA termination, allowing a return to homeostasis. Therefore, as theorized by Ekkekakis and colleagues (2005a), negative affective responses to PA experienced at intensities that disrupt homeostasis continue to manifest as the same feelings that compelled our ancestors to terminate PA prior to injury and possible death. Because evolutionary adaptations occur over many millennia, modern humans may not have had the adaptational impetus that would drive children to inherently seek out and tolerate incremental and sustained vigorous-intensity PA. Whether it is possible to intervene in a manner that overrides these seemingly natural attractions to other forms of PA remains unclear. However, theoretically, for *some* children, depending on their level of maturation and past experiences, it may be possible to cognitively self-regulate their affective responses during incremental or continuous vigorous-intensity exercise to some extent.

The Influence of Cognitive Development

According to Dual-Mode Theory (Ekkekakis, 2009b), cognitive processes are important mechanisms involved in the regulation of affect during exercise, especially when performed at challenging, but manageable, intensity. Hence, in laboratory conditions, healthy adults seldom report declining affective valence in the moderate-intensity domain of PA, as the intensity may be easily manageable and, therefore, not warranting self-regulatory strategies (though this may not be the case among adults with overweight and obesity; Ekkekakis & Lind, 2006). Conversely, at intensities proximal to and beyond VT, interoceptive cues, such as the discomfort associated with accumulating metabolic waste, begin to infiltrate consciousness. Here, cognitive self-regulatory strategies might be spontaneously or deliberately implemented to self-regulate affective responses and facilitate perseverance (i.e., continuing despite increasing discomfort). Therefore, most variability in affective responses during the heavy-intensity domain (i.e., above VT) is explained by factors such as exercise self-efficacy (e.g., "I have succeeded in this activity before"; McAuley, Blissmer, Katula, & Duncan, 2000), sport experiences, and experiences with the same or other exercises (e.g., the belief that suffering is a necessary part of exercise; Ekkekakis, Ladwig, & Hartman, 2019). The constructs *preference for* and *tolerance of* the intensity of exercise have been proposed (Ekkekakis, Hall, & Petruzzello, 2005b) that could differentiate those with exercise self-regulatory capability from those who would likely report discomfort during exercise intensities near or above VT. Like many personality traits, exercise intensity preference and tolerance could be partially explained by genetics, but, ultimately, some interindividual variation may be explained by accumulated exercise experiences and deliberate practice (Macnamara, Hambrick, & Oswald, 2014).

Therefore, negative affective responses (Benjamin et al., 2012) and the often-suboptimal performances provided by children during exercise testing (Rowland, 1989; Washington et al., 1988) are unsurprising for a few reasons. First, the laboratory settings were likely novel to the children and may have evoked fear or apprehension. Secondly, the exercise modality, a treadmill, was likely unfamiliar to most of the younger children. These children may have struggled with and experienced artificially inflated ratings of displeasure while using the new-to-them exercise apparatus. Third, the children had little reason to challenge themselves on these tests (perhaps unless they were athletes or wanted to “show-off” in front of peers or the researchers) and may not have understood the rationale for the test, as has been reported during fitness tests in school (Hopple & Graham, 1995). Finally, most children probably had underdeveloped or nonexistent cognitive strategies to self-regulate their affective responses, such as through attentional dissociation (e.g., focusing attention to something other than the sensations accompanying exercise; see Jones, Karageorghis, & Ekkekakis, 2014) or cognitive reframing (e.g., telling oneself that pain “is a good thing").

A reduced capacity to cognitively inhibit distracting feelings or conflicting information among children (and some adolescents) might introduce additional barriers to the self-regulation of affective responses during exercise (Brooks, Hanauer, Padowska, & Rosman, 2003; Casey & Caudle, 2013; Garon, Bryson, & Smith, 2008; Martin & Ochsner, 2016). Inhibition encompasses the ability to “control one’s attention, behavior, thoughts, and/or emotions to override a strong internal predisposition or external lure, and instead do what’s more appropriate or needed" (Diamond, 2013, p. 137). For example, dissociation of attention outside the body and away from interoceptive cues, such as through music or television, has been found to improve affective responses among adults when the intensity becomes challenging (Jones et al., 2014). However, these and other similar abilities depend on the prefrontal cortex, a brain region underdeveloped in children (Tau & Peterson, 2010). Therefore, the inability to dissociate during increasing exercise intensity due to the physiological and functional development of the brain could make it difficult for children to cognitively self-regulate their feelings of displeasure during exercise.

In addition, achievement-goal orientation may explain differences in affective responses during exercise among children. According to Achievement-Goal Theory (AGT; Ames, 1992; Nicholls, 1989), individuals evaluate their competence and success for a behavior using a mixture of task and ego-related criteria. Therefore, where a child places his or her emphasis may prove important for the experience of exercise and PA. Children who are task-oriented are more likely to engage in PA for personal improvement or for the sake of the movement itself. These children perceive success by focusing on self-referenced criteria, such as mastery and learning, and view mistakes or underperformance as part of the learning process. These children are usually not threatened by the competence of others rather, they are more focused inward (Vazou, Ntoumanis, & Duda, 2005). Accordingly, an environment or activity that supports task-oriented children is related to positive affect, intrinsic motivation, and enjoyment (Harwood, Keegan, Smith, & Raine, 2015; Jõesaar, Hein, & Hagger, 2011; Vazou, Ntoumanis, & Duda, 2006). In contrast, ego-oriented individuals derive perceptions of success from interindividual competition and demonstrations of superior ability. In competitive climates or other ego-involving tasks, children identify outperforming others as a factor that influences their experience (Vazou et al., 2005). Accordingly, ego-involving environments and activities may be associated with increased instances of negative affect and anxiety, especially among those not endorsing an ego-orientation (Harwood et al., 2015; Vazou et al., 2006).

Children may also respond with displeasure to incremental and continuous vigorous-intensity exercise because they are not born with an innate "schema" for exercise testing, a concept that may have only existed for a brief sliver of human history. The existence of cognitive schemata was postulated by the developmental psychologist Jean Piaget (1923) in the early 20th century. Accordingly, schemata are the stored memory "blueprints" that develop through accumulated experiences. Theoretically, over time, humans develop and store schemata for all behaviors and situations. Subsequently, schemata serve as heuristics, or rules of thumb, for making rapid decisions when under time constraints or when attention is limited. When attention or time is limited, existing schemata are retrieved from memory to help make sense of a situation and to inform the proper behavioral response (Kleider, Pezdek, Goldinger, & Kirk, 2008). For young children, there may be no innate conception of what modern exercise is or "should look like," as modern "exercise" may not be necessary to sustain the proliferation of the human species. Therefore, children may engage in play behavior as an innate consequence of human adaptational history and adopt modern exercise behaviors if prompted by their cultural and social environment. One way to illustrate this phenomenon is to attempt to recall instances in which children have been witnessed voluntarily engaging in sustained training runs. However, if parents bring children with them during training runs, perhaps first in a stroller, and, as the child ages, running side-by-side, a schema of "running for exercise" may develop. In addition, through experience, new information may be assimilated (Piaget, Piercy, & Berlyne, 2001) into existing schemata. For example, when children are exposed to sports, they may be exposed to the constructs of competition and perseverance (e.g., persevering through discomfort) which may be integrated into their schema for exercise.

However, individual differences must be considered. Given that past experiences are considered the strongest predictor of self-efficacy (Higgins, Middleton, Winner, & Janelle, 2014), childhood is a sensitive period that could predispose an individual for success or failure with PA adherence. Although experiences with exercise during childhood may lead to strategies for deriving pleasure from incremental or continuous-intensity exercise, deeper, neurophysiological changes may preclude most children from effectively utilizing cognitive strategies to self-regulate their affective responses during exercise. These requisite developments could limit the potential to educate children to use cognitive strategies during exercise, even rendering them counterproductive in instances in which self-regulatory success is untenable.

The Role of Neurophysiological Maturation

By late adolescence and adulthood, most of the brain regions that subserve cognitive functions and affective and emotional self-regulation are well-established (Casey, Jones, & Hare, 2008). Dense areas of gray matter (i.e., neurons with unmyelinated axons) in the prefrontal cortex (PFC), begin to thin and are replaced by myelinated white matter (Gogtay et al., 2004; Sowell, Thompson, Holmes, Batth, Jernigan, & Toga, 2004). In normally developing adolescents and adults, increases in white matter in brain regions relating to executive control (e.g., PFC) are associated with increased ability to manage affective responses and emotions, even in situations in which there are motivational or emotional conflicts (Aldeman et al., 2002; Bunge, Dudokovic, Thomason, Vaidya, & Gabrieli, 2002). This top-down cognitive regulation of affective responses and emotions is also facilitated by increased reciprocal interconnectivity between the PFC and limbic structures, such as the amygdala (Ernst & Fudge, 2009).

The amygdala, a small almond-shaped structure in the medial temporal lobe (Swanson & Petrovich, 1998), has, until recently, been mostly associated with simple fear conditioning and negative affective and emotional responses (Weiskrantz, 1956). Recent findings have dramatically redefined the amygdala as a brain region responsible for evaluating the motivational importance of stimuli, using these evaluations to reinforce behavior (Holland & Gallagher, 2004). Additionally, the amygdaloid structure has been shown to directly influence cognitive functions, such as attention and perception (Phelps & LeDoux, 2005), through dense interconnections with the regions that underlie cognitive self-regulation, such as the dorsolateral and dorsomedial prefrontal cortices. Interestingly, the regions of the PFC that relate to cognitive self-regulation have few connections that directly influence the amygdala, making it difficult for the PFC to override negative affective responses that may be associated with maladaptive stimuli, such as pain. However, in cases in which the stimulus causes discomfort, but not a threat to life or homeostasis, cognitive reappraisal (e.g., reframing) and dissociation strategies may be employed to influence the action of the amygdala (Phelps, 2006).

The amygdala may also influence the PFC indirectly. For example, when the amygdala receives emotionally salient information, it initiates a cascading release of neuromodulatory chemicals – the catecholamines (i.e., norepinephrine, dopamine), that can alter cognitive processing. In addition, amygdala activity is followed by the release of hormones (McGaugh, 2000), such as glucocorticoids, that travel the bloodstream from the adrenal cortex to the pituitary gland, and eventually attach to the basal aspect of the amygdala. Projections from the basal amygdala may influence hippocampal encoding of emotional experiences, enhancing their storage and retrieval. Thus, the action of the amygdala extends far beyond simple fear conditioning, to an integral "relevancy detector" and "facilitator" for both innate and learned behaviors that increase or attenuate the odds of survival.

The interactions between the PFC and amygdala could also provide explanations for the variability in affective responses during incremental and vigorous-intensity exercise. Ekkekakis (2009a) suggested that, among adults, during moderate-to-heavy-intensity exercise (i.e., 25-75% peak power, ~60% VO_{2max}), significant increases in PFC oxygenation (and, presumably, increased activity) occurs (Ide, Horn, & Secher, 1999; Subudhi, 2007). However, there is considerable interindividual variability as to what intensities facilitate these increases in PFC activity. On the other hand, there is considerably less variability when intensities reach "severe" levels, delineated by the respiratory compensation point (RCP; Bhambhani et al., 2007). At and beyond RCP, especially among untrained individuals, the right PFC, in particular, rapidly deoxygenates until exercise termination. It is theorized that this deactivation, largely confined to the dorsolateral prefrontal cortical (dlPFC) region, may limit the individual's capacity to engage cognitive strategies to downregulate activation in the amygdala (Davidson, 2004; Ekkekakis, 2009a). As the dlPFC influence over the amygdala is reduced, unpleasant interoceptive cues become overwhelming, eventually compelling exercise termination.

Unfortunately, it appears that, given the limited previous research on affective and neurophysiological responses to exercise among children, it may be assumed that their affective responses and self-regulatory mechanisms may function similarly to those of adolescents and adults. However, given the preliminary evidence on the pattern of affective during an incremental exercise test among children (Benjamin et al., 2012) and their proclivity for intermittent, light-to-moderate-intensity physical activities (Bailey et al., 1995), it is plausible to suggest that, in this respect, children are not "little adults."

The human brain develops in a proximodistal manner. The earliest developing regions of the fetal brain are the most "automatic" and evolutionarily archaic and include the hindbrain and midbrain regions. The forebrain, which will comprise the cerebral cortex, begins to differentiate last (Stiles & Jernigan, 2010). From fetal development until early adulthood, neuronal interconnectivity, along with dendritic density, increases dramatically (Toga et al., 2006). In addition, gray matter decreases with age, improving information processing speed and efficiency. However, the most delayed gray to white matter myelination takes place in the prefrontal cortical regions (see Figure 1), where development may last into the late teenage years, and even the early-to-mid twenties (Lebel & Beaulieu, 2009). Consequently, the dlPFC is among these slow-developing regions which may underly the ability to self-regulate affective responses, (D'Esposito, 2007). Moreover, neuronal projections between the amygdala and the prefrontal cortex that allow for the cognitive downregulation of the amygdala are usually not well-established until adolescence (Ladouceur, Schlund, & Segretti, 2018).

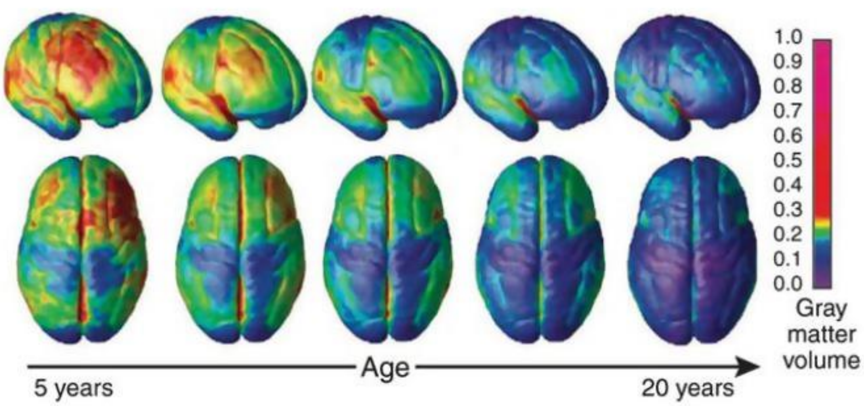


Figure 1. Gray matter maturation across development. This image represents data from 52 anatomical MRI scans from 13 individuals aged 4-21 years, scanned four times at approximately 2-year intervals. Color scale represents gray matter units of volume (reproduced from Gogtay et al., 2004)

Given these developmental discrepancies between children and adolescents, we can hypothesize that one of the limiting factors that may explain increasing displeasure throughout incremental exercise (Benjamin et al., 2012) and continuous, submaximal exercise, is that children lack the neurophysiological "infrastructure" to effectively self-regulate their affective responses during exercise. Because of this developmental delay, children are often more susceptible to negative and unpleasant stimuli (Silvers et al., 2017), as evidenced by reports of greater displeasure to negative stimuli, accompanied by increased amygdala activity. In some respects, it could be argued that children have hyperactive or “runaway” amygdalae that detect and respond to perceived threats more readily, while at the same time having limited dlPFC capacity to downregulate amygdala activity. Given this evidence, children who are instructed to self-regulate their affective responses during exercise through cognitive strategies may quickly exhaust their finite cortical capacity. Some children may come to understand conceptually how cognitive reframing and dissociation techniques work, but dlPFC underdevelopment may limit their ability to effectively employ them.

CHAPTER 3. METHODS

Participants

Sample size estimation remains a contentious subject in multilevel modeling (MLM) approaches. A few problems arise when attempting power analyses with MLMs, but one of the primary issues is their hierarchical, nested structure. Because each level typically includes different sample sizes, it is difficult to power the study sufficiently for each level. However, it has been demonstrated through simulations (Maas & Hox, 2005) that at the highest level of clustering (in the present study, the participant-level) 50 or more participants should be included to avoid biased estimates of standard errors.

To participate in the present study, children had to be deemed healthy enough to participate in vigorous-intensity exercise (assessed via the pediatric version of the Physical Activity Readiness Questionnaire, PAR-Q; Adams, 1999). They also had to be 7-to-9 years of age, speak English as a first language, have normal or corrected vision, have the ability to exercise on a bicycle ergometer, and be able to provide verbal assent. Fifty-six (n_{girls}= 27, n_{boys} = 29) participants ($mean_{Age}$ = 8.07, SD = 0.50 years) met these inclusion criteria and were recruited to participate in the current study using email and flyers. See Table 1 for full descriptive information. University Institutional Review Board approval was attained prior to study initiation. The participants were paid $25 for their time.

Table 1. Sample descriptive statistics.

Variable	**Mean ± SD**
Height (cm)	130.52 ± 8.89
Body mass (kg)	30.70 ± 8.17
Body Mass Index (kg/m²)	17.81 ± 3.13
Body fat (%)	20.44 ± 7.72
V_{O2peak} (ml/kg/min)	50.74 ± 12.02
Test duration (min)	9.00 ± 2.68
PA during week (hours)	6.75 ± 3.32
PA on weekend (hours)	4.64 ± 1.84
Sedentary time (hours)	4.96 ± 1.82
Total sport experience (years)	2.29 ± 1.62

Measures

Measures Completed by Children

Pediatric adaptation (Hulley et al., 2008) of the Feeling Scale (FS; Hardy & Rejeski, 1989)

The FS (see Appendix A) is an 11-point bipolar measure of affective valence that was adapted for children by Hulley and colleagues (2008).The scale ranges from +5, or "I feel *very good*" to -5, or "I feel *very bad*" with verbal anchors included at zero (*neutral*) and each of the odd-numbered responses, along with visual anchors included at every value. Hardy and Rejeski (1989) provided evidence of the measure's concurrent validity. Although reliability may be lower than that of multiitem scales, single-item rating scales may be more appropriate *during* exercise, as they entail reduced participant burden and ease of administration.

Cart and Load Effort Rating Scale (CALER; Eston, Parfitt, Campbell, & Lamb, 2000)

The CALER (see Appendix B) is a measure of perceived exertion developed for use among children between the ages of seven to ten years of age. The CALER is a 10-point unipolar scale ranging from 1 (very easy) to 10 (so hard I'm going to stop). The scale uses images of a cyclist pulling a cart that begins empty (at scale rating 1) and adds bricks gradually to represent the increased effort needed to pull the cart. The visual anchors used in the CALER are featureless. This aspect is important in the context of the present investigation, as facial expressions may bias ratings of affective valence. Eston and colleagues (2000) provided evidence for both the concurrent validity of the CALER related to power output and data indicating intertrial reliability.

Youth Activity Profile (YAP; Saint-Maurice & Welk, 2015)

The YAP (see Appendix C) is a 15-item self-report instrument designed to capture physical activity and sedentary behavior among youth. The YAP includes a total of 15 items divided into three sections: 1) activity at school, 2) activity out-of-school, and 3) sedentary habits. Items in the "out-of-school" section include activity before school, activity right after school, activity during the evening, and activity in each weekend day (Saturday and Sunday). Sedentary items ask about time spent watching TV, playing videogames, using the computer, using a cell phone, and include an overall sedentary time item. The self-reported PA measured by the YAP has been shown to correlate with PA measured by accelerometry (r = .19 to .58).

Eriksen Flanker Task (Eriksen & Eriksen, 1974) adapted for children (Diamond et al., 2007)

To measure cognitive inhibition and selective attention, both theorized to be implicated in affective self-regulation during exercise, the Eriksen Flanker Task (see Appendix D) was utilized. The Flanker Task is composed of a set of response inhibition tests used to assess the capacity to suppress inappropriate prepotent (i.e., automatic) responses. During the task, the target object is "flanked" by non-target stimuli that correspond either to the same directional response as the target (congruent flankers), to the opposite response (incongruent flankers), or to neither (neutral flankers). As in previous investigations (Rueda et al., 2004), children were seated in front of a tablet computer propped up on a stand at a constant angle. To improve consistency between participants, the fingers of the left and right hands were rested on strips of tape positioned on the left and right sides of the bottom of the stand just below the bottom edge of the tablet screen. The tape was designated the "starting point" where the participants rested their fingers until the stimulus appeared on the screen, only then leaving the tape with their index finger to press the left or right response button on the screen. Immediately afterward, the participants returned their index finger to the starting point.

The participants completed a series of three trials, each preceded by a practice trial, during which they were presented with a stimulus comprising horizontally oriented fish (Diamond et al., 2007). During task one (the "Blue Fish" task), participants responded by pressing the button corresponding to the direction in which the central target blue fish was facing. In neutral trials, the target fish was presented alone. In congruent trials, the target was flanked by two pairs of blue fish oriented in the same direction as the target, whereas in incongruent trials targets were flanked by two pairs of blue fish oriented in the opposite direction of the target. Task two (the "Pink Fish" task) was like the first except that, in this instance, the participant attended to the orientation of the two *outer* pairs of pink fish, as opposed to the center blue fish. Throughout congruent trials, the center fish was oriented in the same direction as the outer target fish, whereas, in incongruent trials, the center fish was oriented in the opposite direction of the target fish. During neutral trials, no center pink fish was presented. Task three was designed as a task-switching measure. During these trials, the participants were presented with a random stimulus from either task one or task two. In this case, the participants were required to both remember the rules from the preceding tasks and shift their attention between the two sets of rules.

Task and Ego Orientation in Sport Questionnaire (TEOSQ; Duda, 1989)

The 13-item TEOSQ (see Appendix E) was used to measure achievement-goal orientation. The two orientations that are assessed by the measure are "task" orientation, which is a focus toward task mastery and/or personal improvement, and "ego" orientation, characterized by a focus on achieving superiority over others. Each of the items is prefaced by the stem, "I feel most successful in sport when…" Task-orientation items include examples such as "I learn a new skill and it makes me want to practice more," while ego-orientation items include "I'm the only one who can do the play or skill." Each TEOSQ item is rated using a 5-point Likert-type scale that ranges from "strongly disagree" to "strongly agree." Previous work has reported satisfactory reliability among children (Duda, Fox, Biddle, & Armstrong, 1992; Fox, Goudas, Biddle, Duda, & Armstrong, 1994). The reliability estimates in the present sample were acceptable, at $\alpha = 0.78$ for the task scale and $\alpha = 0.72$ for the ego portion of the questionnaire.

Measures Completed by Parents/Guardians

Emotion Regulation Checklist (ERC; Shields & Cicchetti, 1997)

The ERC (see Appendix F) is a 24-item measure that is completed by someone who knows the child well (e.g., the parent/guardian). Each of the items is scored using a 4-point Likert-type scale with anchors for each item (1 = never, 2 = sometimes, 3 = often, 4 = almost always). The scale is comprised of two subscales, Lability/Negativity and Emotion Regulation. Emotion Lability/Negativity items are intended to assess the child’s mood swings, anger, and intensity of emotions. Some of the items include examples such as: “How often does your child quickly change their mood or experience mood swings? How often is your child easily frustrated? How often is your child prone to angry outburst or tantrums?" The Emotion Lability/Negativity scale is scored from 15-60 with a higher score indicating greater emotion lability. Emotion Regulation items are intended to assess the social appropriateness of the child's emotions, emotional understanding, adaptive regulation, and empathy. Some of the items included examples such as "How often is your child cheerful? How often does your child seem sad or listless? How often can your child say when he or she is feeling sad, angry or mad, fearful or afraid?" Shields and Cicchetti (1997) reported satisfactory reliability data for each subscale (α = .96, .83 for Emotion Lability/Negativity and Emotion Regulation subscales, respectively). In the present sample, the reliability coefficients were acceptable for the Emotion lability/Negativity subscale ($\alpha = 0.80$). However, like previously reported (Lincoln, 2014), the reliability for the Emotion Regulation subscale was low ($\alpha = 0.54$). Because of this low reliability, the Emotion Regulation subscale was not used in subsequent analyses.

Sport Participation and Experience (see Appendix G)

As an additional covariate, parents or guardians reported in which sports, if any, their child participated, as well as the corresponding number of years of experience. The data provided were summed to form a total sport experience variable for use in subsequent analyses.

Procedure

This study was approved by the Iowa State University Institutional Review Board (IRB; see Appendix A) and was conducted at the Exercise Psychology Laboratory. Prior to data collection, the researcher obtained informed consent from the parents/guardians, as well as responses to the pediatric PAR-Q, followed by verbal assent from each child. Participant height was measured (wall-mounted stadiometer) as well as body mass and body composition via bioelectrical impedance (Tanita, Arlington Heights, IL, USA).

The participants visited the laboratory once. Prior to and following the exercise portion of the session, the child completed the Eriksen Flanker Task. While the child completed the Eriksen Flanker Task, the parent/guardian responded to the ERC and sport experience questions. Following this, the participants completed an incremental cycle ergometric (Corival Pediatric Ergometer, Lode B.V., Groningen, Netherlands) exercise test to volitional exhaustion. To reduce the perception that they were being watched, children were separated from the researcher during the exercise test with dividers. In addition, the bicycle was positioned facing a white wall with a fixation cross located at the participant's eye-level. The child was instructed to look straight ahead at the fixation-cross during exercise. During exercise, expired gases, dorsolateral prefrontal cortical (dlPFC) hemodynamics, affective valence, and perceived exertion were recorded. The ergometer was first adjusted for comfort. Next, NIRS sensors were positioned on the forehead over the dorsolateral prefrontal cortex of both the right and left hemispheres (i.e., AF3 and AF4 in the International 10-20 system) using a template (pediatric BrainNet, JNS, Redlands, CA). The sensors were secured to the head with a flexible opaque bandage to prevent ambient light intrusion. NIRS data were recorded at 1 cycle-per-second (1 Hz). To measure expired gases during the exercise test, a face mask with a two-way rebreather valve was attached to the head using elastic straps. The mask was checked for fit and leakage prior to connection to the metabolic cart. Metabolic data were collected using a Parvo Medics TrueOne 2400 metabolic analysis system. VT was identified using the procedure recommended by Gaskill and colleagues (2001). Accordingly, VT was determined via the agreement between two raters using the ventilatory equivalent method, excess CO_2 method, and V-slope method. Although RCP was not expected to be identifiable in all cases, the raters were unable to determine RCP from any participant data. Following the determination of VT, the FS and NIRS data were split into baseline to VT-1 min and VT to volitional termination time segments for subsequent data analyses.

Based on recommendations for an approximately 9- to-12-minute test among sedentary children, the exercise began at 10W of resistance for 30 s and increased linearly based on the participant's weight. Because during pilot testing, children struggled to provide enough data for analysis, the intensity was set at 0.15 W/kg/min, as opposed to the 0.25/W/kg/min recommended for a homogenously active sample (Tanner, Heise, & Barber, 1991). Children cycled until the point at which they decided to terminate the test. They were instructed to maintain a cadence between 50-80 revolutions per minute (RPM). If a child dropped below 50 RPM for more than 10 seconds, the test was terminated. The child was not offered verbal encouragement at any point during the test, as this may bias estimates of VO_{2max} (Midgley, Marchant, & Levy, 2018) and could have startled or artificially influenced affective responses. The only interaction between researcher and child during exercise occurred during the opening minute if the child was not maintaining the required cadence, in which he or she was encouraged to “keep the light green for as long as possible.” Pilot testing revealed that many children had difficulty maintaining a consistent cadence during the test. To aid the children, only the section of the monitor corresponding to the desired cadence range was visible. In this setup, a green light indicated an acceptable cadence, a yellow light too slow, and a cadence that was too high caused the green light to disappear. After exercise termination, the participant was provided with up to a 5-min cool-down.

Psychological scale ratings (i.e., FS) were recorded at baseline (i.e., after NIRS sensors had been positioned but prior to fitting the mask and beginning exercise) and at 1-min intervals during exercise. To reduce the inconsistency possibly introduced by humans verbally administering repeated self-report measures, instructions and responses to the scales during exercise were prompted and recorded using a female computer-generated voiceover on the tablet computer. Fivemin following exercise termination, the child completed the postexercise Eriksen Flanker Task. Finally, the child completed the TEOSQ followed by the YAP.

Near-Infrared Spectroscopy (NIRS) data preprocessing and restructuring

Raw NIRS data were imported to MatLab (MathWorks, Natick, MA) for cleaning and restructuring prior to analyses. Currently, few standardized recommendations are available for preprocessing NIRS data. Therefore, recent recommendations provided by Pinti, Scholkmann, Hamilton, Burgess, and Tachtsidis (2019) were used to inform the methodology implemented here.

First, movement artifacts (i.e., inflections in the signal that were much larger than the typical hemodynamic signal) were analyzed and removed using the NIRS Analysis Package (NAP; Fekete, Rubin, Carlson, & Mujica-Parodi, 2011). The NAP uses piecewise low-order polynomial interpolation to reconstruct data segments affected by movement artifacts. In the present sample, removing inflections 0.5 standard deviations above or below the mean response during each 20 s window satisfactorily reduced noise while maintaining the integrity of the original signal. Next, the denoising algorithm of Feuerstein, Parker, and Boutelle (2009) was applied. The goal of this algorithm is to separate the noise from the signal given their differences in amplitude (assuming the noise has larger amplitude than the underlying hemodynamic signal). The algorithm first calculates the difference between the original signal and a smoothed signal resulting from a quadratic Savitzky-Golay filter and then uses a histogram of this signal difference to iteratively seek the filtering threshold that minimizes the variance overlap between the presumed signal and the presumed noise.

The final data preprocessing step was accomplished using a lowpass filter. Because these data were collected at a low frequency (1 Hz), it was impossible to filter noise components above 1 Hz, such as the heart rate component (~1.3 Hz > during exercise), but low-frequency noise components could be filtered, such as respiration rate (~0.5 Hz > during exercise) and the Mayer Waves associated with blood pressure oscillations during exercise (~0.09 Hz; Yücel et al., 2016). In addition, the low sampling frequency precluded the use of filter orders greater than 3.

Following signal denoising, a linear regression was fit over the 60 s preceding the start of the exercise and the intercept values for oxygenated hemoglobin (O_2Hb) and deoxygenated hemoglobin (HHb) were used as baseline values. Next, the baseline value was subtracted from each O_2Hb and HHb value to express data as changes from baseline. To correspond with the timing of Feeling Scale administration during exercise, the median value of each 60 s period of exercise was calculated. Next, large shifts in data were hand-processed by subtracting a constant from the minute prior to the shift. Finally, the hemoglobin difference (Bhambhani et al., 2007; Rupp & Perry, 2009), an index of cerebral blood delivery and utilization, was calculated for both hemispheres at each time point by subtracting HHb values from each corresponding O_2Hb value. These minute-by-minute median hemoglobin difference values were used in subsequent analyses.

Data Analyses

Generalized linear model

Linear regression analyses were conducted for the prediction model for Flanker Task scores postexercise.

Multilevel growth models

A multilevel growth modeling approach was used to model whether change over time in affective valence and dlPFC activation were moderated by select covariates. Although traditional repeated-measures analysis of variance (RMANOVA) remains a popular choice among researchers working with longitudinal data, these data often violate several of the ANOVA assumptions. Overall, multilevel models have less stringent assumptions. Whereas RMANOVA assumes constant variances (i.e., homoscedasticity) and constant variances of difference scores (i.e., sphericity), multilevel models do not require these be met. In addition, multilevel models allow for the data to take on a nested, hierarchical structure. In RMANOVA or traditional regression approaches, the units of analysis are treated as independent observations. Because these data are hierarchical (i.e., repeated measures nested within individuals), and not independent, standard errors of regression coefficients are underestimated, inflating Type I error. In the present study, repeated measures over time were nested within individuals, to avoid this violation of independence. Additionally, nesting data in this manner allows for the analysis of both within-and-between-subject change, or, stated alternatively, interindividual differences in intraindividual change (McArdle & Nesselroade, 2014). Finally, unlike ANOVA or linear regression, multilevel growth models do not require complete or symmetrical datasets, avoiding the reduction in power associated with listwise deletion. Each of the following models were fit based on best-practice recommendations provided by Finch, Bolin, and Kelley (2014), Gee (2014), and Grimm, Ramm, and Estabrook (2017). Analyses were performed using R (R Core Team, 2018) and the linear mixed-effects software package “lme4” (Bates, Maechler, Bolker, & Walker, 2015).

Prior to fitting a full multilevel growth model, preliminary *no-growth* and *linear growth* models were fit to the data. The no-growth model is also known as the “null” or “intercept only” model, as it predicts that the outcome variable does not change over time. It has no predictors, only fixed intercept effects at each level (i.e., effects that do not vary between subjects) that estimate the grand mean of the response across all occasions and individuals. Thus, the primary reason to fit this model is to explore whether there is within-subjects variation and to estimate the amount of between-subjects variation in the outcome. This between-subjects variance is provided by the estimates of participant-level and residual error variance.

In the linear growth model, the intercept is held constant and the slope can vary over time both within (i.e., the *fixed* effect) and between-subjects (i.e., the *random* effect). The linear model partitions and quantifies variance across both individuals *and* time. Here, the fixed effects estimate the group mean starting point (intercept) and group mean slope trajectory and the random effects estimate the variation in intercepts and slopes between subjects and the unexplained residual error variance.

After each model, the intraclass correlation coefficient (ICC) is calculated to measure the total variation in the outcome that can be explained between subjects. The ICC, ρ is calculated with the formula

$$\rho = \frac{\sigma_0^2}{\sigma_0^2 + \sigma_\varepsilon^0}$$

where σ_0^2 is the variance of the nesting factors, in this case time and participant, divided by the sum of the nesting factor variances and error variance. The amount of residual variance for each nesting factor is an indication of whether further predictors should be included to help explain it (e.g., the random and fixed effects of time).

Another decision made prior to running the following models was whether they would be estimated using maximum likelihood (ML) or restricted-maximum likelihood (REML). According to Korner-Nievergelt and colleagues (2015), "ML estimates are unbiased for the fixed effects but biased for the random effects, whereas the REML estimates are biased for the fixed effects and unbiased for the random effects … As a guideline, use REML if the interest is in the random effects (variance parameters) and ML if the interested is in the fixed effects" (p. 101). Additionally, ML is preferred for nested models. Finally, models fit with REML with differing fixed effects cannot be compared, whereas those fit with ML can (Bates & Pinheiro, 2000). In this study, because changes over time were nested within subjects, and models with differing fixed-effect structures were to be fit, ML was used.

No-growth models

The no-growth model is specified as

$$Y_{ij} = \beta_{00} + \mu_{0i} + \varepsilon_{ij}$$

where Y_{ij} is the intercept of the outcome *Y* for individual *i* at time *j*, β_{00} is the overall mean outcome score across all measurement times and individuals, μ_{0i} represents the variance in intercepts between subjects, and ε_{ij} represents the variation in intercepts within subjects.

Linear growth models

In the linear growth model, the level-1, or within-subject, model represents repeated measurement of the dependent variable over time. The level-1 results indicate whether two growth factors differ over time based on the initial status (i.e., baseline intercept value) and the effect of time on the outcome (i.e., the slope of change). Also included at level-1 is unobserved between-subjects residual error variance. The level-1 equation can be written as

$$y_{ti} = b_{1i} + \ b_{2i} \ \cdot \ \left(\frac{t - k_1}{k_2}\right) + \mu_{ti}$$

where y_{ti} is the repeatedly measured variable at time t for individual i, b_{1i} is the random intercept or predicted score for individual *i* when *t* =k_1 , b_{2i} is the random slope or rate of change for individual *i* for a one-unit change in *t*/k_2, *t* represents time, and u_{ti} is the time-specific residual score.

Because there may be interindividual (i.e., between-subjects) variability in the outcome measure at both baseline and in growth rate over time, a level-2 model is included. The level-2 equation for the random intercept and slope is written as

$$b_{1i} = \ \beta_1 + d_{1i}$$

$$b_{2i} = \ \beta_2 + d_{2i}$$

where β_1 and β_2 are sample-level means for the intercept and slope, and d_{1i} and d_{2i} are individual deviations from their respective sample-level mean. Combining these two equations leads to

$$y_{ti} = \ (\beta_1 + \ d_{1i}) + \ (\beta_{2i} + \ d_{2i}) \ \cdot \ \left(\frac{t - k_1}{k_2}\right) + \mu_{ti}$$

In the linear growth model, there are six estimated parameters. These parameters include the mean intercept (β_1) and slope (β_{2i}), representing the predicted average score for the sample when *t* = k_1 and the predicted average rate of change for the sample with respect to the chosen time metric (i.e., *t*/k_2); the variances of the intercept (σ_1^2)and slope (σ_2^2) indicating the magnitude of between-subject differences in predicted scores when *t* = k_1 and in the rate of change; and the residual variance (σ_u^2).

Full growth models

The level-1 formula for the full growth model for L-dlPFC is

$$y_{ti} = (\beta_1 + d_{1i} \cdot covariate) + (\beta_{2i} + d_{1i} \cdot covariate) \cdot (Time1 + Time2) + \mu_{ti}$$

The difference from the unconditional models was the addition of conditional terms; time-invariant covariates (i.e., moderators) of the slope and intercept term. These included: age, sex, BMI, Flanker Task score preexercise, affective lability, total sport experience, weekly PA, and goal orientation. The predictor variables were each grand mean-centered to ease their interpretation.

CHAPTER 4. RESULTS

Hypothesis 1

At intensities below VT, dlPFC activity would be negatively associated with affective responses (i.e., affective responses would decline, and dlPFC activity would increase), while at intensities above VT, they would be positively associated (i.e., both affective responses and dlPFC activity would decline concurrently).

No-Growth Models

The overall mean FS score across all measurement occasions and participants was 2.79 (*SE* = 0.18, 95% CI = 2.41 – 3.16). The estimate of the variance parameter for the participant-level residual was 1.60 (95% CI = 1.04 – 2.50). These data suggested that mean FS scores differed between participants. The residual error variance was 1.86 (95% CI = 1.59 – 2.16), representing variance unexplained by the model. The ICC, calculated as 1.595/(1.595 + 1.859) = 0.46, indicated that approximately 46% of the variation in FS scores was due to between-subject differences. This also suggested that including predictors in the level-2 (i.e., participant-level) model could help to explain the variation between participants.

The overall mean hemoglobin difference in the left dlPFC (L-dlPFC) was 0.61 (*SE* = 0.20, 95% CI = 0.21 – 1.01). The estimate of the participant-level residual was 1.77 (95% CI = 1.14 – 2.79. The residual error was 1.85 (95% CI = 1.58 – 2.18). The ICC (1.765/(1.765 + 1.849) = 0.48) indicated that approximately 48% of the variation in L-dlPFC activation was due to between-subject differences. Just as with FS, these results suggested that including predictors in the level-2 model could help to explain this between-subjects variability.

The overall mean hemoglobin difference in the right dlPFC (R-dlPFC) was -0.05 (*SE* = 0.21, 95% CI = -0.47 – 0.36). The participant-level residual was estimated to be 1.98 (95% CI = 1.31 – 3.10. The residual error was 1.62 (95% CI = 1.39 – 1.91). The ICC was 0.59 (1.979/(1.979 + 1.623) = 0.55), indicating that approximately 55% of the variance in R-dlPFC activation was due to between-subject differences, suggesting additional level-2 predictors were justified.

Multivariate Multilevel Growth Models

Relationship between Left dlPFC and Affective responses: Baseline to VT -1

Multivariate multilevel growth models were used to examine the slopes and slope covariances between affective valence and dlPFC activation at intensities below and above VT. The mean intercept for FS at baseline was 3.83 (*SE* = 0.12, 95% CI= 3.61 – 4.06. The mean slope from baseline to VT-1 was -0.36 (*SE* = 0.06, 95% CI = -0.48 – -0.25), or the mean predicted change in FS per minute. The mean intercept for L-dlPFC at baseline was 0.31 (*SE* = 0.18, 95% CI= -0.05 – 0.67). The mean slope from baseline to VT-1 was 0.11 (*SE* = 0.05, 95% CI = -0.001 – 0.21). The covariance between slopes was 0.11 (95% CI = -0.30 – 0.48).

Relationship between Left dlPFC and Affective responses: VT to Volitional Termination

The mean intercept for FS at VT was 2.06 (*SE* = 0.32, 95% CI= 1.44 – 2.69. The mean slope from VT to volitional termination was -0.78 (*SE* = 0.11, 95% CI = -1.00 – -0.56). The mean intercept for L-dlPFC at VT was 0.85 (*SE* = 0.40, 95% CI= 0.07 – 1.64). The mean slope from VT to volitional termination was -0.15 (*SE* = 0.14, 95% CI = -0.42 – 0.11). The covariance between slopes was 0.58 (95% CI = 0.03 – 0.86).

Relationship between Right dlPFC and Affective responses: Baseline to VT -1

The mean intercept for FS at baseline was 3.78 (*SE* = 0.20, 95% CI= 3.39 – 4.20. The mean slope from baseline to VT-1 was -.34 (*SE* = 0.04, 95% CI = -0.43 – -0.25). The mean intercept for R-dlPFC at baseline was 0.30 (*SE* = 0.15, 95% CI= 0.003 – 0.60). The mean slope from baseline to VT-1 was -0.08 (*SE* = 0.05, 95% CI = -0.19 – 0.02). The covariance between slopes was -0.14 (95% CI = -0.50 – 0.26).

Relationship between Right dlPFC and Affective responses: VT to Volitional Termination

The mean intercept for FS at VT was 2.02 (*SE* = 0.32, 95% CI= 1.40 – 2.65. The mean slope from VT to volitional termination was -0.75 (*SE* = 0.11, 95% CI = -0.97 – -0.54). The mean intercept for R-dlPFC at VT was -0.04 (*SE* = 0.47, 95% CI= -0.96 – 0.88). The mean slope from VT to volitional termination was -0.64 (*SE* = 0.13, 95% CI = -0.90 – -0.39). The covariance between slopes was 0.60 (95% CI = -0.02 – 0.89).

Hypotheses 1a and 1b

1a. Below VT, the slopes of affective responses and dlPFC activation would be moderated by age, sex, BMI, affective lability, goal-orientation, total PA, total sport experience, and cognitive inhibition scores prior to exercise.

1b. While exercising at intensities above VT, these covariates would not moderate the slopes of dlPFC activity and affective responses.

Affective valence full model: Baseline to VT -1

The mean intercept estimate for FS at baseline was 3.41 (*SE* = 0.43, 95% CI= 2.56 – 4.26). Affective responses from baseline were predicted to become less pleasant over time (*Estimate* = -0.19, *SE* = 0.09, 95% CI = -0.36 – -0.02). Participant age moderated the slope of

FS (*Estimate* = -0.23, *SE* = 0.10, 95% CI = -0.44 – -0.03). Children 8 years of age demonstrated steeper negative slopes of affective responses at intensities below VT than 7 and 9-year-old children. There were no further significant covariates noted in this model. See Figure 2 for illustrations of this effect.

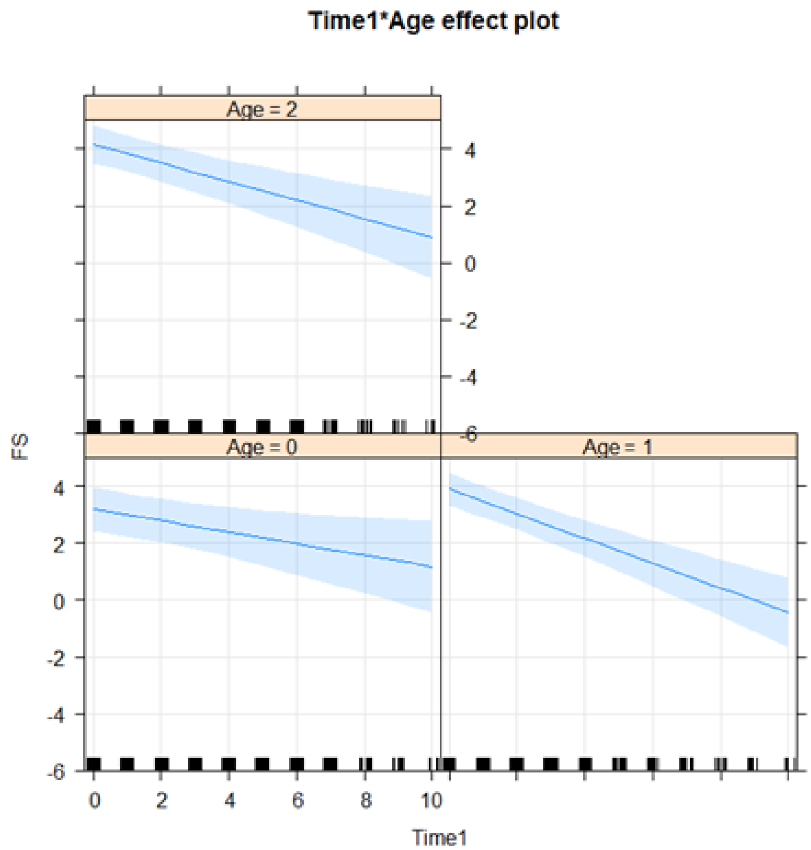


Figure 2. Effect plots for FS covariates below VT. Note that predictors are centered, and shaded areas represent 95% confidence interval for the mean at each time point.

Left dlPFC full model: Baseline to VT -1

For the L-dlPFC, the mean intercept estimate at baseline was 0.26 (*SE* = 0.40, 95% CI= -0.53 – 1.06). The slope of L-dlPFC from baseline to VT-1 did not change over time (*Estimate* = 0.17, *SE* = 0.11, 95% CI = -0.05 – 0.38). The slope of L-dlPFC was moderated by BMI ($Estimate_{Age8}$ = 0.28, *SE* = 0.12, 95% CI = 0.04 – 0.53). The slope of L-dlPFC activation in children with BMI scores at or above the 85th percentile was more positive than those with a lower BMI at intensities below VT. There were no further significant covariates noted in this model. See Figure 3 for illustrations of these effects.

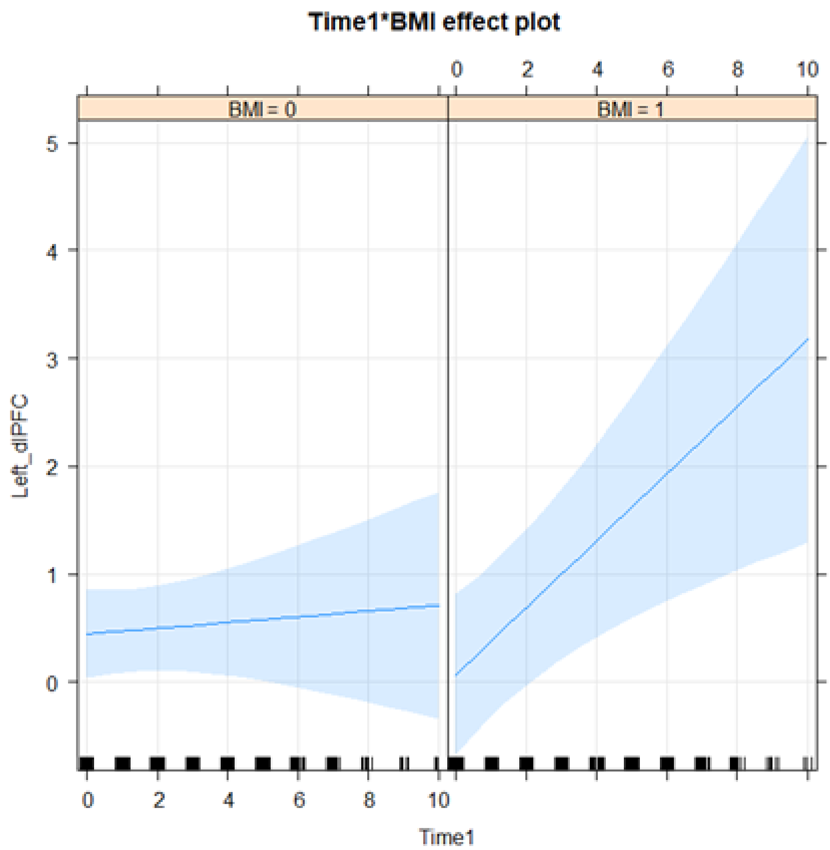
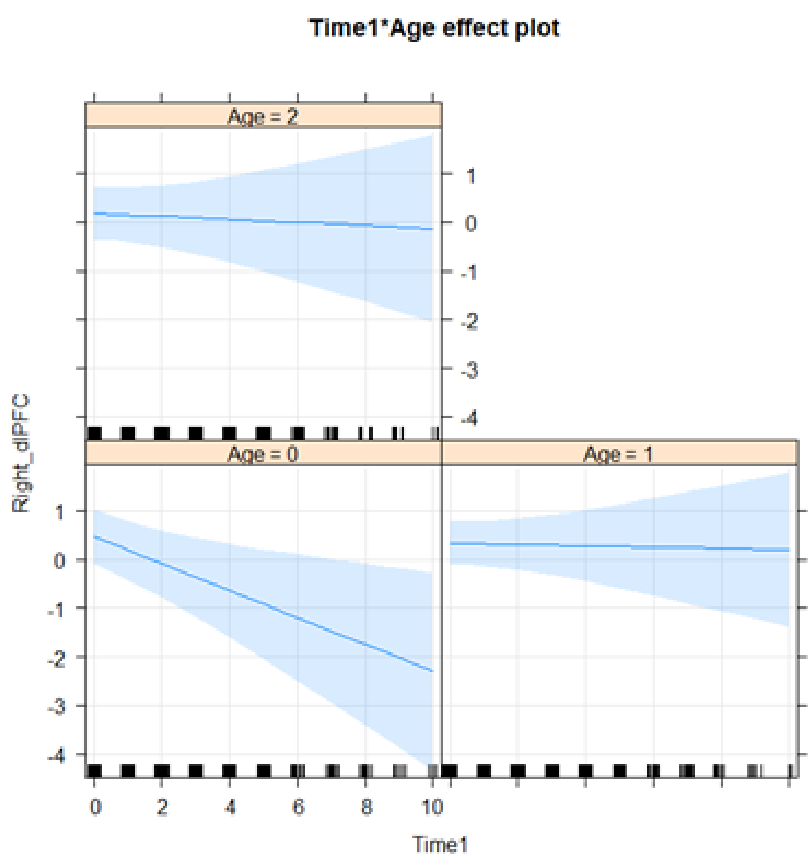


Figure 3. Effect plots for L-dlPFC covariates below VT. Note that predictors are centered, and shaded areas represent 95% confidence interval for the mean at each time point.

Right dlPFC full model: Baseline to VT -1

The mean intercept estimate for R-dlPFC activation at baseline was 0.61 (*SE* = 0.31, 95% CI= -0.01 – 1.23. The slope of R-dlPFC activation was negative below VT (*Estimate*= -0.33, *SE* = 0.11, 95% CI = -0.55 – -0.12). The slope of R-dlPFC activation was moderated by age ($Estimate_{Age8}$ = 0.26, *SE* = 0.12, 95% CI = 0.02 – 0.52). Eight-year-old children demonstrated a positive slope of change in R-dlPFC activity at intensities below VT. In addition, the slope for R-dlPFC at intensities below VT was moderated by BMI (*Estimate*= 0.35, *SE* = 0.13, 95% CI = 0.09 – 0.60). The slope of R-dlPFC activation in children with BMI scores at or above the 85^{th} percentile was more positive than those with a lower BMI at intensities below VT. There were no further significant covariates noted in this model. See Figure 4 for illustrations of these effects.



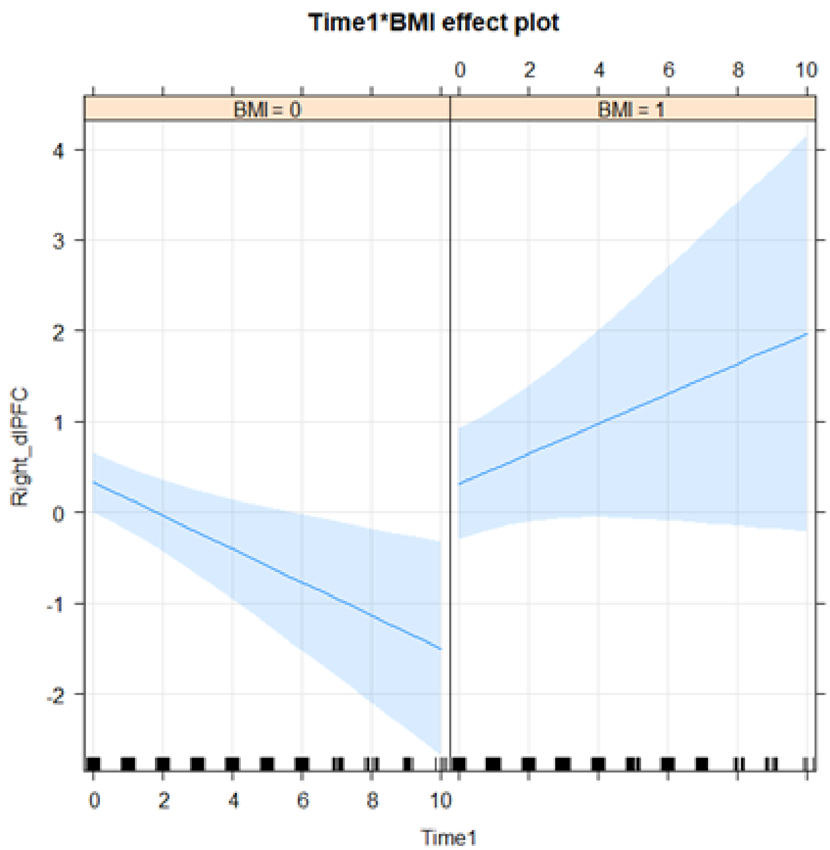


Figure 4. Effect plots for R-dlPFC covariates below VT. Note that predictors are centered, and shaded areas represent 95% confidence interval for the mean at each time point.

Affective valence full model: VT to volitional termination

There were no significant covariates noted in this model.

Left dlPFC full model: VT to volitional termination

There were no significant covariates noted in this model.

Right dlPFC full model: VT to volitional termination

There were no significant covariates noted in this model.

Hypothesis 2

Affective valence, dlPFC activity, and time spent at intensities above VT would be negatively associated with postexercise inhibition scores.

Linear regression results

The model accounted for approximately 12% of the variance in Flanker Task scores postexercise ($R^{2\text{adjusted}}$ = 0.124, $F(4, 496) = 17.51$, $p < .001$). The full results for this model are presented in Table 2.

Table 2. Linear regression results predicting Flanker Task scores post exercise.

Coefficients

Model		Unstandardized	Standard Error	Standardized	t	p
1	(Intercept)	96.907	0.247		391.870	< .001
	L-dlPFC	-0.125	0.058	-0.094	-2.162	0.031
	R-dlPFC	0.229	0.049	0.206	4.688	< .001
	FS	0.152	0.054	0.121	2.836	0.005
	TimeAboveVT	-0.453	0.077	-0.250	-5.913	< .001

CHAPTER 5. DISCUSSION

The primary purpose of the present study was to examine the relationship between dlPFC activation and affective responses during incremental cycle exercise among children. The group mean slope of affective responses at intensities below VT was predicted to be negative (-0.36), while left dlPFC activity and activity of the right dlPFC were unchanged. At intensities from VT to volitional termination, affective responses declined around twice as rapidly than at intensities below VT (i.e., -0.36 to -0.78), while the right dlPFC showed reduced activation (-0.64), whereas the left dlPFC did not change at these intensities. Affective responses did not covary with activity of the left or right dlPFC below VT. At intensities from VT to exercise termination, activity of the left dlPFC (0.58) positively covaried with affective responses. In addition, below VT, the slope of affective responses was moderated by participant age. The slope of left dlPFC activity for children above the 85th percentile for BMI was more positive compared to those with lower body mass indices. Finally, the activity of the right dlPFC was positively moderated by age and BMI percentile at sub-VT intensities. However, no moderators were significant from VT to the end of exercise.

These data suggest a decline in affective responses from the outset of the incremental exercise test. In this respect, the present study supports the findings of the only other investigation of affective responses during incremental exercise among children (Benjamin et al., 2012). Moreover, the results suggest that the decline in affective valence accelerated over time. These data contrast with those collected among healthy, normal weight adults (see Ekkekakis et al., 2011, for a review), who tend to report stable or increased ratings of pleasure during the moderate-intensity domain (i.e., at intensities below VT) and begin to show response heterogeneity as exercise intensities approach and exceed the VT. That is, while some adults do report increasing pleasure above the VT, this was not the case for children in the present sample. Instead, there was near response homogeneity at intensities below and above VT. In fact, the growth curves of affective responses among children in this study closely resembled those collected among sedentary, overweight and/or obese adolescents (Stych & Parfitt, 2011) and adults (Ekkekakis, Lind, & Vazou, 2010; Sheppard & Parfitt, 2008; Welch et al., 2007), particularly when exercise intensity was imposed rather than self-selected (Ekkekakis & Lind, 2006; Hamlyn-Williams, al., 2014).

Affective responses during the incremental cycling test were unrelated to activity of the activity of the right and left dlPFC intensities below VT. Recent evidence with adult participants suggests that activity of both hemispheres typically increases during exercise below VT and decreases at near-maximal intensities (i.e., proximal to the respiratory compensation point). Ekkekakis (2009a), theorized that increased activation of the dlPFC during exercise may indicate attempts to utilize cognitive strategies to self-regulate affective responses (i.e., the larger the affective decline, the larger the recruitment of dlPFC in an effort to downregulate the negative affect). Alternatively, activity upregulation may be related to the prefrontal cortices' theorized roles in downregulating amygdalar activity (Frank et al., 2014). Among children, the lack of association between affective valence and activity of the dlPFC during incremental exercise below VT may be associated with an absence of, or unsuccessful attempts to cognitively self-regulate affect.

In addition, activation of the right hemisphere decreased from VT to the end of exercise. This reduction in cortical activity may indicate a deactivation of those prefrontal networks involved in amygdala downregulation, perhaps due to reduced availability of cellular energy and/or the absence of cognitive strategies for affective self-regulation among children. It appears that decreased activity within the right dlPFC may have occurred at VT, as opposed to near the RCP in adults (Bhambhani et al., 2007; Rupp & Perrey, 2008). These earlier decreases in activity may help to explain why most children fail to reach true maximal aerobic capacity during incremental exercise. In fact, in the present study, although most children (54 out of 56) persevered long enough to reach VT, not one presented an identifiable RCP or VO_2 plateau.

Despite the hypothesis that affective responses and dlPFC activation would be moderated by various psychological and biological covariates below VT, there were few meaningful moderators and only those that were biological (age, BMI) were associated with the outcome variables. The lack of psychological moderators of affective and hemodynamic responses at intensities below VT may be due to the tendency for children to demonstrate increased amygdala reactivity and less recruitment of dorsal prefrontal brain regions during emotion regulation compared with adolescents and adults (Silvers et al., 2017). Indeed, participant age positively moderated the slope of right dorsolateral responses at sub-VT intensities, though this activity was not associated with changes in affective responses. Interestingly, 8-year-old children showed a steeper decline in affective responses than did children 7 or 9 years-of-age.

Additionally, children above the 85^{th} BMI percentile showed greater dlPFC activity in both hemispheres below VT. While there is a dearth of evidence concerning obesity and child brain structure and development, adults with obesity have been shown to have reduced gray matter density in several brain regions, including the prefrontal cortex (Hermann, Tesar, Beier, Berg, & Warrings, 2019). Furthermore, recent work with diffusion tensor imaging (DTI) has revealed that the structural integrity of white matter tracts is often compromised among people with obesity (van Bloemendaal et al., 2016). This reduced integrity could be related to increases in radial diffusivity (or axonal "leaking") and decreases in axial diffusivity (less axonal diffusion down the length of the axon) of white matter axons (Verstynen, Weinstein, Schneider, Jakicic, Rofey, & Erickson, 2012). People with obesity may leak (i.e., lose to waste) and fail to diffuse more electrochemical ions than do their normal-weight counterparts, leading to reduced signaling potential. Importantly, obesity may interfere with the functional activity of the dlPFC and the hippocampus (Cheke, Bonnici, Clayton, & Simons, 2017), thus reducing the capacity to use executive functions.

Because children exhibit less prefrontal development (Lebel & Beaulieu, 2009, 2011), any reductions to prefrontal axonal integrity might have more deleterious implications than among adults. If deficits in axonal integrity occur in children as in adults, children above the 85^{th} percentile for BMI in the current sample may have exhibited increased dlPFC activity to compensate for axonal waste and inefficiency. Therefore, it is plausible that children with obesity may have needed to utilize more cortical resources to perform the exercise compared to their normal-weight peers. This explanation is bolstered by the fact that, in the present sample, children with higher BMI exercised for a shorter duration (9.3 vs 9.8 min) and spent less time above VT (1.9 vs 2.2 min) than did normal-weight children. However, greater increases in dlPFC activity among high-BMI children may also be related to their exercise intensity increasing relatively more rapidly than children with normal body mass indices, necessitating more prefrontal mediation (and, therefore, energy consumption).

In the present study, several psychological and PA measures may have been influenced by biased reporting by parents and children. For example, although Shields and Ciccetti (1997) reported satisfactory-reliability data during their initial validation studies for the Emotion Regulation Questionnaire, parental responses in the present sample may have been inadvertently influenced by the presence of researchers in the room while the questionnaire was completed (e.g., social desirability response bias; Edwards, 1957). This influence may have remained despite parents completing the questionnaire without the researchers watching and being reminded that their responses would be unidentifiable and confidential. The low reliability coefficients reported in the present sample and others (Lincoln, 2014) suggest underlying structural issues of the Emotion Regulation Questionnaire among contemporary adult samples.

Self-reported PA measures remain inexpensive and easily administered, while at the same time being prone to bias and inaccuracy (Sylvia, Bernstein, Hubbard, Keating, & Anderson, 2014). Measuring PA among children introduces additional challenges that further compound the limitations of self-report measures. Children are more likely to make mistakes when retrospectively analyzing their PA behavior (Welk, Corbin, & Dale, 2000). More recent measures, such as the Youth Activity Profile used in the present study, have improved on some of the reliability shortcomings among children, but there remains room for improvement (Saint-Maurice & Welk, 2015). Therefore, children in this sample may have under- or overestimated their weekly PA, thus reducing the ability to draw accurate inferences.

Preexercise scores on the Eriksen Flanker Task, assumed to be a measure of the ability to inhibit, or suppress, inappropriate responses (Eriksen & Eriksen, 1974) did not relate to any outcome variables as initially hypothesized. There are several potential explanations for these unexpected results. First, the overall variability of scores from this measure was low – most children were close to 100% accurate. Consequently, in this sample, the task lacked the sensitivity to distinguish meaningful differences in this subset of executive functioning (i.e., without variance there can be no covariance). In addition, the brain regions theorized to be most involved during the Eriksen Flanker Task may not be the same regions that are involved in the downregulation (i.e., inhibition) of affective and emotional responses. For instance, the anterior cingulate cortex appears to be most active during these kinds of interference tasks (Kerns et al., 2004), while the medial and lateral aspects of the dlPFC may be most active during the attempted suppression of aversive stimuli (Frank et al., 2014; Silvers et al., 2017).

However, the results from the predictors of the postexercise Flanker Task scores support the notion that there may be some overlap between the brain regions activated during affective self-regulation and general response inhibition. Children who demonstrated higher right dlPFC activation and reported feeling better during the exercise test scored better on the postexercise Flanker task than other children, while those who activated the left dlPFC to a greater extent and persisted longer beyond VT performed worse on the task. Perhaps those with higher right dlPFC activity and more pleasant ratings of affective valence were more likely to have stopped the exercise earlier than their peers, saving more cognitive resources for the postexercise task, whereas those who persisted used dlPFC resources that may not have been replenished prior to the Flanker Task. At the same time, it is possible that the activation of this brain region during exercise “carried over” between the relatively short five-minute period between exercise cessation and the cognitive inhibitory task. It is reasonable, therefore, to hypothesize that, if the right dlPFC is at least tangentially involved in both affective self-regulatory and general inhibitory processes, then learning to do one or the other better may have implications for the ability to do both.

Moreover, it is becoming increasingly clear that many reciprocal connections exist between brain regions, and that they likely work in concert during emotion regulation (Frank et al., 2014; Silvers et al., 2017). Therefore, large changes in activation in one region may be associated with smaller, or even reciprocal changes, in others. Because current imaging techniques continue to lack the resolution necessary to detect changes in regional brain activity during exercise (Ekkekakis, 2009a), it remains difficult, if not impossible, for exercise scientists to achieve a better understanding of these complex underlying processes.

Nonetheless, at intensities exceeding VT, all results were in the hypothesized directions. Affective valence and dlPFC of both hemispheres declined and were not moderated by any of the included covariates. As with evidence from adult samples, right dlPFC activity decreased near volitional termination (Ekkekakis, 2009a). However, in contrast with adults, these decreases began before evidence of RCP was apparent. Most children in the present sample were asked why they stopped exercising when then did. Few children appeared out of breath or showed signs of extreme discomfort upon stopping, unlike the typical adult after completing maximal exercise testing. This, along with the absence of a VO_2 plateau, as in previous work (Rowland & Cunningham, 1992; Washington et al., 1988), suggests that most children terminated exercise well before maximal aerobic capacity had been reached. Several children reported stopping because they felt “hot” or “sweaty” as well as due to discomfort in their legs, while others could not articulate their reasons for stopping. Because children are assumed to lack the requisite cortical development and experience to engage cognitive strategies to persevere despite increasing discomfort, children may have had little impetus or capacity to persevere, thus simply “giving up” when the intensity felt less easily manageable.

Limitations

Though the results of the present study may help to clarify gaps in the extant literature relating to the affective experience of exercise among children, there were several limitations that must be considered. First, children performed the exercise task in an unfamiliar, artificial laboratory environment, in relative seclusion, while wearing a mask over their noses and mouths and NIRS probes on their foreheads. Any one of these environmental and contextual factors might have negatively influenced the trajectory of affective responses and prefrontal hemodynamics during exercise. In addition, unfamiliarity with the setting may have reduced self-regulatory capacity before exercise had begun. Managing an anxiety (i.e., emotional) response requires substantial input from the same regions theorized to be implicated in the self-regulation of affective responses during exercise. The positioning of the NIRS sensors on the forehead was accomplished using a template based on the International 10-20 electroencephalographic electrode placement system, but this only provided an approximation of the location of the dorsolateral prefrontal cortices of each hemisphere. These templates are developed based on "standard head" models, using the average positions of various cortical regions based on the accumulated data from many individuals (Cuffin, 1996). Therefore, the dlPFC in one individual may be slightly differently positioned relative to others. In the future, one method to overcome this would be to individually scan each individual brain via magnetic resonance imaging (MRI) for more precise placement over the region(s) of interest. Additionally, the Flanker Task prior to exercise may have reduced the total capacity each participant had to employ cognitive self-regulatory strategies (if any were available) during the exercise test. Finally, while most children ride bicycles at some point, and one of the inclusion criteria was that children knew how to ride, a stationary bicycle may have been an unfamiliar PA modality. Like the noted limitations with previous work using treadmills (Benjamin et al., 2012), the stationary bicycle used here may have inadvertently influenced affective responses. The modality, combined with the unfamiliarity of the laboratory environment, may render it difficult to generalize these results to other forms of exercise or to the wider domain of PA.

Implications for Practice

The results from the present study may have important implications for pediatric exercise prescriptions and PA recommendations, as well as for clinical exercise testing among children. The use of a multilevel growth-curve modeling approach allowed for the exploration of both within- and between-subjects differences in affective responses and dlPFC activity during incremental exercise. These results suggest that the ability to employ cognitive strategies to self-regulate affective responses to exercise may not be an inherent human ability (i.e., one that emerges naturally without practice and/or biological development). Without explicit instructions and real-life practice, children may not develop the ability to self-regulate their affective responses during incremental exercise. Even among children who did show brain activity that may have been indicative of attempts at self-regulation strategies, affective responses became increasingly unpleasant from the beginning of the exercise test. Therefore, expecting children to self-regulate their affective responses during PA to the same extent as adolescents and adults may be unrealistic.

The affective responses reported among the children in this and other samples (Benjamin et al., 2012) became less pleasant from the beginning of exercise with little interindividual variability, suggesting that critically reexamining the costs versus benefits of mandated fitness testing within PE curricula may be warranted. Because recent theoretical developments (Brand & Ekkekakis, 2017) have suggested that the pleasure or displeasure that is automatically associated with PA may influence PA behavior, mandating fitness tests, or other patterns of movement that do not take into consideration children's natural propensities and apparently unique affective responses to exercise may undermine the goal of forming pleasant affective associations for PA.

Furthermore, despite associations between PA and cognitive functioning (Pontifex et al., 2018), following the current exercise to volitional exhaustion, children who spent more time at intensities above VT performed worse on subsequent tests of inhibitory control. Therefore, sustained exercise above the VT in children may, for a certain period of time, reduce the cognitive resources that can be devoted to other, more general, executive functions. It is unclear for how long these effects might persist, as in the present study only five minutes elapsed between the end of exercise and the tests of inhibition. Because it is likely that the brain regions implicated in these behaviors overlap to some extent, it is possible that learning to utilize cognitive strategies to self-regulate affective responses during exercise could lead to both improved experiences of exercise and improvements in general executive processes that are necessary beyond exercise and sport (e.g., reducing the frequency of classroom interruptions, waiting one's turn before speaking, avoiding anger or sadness over trivial matters).

Furthermore, instructing children to self-regulate their PA intensity to maintain pleasure may have important educational implications. For example, intriguing research using animal models has suggested the experience of pleasure during PA may be necessary to facilitate the release of the precursors of PA induced neuroplasticity and learning (Ekkekakis, 2009a). Recent findings suggest that pleasure during PA is associated with the release of the endocannabinoid anandamide (Raichlen, Foster, Gerdeman, Seillier, & Guiffirda, 2012), which is associated with increased circulating brain-derived neurotrophic factor (Heyman et al., 2012). In this case, a maximization of pleasure during PA through self-regulation (Schmidt, Jäger, Egger, Roebers, & Conzelmann, 2015; Buckley, Cohen, Kramer, McAuley, & Mullen, 2014) may lead to greater enhancements in cognitive functioning than proffered by standard models of pediatric exercise prescription.

Importantly, these results should be replicated and expanded within ecologically valid contexts, as well as with different modes and intensities of exercise (e.g., continuous-intensity PA, high-intensity interval training). In addition, research to understand the immediate and long-term implications of negative affective experiences during PA in childhood must be undertaken, as accumulated pleasant or unpleasant experiences with PA during childhood may have powerful implications for future behavior.

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APPENDIX A: INSTITUTIONAL REVIEW BOARD (IRB) APPROVAL LETTER

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office for Responsible Research
Vice President for Research
2420 Lincoln Way, Suite 202
Ames, Iowa 50014
515 294-4566

Date: 10/04/2018

To: Matthew Ladwig Panteleimon Ekkekakis, PhD

From: Office for Responsible Research

Title: **Affective and Neurophysiological Responses to Incremental Exercise among Children**

IRB ID: **18-385**

Submission Type: Initial Submission **Review Type**: Full Committee

Approval Date: 10/02/2018 **Date for Continuing Review: 10/01/2019**

The project referenced above has received approval from the Institutional Review Board (IRB) at Iowa State University according to the dates shown above. Please refer to the IRB ID number shown above in all correspondence regarding this study.

To ensure compliance with federal regulations (45 CFR 46 & 21 CFR 56), please be sure to:

Use only the approved study materials in your research, including the **recruitment materials and informed consent documents that have the IRB approval stamp**.

Retain signed informed consent documents for 3 years after the close of the study, when documented consent is required**.**

Obtain IRB approval prior to implementing any changes to the study.

Inform the IRB if the Principal Investigator and/or Supervising Investigator end their role or involvement with the project with sufficient time to allow an alternate PI/Supervising Investigator to assume oversight responsibility. Projects must have an eligible PI to remain open.

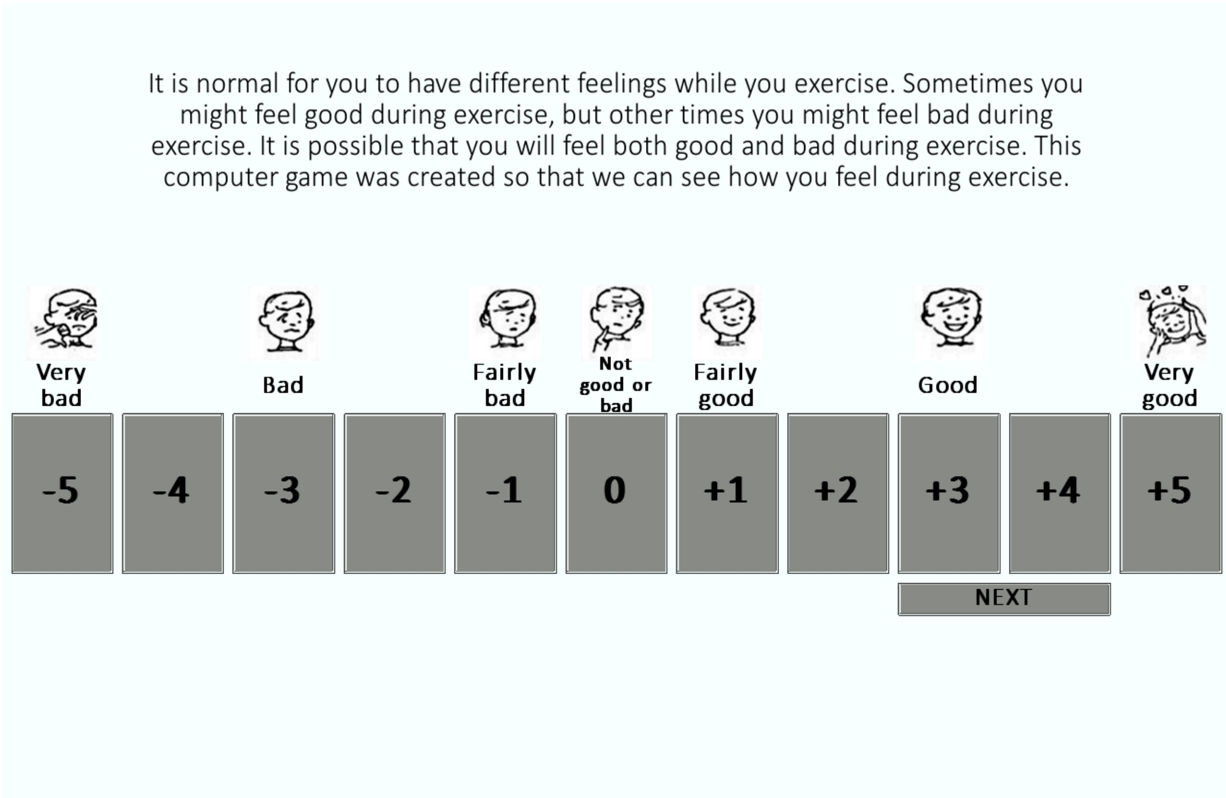
Immediately inform the IRB of (1) **all serious and/or unexpected adverse experiences** involving risks to subjects or others; and (2) **any other unanticipated problems involving risks** to subjects or others.

Stop all human subjects research activity if IRB approval lapses, unless continuation is necessary to prevent harm to research participants. Human subjects research activity can resume once IRB approval is re-established.

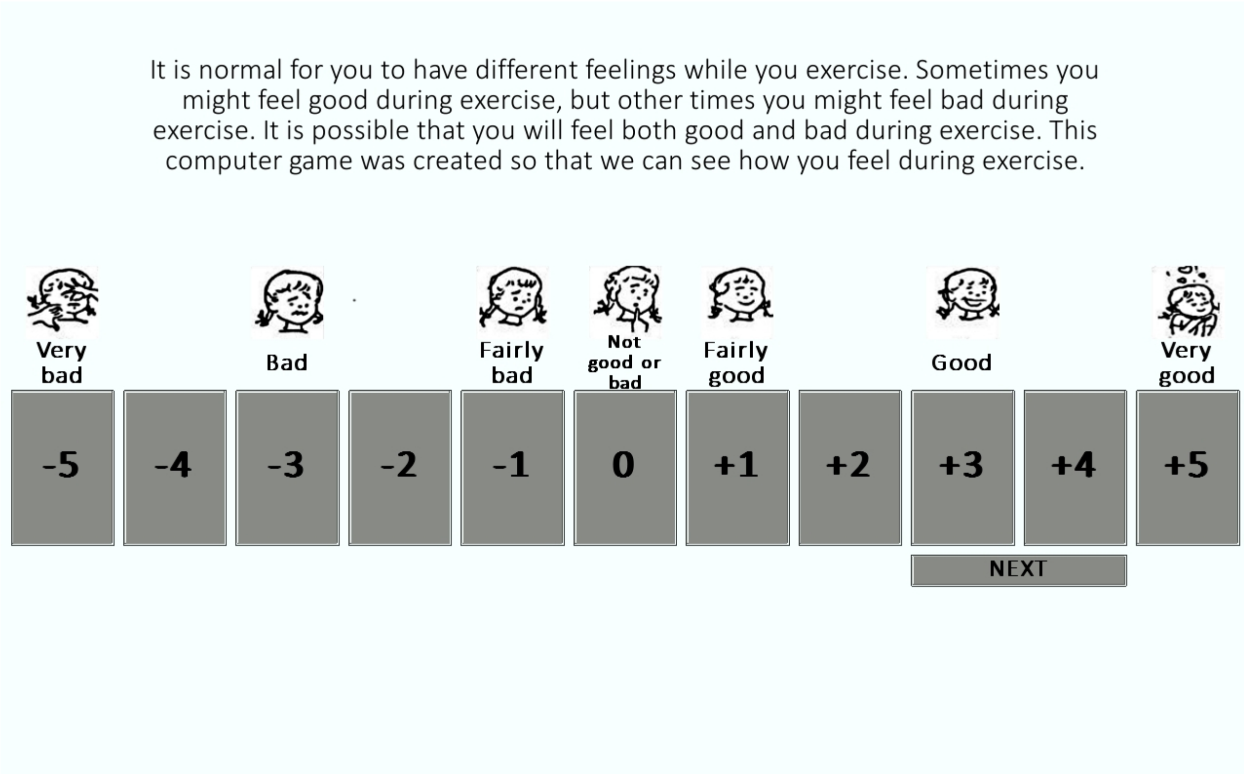
Submit an application for Continuing Review at least three to four weeks prior to the **date for continuing review** as noted above to provide sufficient time for the IRB to review and approve continuation of the study. We will send a courtesy reminder as this date approaches.

APPENDIX B: FEELING SCALE ADAPTED FOR CHILDREN

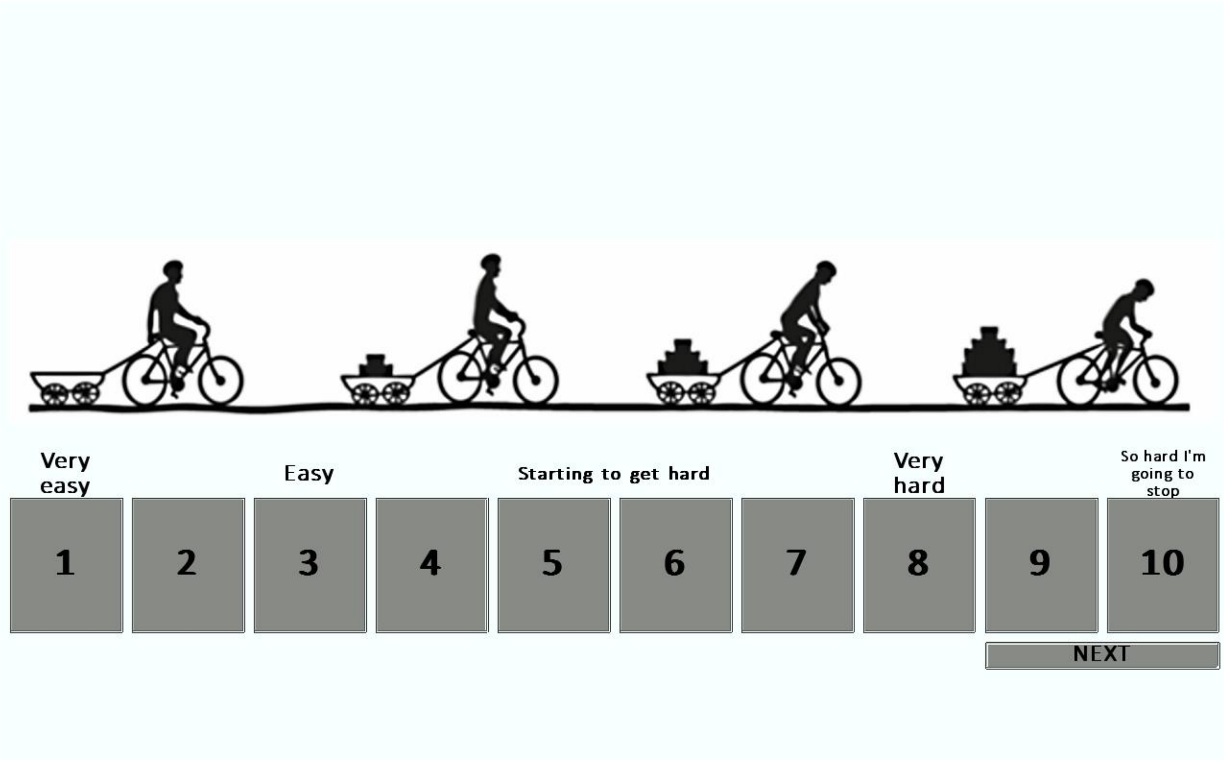
Boys Version



Girls Version



APPENDIX C: CART AND LOAD EFFORT RATING (CALER) SCALE



"We would like you to ride on this bike for a little while. Over time it will get harder to pedal the bike. You will use the numbers on this picture to tell us how hard it feels to ride bike. Please look at the person right here who is just starting to ride a bike (point to far-left bicycle rider). This person is not working hard because they are pulling no weight in their trailer. If you feel like this when you are riding, you should press the one button. Now look at the person who is barely able to pull their trailer with all the weight (point to the far-right bicycle rider). If you feel like this person when riding this means it is very, very hard to pedal the bike. If you feel like this, you should press to the ten button If you feel like you are pulling a trailer with your bike that is between empty (1 point) with no weight and very, very heavy (10 point), then can should press any of the number between 1 and 10."

APPENDIX D: YOUTH ACTIVITY PROFILE*

*Note, crossed out sections were not collected due to time constraints and redundancy with other collected data.

~~Before you begin, it is important to get some basic information about your school and about you.~~

~~Circle your Gender: Male Female~~

~~Circle your School Level: Elementary School Middle School High School~~

~~Circle your Grade: 3 4 5 6 7 8 9 10 11 12~~

~~ID ______________~~

~~How many days each week do you have PE?~~

~~a. 0 days (never)~~
~~b. 1 day~~
~~c. 2 days~~
~~d. 3 days~~
~~e. 4 days~~
~~f. 5 days~~

~~How many break/study hall periods do you have per day?~~

~~a. 0~~
~~b. 1~~
~~c. 2~~
~~d. 3~~
~~e. 4~~

~~How many times last week did you attend sessions or practices for sports or structured physical activities that were led by a coach, instructor or leader~~

~~a. 0~~
~~b. 1~~
~~c. 2~~
~~d. 3~~
~~e. 4~~
~~f. 5 or more~~

The Youth Activity Profile will ask you about the time you spend being active (both in school and out of school) and the time you spend being sedentary.
Physical activities are things that involve a lot of walking, running or moving around. It includes biking and dancing as well as sports or outdoor play that involves a lot of moving around.

Sedentary activities are things such as watching TV, or playing video games, computer games, or hand-held games that you do in your free time. It does NOT include the time you spend sitting while eating or while doing homework.

Most questions will ask you only to think about the last 7 days but a few questions will ask about what you typically do (on a normal week). There are no right or wrong answers so provide honest answers.

Youth Activity Profile

~~**Activity Levels - at School**~~

~~Activity Levels – at School. These questions ask about your physical activity at school. This includes physical education but you may also be active on your way to school, during breaks, or at lunch. Answer the questions based on your physical activity at school in the last 7 days.~~

~~1. **Activity To School**: How many days did you walk or bike to school? (If you can't remember, try to estimate)~~

~~a. 0 days (never)~~
~~b. 1 day~~
~~c. 2 days~~
~~d. 3 days~~
~~e. 4-5 days (most every day)~~

~~2. **Activity during Physical Education Class**: During physical education, how often were you running and moving as part of the planned games or activities? (If you didn't have PE, choose "I didn't have physical education")~~

~~a. I didn't have physical education~~
~~b. Almost none of the time~~
~~c. A little bit of the time~~
~~d. A moderate amount of time~~
~~e. A lot of the time~~
~~f. Almost all of the time~~

~~3. **Activity during Breaks/Study Hall**: During breaks/study hall, how often were you playing sports, walking, running, or playing active games? (If you didn't have a break at school, choose "I didn't have breaks/study hall")~~

~~a. I didn't have breaks/study hall~~
~~b. Almost none of the time~~
~~c. A little bit of the time~~
~~d. A moderate amount of time~~
~~e. A lot of the time~~
~~f. Almost all of the time~~

~~4. **Activity during Lunch**: During lunch break, how often were you moving around, walking or playing? (If you didn't have a lunch break at school, choose "I didn't have lunch breaks")~~

~~a. I didn't have lunch breaks~~
~~b. Almost none of the time~~
~~c. A little bit of the time~~
~~d. A moderate amount of time~~
~~e. A lot of the time~~
~~f. Almost all of the time~~

~~5. **Activity from School**: How many days often did you walk or bike from school? (If you can't remember, try to estimate)~~

~~a. 0 days (never)~~
~~b. 1 day~~
~~c. 2 days~~
~~d. 3 days~~
~~e. 4-5 days (most every day)~~

Youth Activity Profile

Activity Levels at Home

Activity Levels - Outside of School. These questions ask about your overall levels of physical activity during different periods of time (outside of school time). This would include structured exercise or sport activities as well as activity playing with friends, dancing or doing work/chores. Answer the questions based on your physical activity outside of school in the last 7 days.

6. **Activity before School**: How many days before school (6:00-8:00 am) did you do some form of physical activity for at least 10 minutes? (This includes activity at home NOT walking or biking to school)

a. 0 days
b. 1 day
c. 2 days
d. 3 days
e. 4 to 5 days

7. **Activity after School**: How many days after school (between 3:00 -6:00 pm) did you do some form of physical activity for at least 10 minutes? (This can include playing with your friends/family, team practices or classes involving physical activity but NOT walking or biking home from school)

a. 0 days
b. 1 day
c. 2 days
d. 3 days
e. 4 to 5 days

8. **Activity on Weeknights**: How many school evenings (6:00-10:00 pm) did you do some form of physical activity for at least 10 minutes? (This can include playing with your friends/family, team practices or classes involving physical activity but NOT walking or biking home from school)

a. 0 days
b. 1 day
c. 2 days
d. 3 days
e. 4 to 5 days

9. **Activity on Saturday**: How much physical activity did you do last Saturday? (This could be for exercise, work/chores, family outings, sports, dance, or play. If you don't remember, try to estimate)

a. No activity (0 minutes)
b. Small amount of activity (1 to 30 minutes)
c. Small to Moderate amount activity (31 to 60 minutes)
d. Moderate to Large amount of activity (1 to 2 hours)
e. Large amount of activity (more than 2 hours)

10. **Activity on Sunday**: How much physical activity did you do last Sunday? (This could be for exercise, work/chores, family outings, sports, dance, or play. If you don't remember, try to estimate)

a. No activity (0 minutes)
b. Small amount of activity (1 to 30 minutes)
c. Small to Moderate amount activity (31 to 60 minutes)
d. Moderate to Large amount of activity (1 to 2 hours)
e. Large amount of activity (more than 2 hours)

Youth Activity Profile

Sedentary Habits

These questions ask about time spent resting and sitting. You probably sit while eating, doing homework, or playing musical instruments. But you also may spend time sitting while watching TV, playing video games, using the computer or using your phone, or iTouch/iPad). Answer these questions about the time you spent sitting during these activities in the past 7 days.

11. **TV Time**: How much time did you spend watching TV outside of school time (This includes time spent watching movies or sports but NOT time spent playing video games).

a. I didn't watch TV at all
b. I watched less than 1 hour per day
c. I watched 1 to 2 hours per day
d. I watched 2 to 3 hours per day
e. I watched more than 3 hours per day

12. **Video Game Time**: How much time did you spend playing video games outside of school time? (This includes games on Nintendo DS, wii, Xbox, PlayStation, iTouch, iPad, or games on your phone)

a. I didn’t really play at all
b. I played less than 1 hour per day
c. I played 1 to 2 hours per day
d. I played 2 to3 hours per day
e. I played more than 3 hours per day

13. **Computer Time**: How much time did you spend using computers outside of school time? (This doesn’t include home work time but includes time on Facebook as well as time spent surfing the internet, instant messaging, playing online video games or computer games)

a. I didn’t really use the computer at all
b. I used a computer less than 1 hour per day
c. I used a computer 1 to 2 hours per day
d. I used a computer 2 to3 hours per day
e. I used a computer more than 3 hours per day

14. **Phone / Text Time**: How much time did you spend using your cell phone after school? (This includes time spent talking or texting).

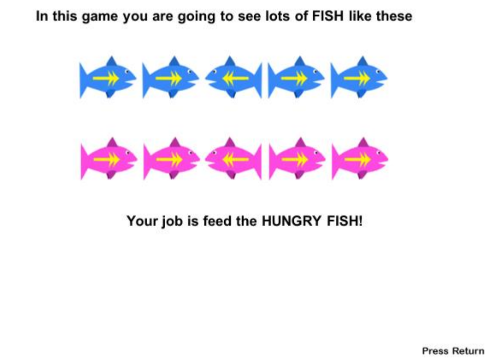
a. I didn’t really use a cell phone
b. I used a phone less than 1 hour per day
c. I used a phone 1 to 2 hours per day
d. I used a phone 2 to 3 hours per day
e. I used a phone more than 3 hours per day

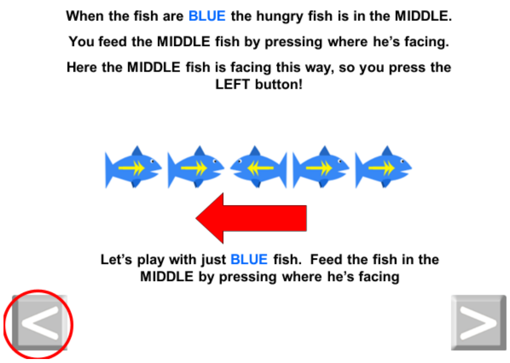
15. **Overall Sedentary Habits**: Which of the following best describes your typical sedentary habits at home? (Try to think about a typical week and not just last week)

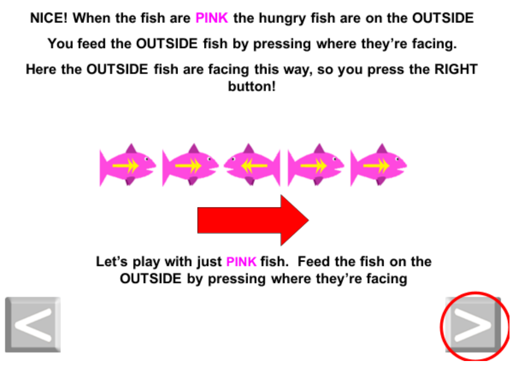
a. I spent almost none of my free time sitting
b. I spent little time sitting during my free time

c. I spent a moderate amount of time sitting during my free time d. I spent a lot of time sitting during my free time
e. I spent almost all of my free time sitting

APPENDIX E: ERIKSEN FLANKER FISH TASK







APPENDIX F:TASK AND EGO ORIENTATION IN SPORT QUESTIONNAIRE

I feel most successful in sport when…	**Strongly disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
I'm the only one who can do a play or skill					
I can do better than my friends					
The others can't do as well as me					
Others mess up and I don't					
I score the most points/goals/hits/etc.					
I'm the best					
I learn a new skill and it makes me want to go practice more					
I learn something that is fun to do					
I learn a new skill by trying hard					
I work really hard					
Something I learn makes me want to practice more					
A skill I learn really feels right					
I do my very best					

APPENDIX G: EMOTION REGULATION CHECKLIST

Please tick the box that applies most to your child. Please answer every question as best you can.

		Never	Sometimes	Often	Almost Always
1.	Is a cheerful child				
2.	Exhibits wide mood swings (child's emotional state is difficult to anticipate because s/he moves quickly from positive to negative moods)				
3.	Responds positively to neutral or friendly approaches by adults.				
4.	Transitions well from one activity to another; does not become anxious, angry, distressed or overly excited when moving from one activity to another.				
5.	Can recover quickly from episodes of upset or distress (e.g. does not pout or remain sullen, anxious or sad after emotionally distressing events)				
6.	Is easily frustrated.				
7.	Responds positively to neutral or friendly approaches by peers.				
8.	Is prone to angry outbursts / tantrums easily				
9.	Is able to delay gratification (wait for good things)				
10.	Takes pleasure in the distress of others (e.g. laughs when another person gets hurt or punished; enjoy teasing others)				
11.	Can modulate excitement in emotionally arousing situations (e.g. does not get 'carried away' in high-energy situations, or overly excited in inappropriate contexts.				
12.	Is whiny or clingy with adults.				
13.	Is prone to disruptive outbursts of energy and exuberance				
14.	Responds angrily to limit-setting by adults.				
15.	Can say when s/he is feeling sad, angry or mad, fearful or afraid.				
16.	Seems sad or listless.				
17.	Is overly exuberant when attempting to engage other in play.				
18.	Displays flat affect (expression is vacant and inexpressive; child seems emotionally absent)				
19.	Responds negatively to neutral or friendly approaches by peers (e.g. may speak in an angry tone of voice or respond fearfully)				
20.	Is impulsive.				
21.	Is empathic towards others; shows concern when others are upset or distressed.				

22.	Displays exuberance that others find intrusive or disruptive.				
23.	Displays appropriate negative emotions (anger, fear, frustration, distress) in response to hostile, aggressive or intrusive acts by peers.				
24.	Displays negative emotions when attempting to engage others in play.				

Version 1 – 4 October 2006

APPENDIX H: SPORT PARTICIPATION AND EXPERIENCE

Has your child ***ever*** participated in organized sports? (**Y/N**)

If yes, please list the sports below. Please indicate the length of time that your child has participated in each sport.

Sport	**Length of Experience**