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Cognitive control as a mechanism linking regular physical activity and emotional health

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COGNITIVE CONTROL AS A MECHANISM LINKING REGULAR PHYSICAL ACTIVITY AND EMOTIONAL HEALTH

by

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ABSTRACT

Growing bodies of research suggests associations between regular physical activity (PA) and emotional health. One promising mechanism of this association is a cognitive process called cognitive control. Emerging evidence links regular PA to better cognitive control in young adult populations (e.g., Themanson, Pontifex & Hillman, 2008; Winneke et al., 2011). However, almost no research has examined associations between regular PA and cognitive control task performance with emotionally-charged stimuli. Such tasks have the potential to help detect cognitive benefits of regular PA and may more effectively elicit cognitive processes related to emotional functioning than do emotionally-neutral tasks. The current study investigated whether cognitive control is a mechanism that links regular PA and emotional functioning in young adults, particularly when emotional processing in incorporated. In other words, cognitive control, particularly in the face of emotional distractors, was expected to mediate the association between regular PA and emotional health.

Participants in this study comprised 115 young adults from an undergraduate population who responded to self-report measures of PA level and emotional functioning, completed neutral and emotional cognitive control tasks, and participated in a fitness assessment.

Bootstrapping to assess indirect effects revealed that contrary to hypotheses, performance on neutral and emotional cognitive control tasks did not mediate the association between PA level and emotional functioning. Regular PA was not associated with better neutral or emotional cognitive control, nor did it relate significantly to emotional functioning. Further, neither neutral nor emotional cognitive control showed a relationship with emotional functioning. Implications and future directions are discussed.

INDEX WORDS: Physical activity, Exercise, Cognition, Cognitive control, Executive functioning, Emotional processing, Emotion regulation, Mental health

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1 INTRODUCTION

1.1 Benefits of Regular Physical Activity

Physical activity (PA) is any bodily movement produced by skeletal muscles that results in energy expenditure (Castpersen, Powell, & Christenson, 1985). Regular PA, such as walking, cycling, or participating in sports, which is frequently associated with improved physical or aerobic fitness, has significant health benefits. For instance, it can reduce the risk of cardiovascular disease, diabetes, and obesity (e.g., Warburton, Nicol, & Bredin, 2006). Moreover, mounting evidence supports the positive association between regular PA and/or fitness and cognitive and mental health (e.g., Anderson & Shivakumar, 2013; Hillman, Erickson & Kramer, 2008; Fox 1999; Guszkowska, 2003; Salmon, 2001; Paluska & Schwenk, 2000; Prakash, Voss, Erickson, & Kramer, 2015; Voelcker-Rehage & Niemann, 2013). In particular, evidence suggests that regular exercisers are less anxious and depressed, and have better mood states than non-exercisers (Ahn & Fedewa, 2011; Arent, Rogers & Landers, 2001; DeMoor, Beem, Stubbe, Boomsma & De Geus. 2006; Penedo & Dahn, 2005; Stephens, 1988; Thirlaway & Benton, 1992). Further, a dose-response relationship between PA and mental health suggests that relative increases in regular PA are associated with greater emotional well-being (Galper, Trivedi, Barlow, Dunn & Kampert, 2006), less psychological distress (Hamer, Stamatakis & Steptoe, 2009), and reduced depressive and anxious symptoms (Dunn, Trivedi & O’Neal, 2001; Kim et al., 2012).

PA shows promise as a low cost and broadly accessible way to treat and prevent mental health problems (Paluska & Schwenk, 2000). Researchers suggest that the lower incidence of mental health disorders in individuals who report being physically active, compared to those who are not regularly active, provides support for the notion that it can play a role in mental illness prevention (Bhui & Fletcher, 2000; Goodwin, 2003; Larun, Nordheim, Ekeland, Hagen, & Heian, 2006; Pasco et al., 2011; Ströhle et al., 2007). For example, using general population data from the United States National Comorbidity Survey (NCS), Goodwin (2003) found that people who engage in regular PA are less likely than infrequent exercisers to meet criteria for diagnoses of major depression, social phobia, specific phobia, and agoraphobia. However, research evidence also suggests that individuals with mental illnesses are less likely than healthy peers to engage in PA (Ekkekakis, 2013). Thus the association between PA and emotional health could be driven by initially healthy emotional functioning that better permits engagement in PA. Nevertheless, previous literature indicates that engaging in regular PA can significantly reduce prior symptoms of depression and anxiety in clinical populations (Carek, Laibstain, & Carek, 2011; O'Connor, Raglin & Martinsen, 2000; Paluska & Schwenk, 2000).

Further, results from studies using quantitative and qualitative methods with clinical samples indicate that regular PA may be an effective intervention for mental disorders characterized by anxious and depressive symptoms (Fox, 1999; Herring, Jacob, Suveg, Dishman, & O'Connor, 2012; Martinsen, 2008; Stathopoulou, Power, Berry, Smits, & Otto, 2006; Ströhle, 2009). Regular PA is also a viable treatment for some mental disorders, like anxiety and depression, and may be comparable or superior to other common treatments, such as psychotherapy and pharmacology (Carek, Laibstain, & Carek, 2011; Petruzzello, Landers, Hatfield, Kubitz, & Salazar, 1991; Wipfli, Rethorst, & Landers*,* 2008). Overall, there is a consensus in the literature that regular PA is positively associated with healthy emotional functioning (Ströhe, 2009).

The association between regular PA and emotional health may be explained by a combination of several psychological and biological mechanisms. For example, regular PA may improve emotional functioning by serving as a coping mechanism, in that it creates a distraction from stress or troubling thoughts (Guszkowska, 2003); contributes to improvements in feelings of self-efficacy that come along with meeting goals or accomplishments (Ströhle, 2009); and fosters social engagement (Harvey, Hotopf, Øverland, & Mykletun, 2010). PA is also associated with increased synthesis and release of both neurotransmitters and neurotrophic factors, which then prompt neurogenesis, angiogenesis, and neuroplasticity in the brain (Nicastro & Greenwood, 2016). These neurological changes are often associated with enhanced cognition, which can subsequently impact emotional health in beneficial ways (Dishman et al., 2006).

Improvement in cognitive functioning constitutes a particularly strong candidate mediator of the relationship between regular PA and emotional health, partly due to the well-established association between regular PA and cognition. Many studies have found evidence that PA powerfully modulates cognitive function by inducing structural and functional brain changes (Ratey & Loehr, 2011; Smith et al., 2010; Gomez-Pinilla & Hillman, 2013; Hötting & Röder, 2013). For example, cross-sectional research suggests that higher PA levels and/or fitness—a correlate of PA that is an index of the body's ability to supply and efficiently use oxygen and energy—are associated with larger gray matter volume and greater processing efficiency in frontal, temporal, and cingulate areas of the brain (Erickson et al., 2011). The cognitive functions that appear to be most sensitive to the effects of regular PA and associated brain-related changes are higher-order cognitive functions that are primarily supported by frontal and temporal areas; these include memory and executive functioning, an overarching construct comprising skills that enable people to plan, organize, remember things, prioritize, pay attention, and get started on tasks (Guiney & Machado, 2013; Pontifex, et al., 2014). Some findings suggest particularly specific effects of regular PA on cognition via neural pathways; prefrontal brain region volume, for instance, has been shown to mediate beneficial effects of exercise on aspects of executive function, particularly cognitive control, in individuals who are active (Weinstein et al., 2012).

1.2 Cognitive Control

Cognitive control (also referred to as inhibitory control, executive control, or attentional control) is a component of executive functioning that helps people to attain a goal, particularly in novel or challenging situations, by adjusting attention, cognition, and action (Banich, 2009). It is one of three domains that make up executive functioning; the others are working memory and cognitive flexibility (Diamond, 2013). A useful conceptualization of cognitive control breaks the construct into three subsystems: goal setting, implementation, and monitoring (Saunders, Milyavskaya, & Inzlicht, 2015). Goal setting involves determining current performance intentions (e.g., studying for an exam or responding in a particular manner to a central target within an array of distractors). Implementation is the regulation of ongoing information processing towards goal attainment (e.g., continuing to read the next page in the textbook or pressing a key on the keyboard). The monitoring process detects events that are in conflict with current objectives (e.g., unwanted impulses, distractions, or errors), providing feedback to the implementation system about the need to increase or decrease the level of control exerted.

Given its broad and multidimensional character, cognitive control can be operationalized in different ways. In the context of the current study, the term refers specifically to higher-order processes associated with the control of attention and action amid conflicting or interfering information (Botvinick, Braver, Barch, Carter, & Cohen, 2001). The construct of cognitive control encompasses a range of mental abilities, including selective attention, inhibition, flexible thinking, and maintenance of working memory. These abilities permit efficient and effective cognitive functioning across varied contexts. For example, cognitive control has been implicated in academic achievement and healthy cognitive aging (Braver & Barch, 2002; Bull & Scerif, 2001; St Clair-Thompson & Gathercole, 2006). Functionally, cognitive control is required when studying for an exam while resisting the impulse to check Facebook, or having fruit instead of a sugary dessert when on a diet (Dixon, 2015). More broadly, research has shown the importance of effective cognitive control in daily life (Mäntylä, Karlsson, & Marklund, 2009; Vaughan & Giovanello K, 2010).

Cognitive control processes are often engaged in the face of emotional information, which people commonly encounter in daily life (Pessoa, 2008). When people are confronted with emotional stimuli and events, they must regulate the responses that those stimuli and events elicit. Early in this emotion regulation process, which encompasses an individual's regulatory response to emotions that unfolds over time (e.g., attempts to reduce anxiety; Davidson, 1998), the individual engages cognitive control mechanisms.

People vary in the facility with which they engage cognitive control in the face of emotional stimuli and events, particularly those that might be distressing. Some individuals can smoothly shift their attention away from such cues when they are presented and direct attention more intentionally to influence desired behavioral outcome; others cannot. Difficulty with cognitive control or regulating attention flexibly in the context of emotional information has been linked to, and is considered a marker for, a range of mental health problems (Alderman et al 2014; Pe, Vandekerckhove, & Kuppens, 2013; Zetsche, D'Avanzato, & Joormann, 2012). In addition, research suggests that cognitive training aimed at enhancing cognitive control may be a viable treatment for mental health problems, improving resilience and relieving symptoms of depression and anxiety (Cohen, Mor, & Henik, 2015; Cohen et al., 2016; Horelbeke, Koster, Vanderhasselt, Callewaert, & Demeyer, 2015; Siegle, Ghinassi, & Thase, 2007). Regular PA, which has been linked to both effective cognitive control and mental health (Guiney & Machado, 2013; Crone, Smith, & Gough, 2006), could thus exert at least some of its beneficial effects on emotional functioning by supporting effective engagement of this aspect of executive functioning.

1.2.1 Measuring Cognitive Control

Various task paradigms are used in research contexts to engage and assess cognitive control processes, but each task yields slightly different data and taps distinct facets of the overarching cognitive control construct. Although cognitive control appears to be multifaceted (Nee, Wager, & Jonides, 2007), this review focuses on two of the most commonly studied components of cognitive control: 1) selective attention and inhibitory control, and 2) task switching.

In this review, I group tasks that tap selective attention and inhibitory control together because task designs typically prevent separate measurement of the two constructs (Sanders &

Lamers, 2002); some tasks, however, may rely more on one construct than the other. The widely used Flanker task (Eriksen & Eriksen, 1974) requires selective attention and response to a target while inhibiting attention and responses to distracting flanking stimuli. Similarly, the most common version of the Stroop task (Stroop, 1935), another well-established measure of cognitive control, involves asking participants to name the color of ink (e.g., “blue”) that a congruent (e.g., “blue”) or incongruent (e.g., “red”) color name appears in, rather than reading the color word itself. On incongruent trials, one must selectively attend to the color of the word and inhibit the more automatic response to read the word.

Additional tasks that rely more on inhibitory processing than on selective attention are the Stop Signal Task (SST: Logan, 1994), the Continuous Performance Task (CPT; Conners, 1995) and the Go/No-go (Newman, Widom & Nathan, 1985). Each of the tasks requires selective attention to specific targets that appear within a series of stimuli. Targets signal the need for a unique response on most, but not all, trials; thus, people must periodically exert inhibitory control to interrupt the production of that response. In the Go/No-go task, specifically, participants must respond to stimuli that have been paired with rewards (i.e., the go trial) and withhold a response to cues that have been paired with punishment (i.e., the no-go trial). Thus, the SST, CPT, and Go/Go-go tasks do not require selective attention to a particular stimulus location on the screen or to a specific stimulus feature, as do the Flanker and Stroop tasks.

Switching paradigms take tasks with an emphasis on inhibitory processing one step further. Instead of simply requiring a person to inhibit a rapid response on some trials–one rule of the task—a typical switching task paradigm introduces an additional rule, and requires respondents to switch between the two different rules throughout the task. For example, when color words (e.g., red, green, yellow) are printed in different color inks, one rule might be that the respondent must name the ink color of the color word and not read the word, and the additional rule might be that when a color word is inside a box, the respondent must read the word and not name the ink color. On non-switch trials, the rule remains the same as on the previous trial. On switch trials, the response rule changes within a block of trials. This shift incurs a switching cost or a degree of slowing in order to change task goals before responding. In some cases, one of the rules might require selective attention and inhibition (i.e., like the first rule described in the example above), thus integrating inhibition into the switching task.

1.2.2 Neural Correlates of Cognitive Control

A rich and growing literature documents the use of brain imaging techniques to help us better understand the brain areas involved in cognitive control in the context of both non-emotional and emotional stimuli. Although the current study does not examine the neural underpinnings of cognitive control, this literature provides important background and context and thus warrants review. Broadly, research to date suggests that mental processes engaged during cognitive control tasks with and without emotional stimuli differentially recruit overlapping neural circuits (e.g., Chiew & Braver, 2011). Given that tasks with both stimulus types include similar task instructions and requirements to engage cognitive control, distinctions between the neural correlates of these two task types appear to reflect variability in their stimulus content that causes them to differentially place demands on aspects of emotional processing. This differential demand for emotional processing, in turn, alters patterns of neural recruitment.

Cognitive control capacities develop incrementally, in parallel with the maturation of the prefrontal cortex (Casey, Giedd, & Thomas, 2000). Successful cognitive control requires selective attention, inhibition, flexible thinking, and maintenance of working memory. As noted earlier, cognitive control tasks place particular demands on inhibitory processing, during which the prefrontal cortex regulates subcortical structures in a top-down fashion. This inhibitory component of cognitive control is associated with dynamic activation of varied prefrontal regions, including the dorsolateral and anterior prefrontal cortices (dlPFC & aPFC) and the dorsal anterior cingulate cortex (dACC; Botvinick, Nystrom, Fissell, Carter & Cohen, 1999; Casey et al., 2000; Hazeltine, Poldrack & Gabrieli, 2000; Voss et al., 2011). The dlPFC is hypothesized to initiate flexible adjustments in control, the aPFC maintains context-driven task goals over prolonged periods of time, and the ACC evaluates and monitors for conflict and errors that signal need to adjust control (Dosenbach et al., 2007, Forster & Brown, 2011). In the adult brain, the aPFC and the dACC are embedded in a brain network called the cingulo-opercular network, which is involved in sustained attention (Dosenbach et al., 2007). The cingulo-opercular network is proposed to work in concert with the fronto-parietal network, which includes the dlPFC and complements the sustained activity of the cingulo-opercular network with adjustment of cognitive control (Dosenbach et al., 2007, 2008). As the brain develops, the architecture of the cognitive control system becomes increasingly effective at flexibly balancing rapid and sustained goal-oriented control.

The neurocircuitry of cognitive control has also been researched using tasks that incorporate affectively-charged stimuli, which engage elements of emotional processing. Details about parallels and distinctions between neural regions that activate in response to non-emotional and emotional stimuli remain poorly defined. There is reason, however, to suspect that the mechanism of cognitive control in the face of emotional stimuli may differ from that of cognitive control when stimuli lack emotional valence. People tend to process emotional stimuli preferentially, which can modulate responding (Williams, Mathews, & MacLeod, 1996). In other words, because emotional stimuli are salient and thus capture attention, they may be more likely to require concerted effort to modulate. In effect, emotional stimuli demand more cognitive control to override or ignore them.

Initial research exploring cognitive control elicited by emotional versus non-emotional stimuli was conducted through the lens of the traditional view that cognition and emotion occupy distinct anatomical areas in the brain. This work resulted in an early hypothesis that emotional and non-emotional cognitive control processes were mediated by distinct subdivisions of the ACC (ventral and dorsal regions, respectively; Bush, Luu, & Posner, 2000). However, more recent research has challenged this view (Pessoa, 2008). Instead, newer theories propose that affective and cognitive stimuli are processed via more shared neurocircuitry than was previously thought (Shackman et al., 2011). For example, studies focused on ACC function during emotional and non-emotional cognitive control tasks suggest that *both* dorsal and ventral subdivisions of the ACC make key contributions to emotional processing (Etkin, Egner, & Kalisch, 2011). Findings from other recent investigations (Chiew & Braver, 2011; Levens & Phelps, 2010) suggest that both emotional and non-emotional conflict during a cognitive control task commonly engage a number of brain regions associated with cognitive control. These include the dACC and lPFC, as well as areas implicated in both emotional processing and cognitive control, such as the bilateral anterior insula. However, Chiew and Braver (2011) found that activity in these brain regions peaked when emotional and cognitive processes were both required. This set of findings suggests that emotional and non-emotional cognitive control may be mediated by similar neural processes, but emotional and cognitive influences on processing may be additively combined to produce increased cognitive control demands.

In contrast to the studies suggesting shared neural processes in emotional and non-emotional contexts, research has also shown that additional brain regions are activated during cognitive control in the context of emotional information, including the inferior frontal junction, amygdala, (Cromheeke & Mueller, 2014; Van Dillen et al., 2009), striatum (Padmala & Pessoa, 2010), and parietal cortex (Chromheeke & Mueller, 2014; Schulz et al., 2009). Further, results from studies aimed at exploring the influence of emotional content on cognitive control have concluded that the subgenual ACC and the precuneus, in particular, are involved in the integration of cognitive control and emotion-related neutral processes (Cromheeke & Mueller, 2014).

These findings suggest that cognitive control with and without emotional processing rely on many shared neural processes, but that cognitive control in the presence of emotional material may also engage some regions that differ from those recruited for cognitive control without emotional material. Some suggest that alternate brain regions that activate when emotional processing is incorporated with cognitive control are linked to inhibitory processes (Chromheeke &

Mueller, 2014). Thus, these regions of the brain may serve to suppress emotional material and/or to counteract the influence of emotional distractors (Chiew & Braver, 2011). In sum, there is no clear consensus on the precise neural networks involved in the two cognitive control task variations (emotional and non-emotional), but they appear to *differentially* recruit overlapping neural circuits with additional regions or degrees of recruitment when emotional processing is engaged. Nevertheless, the shared neural circuitries that seem to mediate cognitive control with and without emotional processing are consistent with those that regular PA has been shown to alter in beneficial ways.

1.3 Physical Activity and Cognitive Control

Regular PA has been shown to enhance function in areas of the brain that are amenable to plasticity (i.e., frontal, temporal, and anterior cingulate cortices) and that are responsible for implementing higher-order cognitive processes, such as executive functioning and memory (Guiney & Machado, 2013; Voelcker-Rehage & Niemann, 2013; Weinstein et al., 2012). Some research links regular PA, as well as physical fitness, to performance on emotionally neutral cognitive control tasks (see Table 1). In such studies, regular PA and/or aerobic fitness have each been shown to alter brain structure and function in regions implicated in cognitive control, thus presumably strengthening this aspect of cognitive processing. This body of research typically defines aerobic or cardiorespiratory fitness as one's ability to transport and use oxygen and is determined with a measure called $VO_{2\ max}$ that indexes maximum oxygen consumption. For simplicity, references to fitness from this point forward will reflect VO_{2max}, unless stated otherwise.

Most of the research yielding evidence that regular PA benefits cognitive control has sampled from healthy populations at either end of the lifespan (i.e., older adults and pre-adolescent children), but evidence is beginning to emerge that regular PA also might enhance young adults' cognitive control capacities. While the current study is focused on this understudied young adult population, the extant literature on all age groups is reviewed to inform understanding of and predictions about the study population.

It is also important to acknowledge that the relationship between regular PA and cognitive control is reciprocal (Daly, McMinn, & Allan, 2013). While most studies and this review focus on the beneficial effects of regular PA on cognitive control, research also indicates that successfully implementing intentions to be active and engaging in healthful lifestyle behaviors like PA depends on cognitive control and self-regulation abilities (Buckley, Cohen, Kramer, McAuley, & Mullens, 2014). Further, there is evidence that PA-associated gains in cognitive control predict better long-term adherence to PA (Best, Nagamatsy, & Liu-Ambrose, 2014; Mullens & Hall, 2015). Therefore, PA and cognitive control appear to be related via a feedback loop.

1.3.1 Children

Several cross-sectional studies of PA level/fitness and cognitive control in children have compared performance on Flanker tasks between preadolescent children classified as low-fitness (<30th percentile) or high-fitness (>70th percentile). These studies have yielded varying results; broadly, however, they suggest better cognitive control task performance in high-fit, compared to low-fit preadolescent children. More specifically, results indicate that compared to low-fit children, those with higher fitness perform more accurately across conditions and following incorrect responses on previous trials (Hillman et al., 2009; Pontifex et al., 2011), show less variability in response latencies across conditions (Wu et al., 2011), are better able to sustain accuracy over the course of the task (Chaddock et al., 2012), and are less vulnerable to Flanker effects (Chaddock et al., 2010a). Further, low-fit children have shown greater accuracy cost for the incongruent condition, which means that their accuracy decreases when greater cognitive control is required (Pontifex et al., 2011; Voss et al., 2011).

Additional studies of fitness and cognitive control in children that explored the link between aerobic fitness and performance on Stroop tasks have yielded mixed findings. In one of these studies, children completed three 45-second Stroop trials: color, word, and color word. In 74 children ranging from 7 to 12 years old, Buck et al. (2008) found that greater aerobic fitness, measured by the Progressive Aerobic Cardiovascular Endurance Run (PACER) where fitness is assessed based on how long participants can run at a specified pace that increases over time (Prudential FITNESSGRAM, 1994), was positively associated with number of items reported in 45 seconds across conditions. Fitness was not, however, associated with interference effects, based on items reported in the 45 second condition. Similarly, findings from a randomized, un-controlled intervention study suggested that increased aerobic fitness after children exercised for 75 min/day, 5 days/week for 9 months was not significantly associated with Stroop interference effects, based on items reported in the 45 second color word condition (Castelli, Hillman, Hirsch, Hirsch, & Drollette, 2011).

Findings from several studies within the child literature converge to suggest that cognitive control is generally better among higher-fit children than lower-fit children (i.e., high fit children show faster RT or greater accuracy across all conditions; Chaddock et al., 2012; Hillman et al., 2009; Pontifex et al., 2011; Wu et al., 2011). However, more recent studies in children have shown that regular PA/fitness's effects might also be selectively larger for task components that place greater processing demands, as evidenced by findings of smaller Flanker effects or less accuracy cost in high-fit children compared to their less-fit counterparts (Chaddock et al., 2010a; Pontifex et al., 2011; Voss et al., 2011). Therefore, a comprehensive appraisal of the existing literature points to both general and selective effects of fitness of cognitive control performance in children.

Two studies have examined children's performance on the Flanker task while they are undergoing functional magnetic resonance imaging (fMRI). This approach allowed researchers to examine how activation of brain networks mapped onto performance differences between groups with different fitness levels. Voss and colleagues (2011) found VO_{2max} fitness group differences in brain activity for regions associated with aspects of cognitive control, including response execution and inhibition, task set maintenance, and top-down regulation. These regions included the prefrontal, supplementary motor, and anterior cingulate cortices (see Figure 1). Specifically, results showed that high-fit children showed greater activation in salient regions during the congruent compared to the incongruent condition, whereas low-fit children showed the inverse pattern of activation during task conditions.

The observed differences in brain activity could suggest that the two fitness groups use different strategies during task performance. Chaddock et al. (2012) found that high-fit children compared to low-fit peers, showed initially increased recruitment of frontal areas (i.e., middle frontal gyrus and supplementary motor cortex) and superior parietal cortex, but reduced activity as the task progressed (Chaddock et al., 2012). The authors interpreted this pattern as a reflection of better activation and adaptation of neural processes to maintain performance over the course of the task in the high-fit group. Taken together, these two neuroimaging studies (Chaddock et al., 2012; Voss et al., 2011) provide evidence for an association between fitness and overall efficiency of the cognitive control network.

Whereas functional imaging techniques such as fMRI yield useful information about location of neural activity, their temporal resolution is poor (Kim, Richter, & Ugurbil, 1997). Alternate imaging techniques, such as EEG, that provide measures of neuroelectric activity, are better suited to elucidating the time course of neural events (Tucker, Liotti, Potts, Russell, & Posner, 1994). This measurement approach provides more detailed moment-by-moment neural correlates of specific aspects (e.g., stages) of mental processes such as cognitive control.

Most research on neuroelectric activity associated with cognitive control and regular PA describes event-related potential (ERP) waveforms that are associated with task performance. ERPs are changes in electrical activity in the brain called waveforms. Waveforms occur in response to events (Niedermeyer & da Silva, 2005) and can be stimulus-locked, meaning that they are measured with respect to the moment a stimulus appears, or response-locked, meaning they are measured with respect to the moment the subject performs a motor activity (Luck, 2012; Mattler, van der Lugt, & Munte, 2006). Each type of waveform is composed of a series of positive and negative voltage deflections, which are related to a set of underlying components. Most components are referred to by a letter—N or P indicating negative or positive change in electrical activity—followed by a number that suggests either the latency in milliseconds or the serial order of the waveform.

Whereas an EEG can detect many components, only a few have been explicitly linked to cognitive control processes. The P3 component (also known as the P300) is a positive change in electrical activity; its amplitude reflects the allocation of attention towards salient stimuli and its latency is a marker for speed of processing (Hajcak, MacNamara, & Olvet, 2010). Error-related negativity (ERN), a different ERP, is detected towards the front of the scalp where the ACC is thought to be involved in its generation. The ERN reflects the activity of a general error detection system. As such, the ERN has been shown to occur after an error and to include the error-correcting response (Meyer, Riesel, & Proudfit, 2013). The ERN is often a primary component of interest in studies of brain activity during cognitive control tasks. Event positivity (Pe), a third ERP, is also associated with error-related processing. It occurs after the ERN, and is thought to be involved in the detection of errors or error recognition (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000). Lastly, an ERP called N2 reflects action monitoring or response inhibition. For example, the N2 specifically marks the conflict that must be resolved in an incongruent Flanker trial prior to responding, such that larger N2 amplitude is associated with increased conflict. (Schmitt, Münte, & Kutas, 2000; Yeung & Cohen, 2006).

Consistent with behavioral and MRI studies linking children’s fitness with better cognitive control, findings from studies that measure neuroelectric activity suggest that high-fit children can more flexibly modulate cognitive control-related neural processes to meet task demands than can low-fit children. When examining ERP data collected during completion of the Flanker task, Hillman et al. (2009) found that high-fit, compared to low-fit children, had larger P3 amplitude across conditions, as well as smaller ERN amplitude and larger Pe amplitude while performing more accurately across conditions and after commission errors. Hillman et al. (2009) concluded that these neuroelectric findings indicate that high-fit children have greater allocation of attentional resources during stimulus encoding and a subsequent reduction in conflict during response selection. In research replicating Hillman and colleagues' (2009) findings, high-fit compared to low-fit children performed more accurately and exhibited larger P3 amplitude, shorter P3 latency, smaller N2 amplitude, and shorter N2 latency relative to low-fit peers. These findings suggest that higher-fit children have a greater capacity to allocate attentional resources, experience less response conflict, and have quicker stimulus classification and processing speed relative to lower-fit peers (Pontifex et al., 2011). High-fit compared to low-fit children also showed a larger ERN and P3 amplitude in response to the incompatible, relative to the compatible, condition, which reflects a better ability to flexibly modulate cognitive control.

Broadly, then, pre-adolescent children categorized as high-fit exhibit better performance on the Flanker and Stroop task generally—meaning across all trials—than their less-fit peers. They also show some more specific strengths, such as less vulnerability to interference effects and less accuracy cost on incongruent trials. Whereas fMRI studies yield evidence of greater cognitive control network efficiency in children with high-fitness across task conditions, ERP research yields evidence of better allocation of attentional resources and reduced conflict, resulting in efficient adaptation of processes involved in cognitive control relative to low-fit peers. These literatures converge to provide a foundation of solid evidence regarding neural correlates of the link between regular PA and cognitive control in youths.

1.3.2 Older Adults

In research focused on people at the other end of the lifespan, several studies have compared performance on cognitive control tasks between high- and low-fit older adults. Results from studies using these tasks indicate broadly that regular PA attenuates age-related decline in cognitive control. On the Flanker task, for example, older adults with higher, compared to lower, self-reported regular PA and/or fitness have been shown to exhibit faster response times, smaller Flanker effects, and greater accuracy both across all conditions, and, in several studies, on incongruent trials specifically (Colcombe et al., 2004; Hillman et al., 2006; Voelcker-Rehage, Godde, & Staudinger, 2010).

Further, evidence from a randomized controlled trial (RCT) showed that older adults who received aerobic training exhibited smaller Flanker effects than did members of the control group, who received a nonaerobic stretching and toning intervention (Kramer et al., 2001). Other RCTs have yielded similar results; for example, one study found that older adults in an aerobic intervention group showed improved accuracy across all conditions, a change that was not observed in the control group enrolled in a relaxation and stretching intervention (Voelcker-Rehage, Godde, & Staudinger, 2011). Findings in the literature on regular PA and Flanker task performance are not, however, entirely uniform. In contrast to the studies suggesting more efficient Flanker task performances in fit older adults compared to non-fit counterparts, Hillman, Belopolsky, Snook, Kramer, and McAuley (2004) did not detect Flanker performance differences among low, moderate, and high fit older adults (mean age = 67 years); however, the small sample size (N = 24) may have reduced their ability to detect an effect.

In research examining older adults' performance on the Stoop task, similar findings emerge to those observed in studies using the Flanker task. Dustman et al. (1984) found that 13 older adults (ages 55-70) in an aerobic exercise intervention group demonstrated reduced interference on the Stoop task after 4 months of aerobic training, a change that was not observed in either of 2 control groups: one group that trained with strength and flexibility exercises and another group that was not engaged in a supervised exercise program. This finding was replicated in a study of 57 older adults (ages 64-74) who participated in aerobic or strength-and-flexibility exercise training for 10 months. After aerobic training, older adults showed reduced interference and improved accuracy; participants who engaged in strength and flexibility training did not (Smiley-Oyen, Lowry, Francois, Kohut, & Ekkekakis, 2008).

Cross-sectional studies also yield support for the idea that regular PA/fitness relates to better performance on the Stroop task. One study found an association between older adults' (ages 60-75) fitness and Stoop task performance, with greater fitness linked to less interference and higher accuracy (Prakash et al., 2011). Similarly, Weinstein et al. (2012) found that in 142 older adults (mean age = 66.6), higher fitness levels were associated with less interference. A more recent study compared Stroop task performance between 20 regularly physically active (lifelong) older adults (aged: 65-87) and 20 age-matched, physically low active peers. Results indicated that the regularly active participants had a significantly smaller interference effect than their low active counterparts (Gajewski & Falkenstein, 2015). Further, this difference in cognitive performance was exclusive to cognitive control and did not extend to other cognitive functions, such as attention, processing speed, and working memory, and memory, that were evaluated in the study. In a third cross-sectional study, Hyodo et al.'s (2016) findings in a sample of 60 older (mean age: 70.3 ± 3.2) men yielded similar support for the idea that there is a link between greater fitness and shorter Stroop interference time.

Studies that have collected neuroimaging data while older adults completed the Flanker task have also yielded evidence of the cognitive benefits of regular PA and fitness; however, there do not yet appear to be published imaging studies of older adults that have included the Stroop task. Colcombe and colleagues (2004), for instance, found evidence that during the Flanker task, highly fit (Study 1: age 55+) or aerobically trained (Study 2: ages 58-77) older adults showed greater task-related brain activity in regions of the prefrontal and parietal cortices that are involved in regulating attention (i.e., middle and superior frontal gyri, superior parietal lobe), and reduced activity in the ACC, a region associated with the presence of behavioral conflict and the need to adapt cognitive control processes, when compared with low-fit (Study 1) or nonaerobic control (Study 2) older adult participants (see Figure 1). Similarly, Voelcker-Rehage, Godde, and Staudinger (2010) found high fitness, compared to low fitness, in older adults (mean age = 68.99 ± 3.66) to be associated with decreased ACC activation and increased activation of prefrontal areas when performing the Flanker task.

In an intervention study of older adults (ages 62-79) Voelcker-Rehage and colleagues replicated some of their own findings, showing that aerobic training, compared to relaxation and stretching (control group), was linked to decreased ACC activation during the Flanker task (Voelcker-Rehage, Godde, & Staudinger, 2011). Results also indicated decreased activity in prefrontal areas among aerobic training participants, but not control participants, when performing the Flanker tasks 6 and 12 months after the intervention. These findings diverged from those of prior research in older adults (e.g., Colcombe, 2004; Voelcker-Rehage, Godde, & Staudinger, 2010). However, this study's key outcome of decreased brain activation accompanied by better cognitive control performance resembles a pattern of association between brain activation and performance that has been observed in studies of young adults (Hollmann, Strüder, Tagarakis, & King, 2007). Further, according to Voelcker-Rehage, Godde, and Staudinger (2011), the reduced activation in prefrontal areas can be interpreted as indicating a reduced need for compensation, which is defined as an increase in neural activity to meet task demands that is commonly seen in aging. This stands in contrast to the compensation typically seen in older adults (see review Greenwood, 2007) and thus suggests more efficient cognitive processing in older adults who are physically active.

In summary, findings from studies exploring the association between regular PA and/or fitness and cognitive control on the Flanker and Stroop tasks in older adults indicate a positive association between regular PA/fitness and task performance. Behaviorally, fit or active older adults perform better than their less fit or active counterparts on both Flanker and Stroop cognitive control task. However, in keeping with the child literature, older adults perform better in different ways in different studies. Some studies report general differences, such as faster RT or greater accuracy across all conditions (Hillman et al., 2006; Voelcker-Rehage et al., 2011), whereas others note selective differences, such as smaller Flanker effects or greater accuracy only on incongruent conditions (Colcombe et al., 2004; Colcombe & Kramer, 2003; Kramer et al., 1999; Kramer et al., 2001; Kramer, Colcombe, McAuley, Scalf, & Erickson, 2005; Hillman et al., 2006; Prakash et al., 2011; Voelcker-Rehage et al., 2010; Weinstein et al., 2012). Neurophysiological differences associated with fitness and/or regular PA in older adults when completing the Flanker task were also apparent, with decreased ACC activation and variable differences in task-related brain activity (Colcombe et al., 2004, Voelcker-Rehage, Godde, & Staudinger, 2010; Voelcker-Rehage, Godde, & Staudinger, 2010). These findings generally suggest greater efficiency of cognitive control in older adults who are fit or active.

Research findings in older adult samples are generally consistent with the established literature in pre-adolescent children. At both ends of the lifespan, high-fit or active groups perform better on cognitive control tasks than do low-fit or low-active groups, but how their performance is better varies across studies. With regard to neuroimaging findings, again no one consistent pattern of activation emerges across all studies; results converge loosely, however, to suggest that more efficient cognitive control is associated with high activity or fitness levels. In literatures regarding both pre-adolescent children and older adults, higher aerobic fitness and/or regular PA is associated with superior cognitive control, as demonstrated by better general and selective performance, and neural activation during the cognitive control task.

1.3.3 Young Adults

Relatively few studies examine regular PA/fitness and its association with cognitive control performance in healthy young adults. This lack of attention to young adults may reflect beliefs among researchers that regular PA/fitness-related performance differences are easier to detect in children and older adults, who are in stages of cognitive development or decline (Best & Miller, 2010; Darowski, Helder, Zacks, Hasher, & Hambrick, 2008). Young adults are also commonly considered to be functioning at peak levels of cognitive performance, at least on indices of cognitive control. This assumption is supported by some evidence suggesting that the relationship between regular PA/fitness and cognitive control is stronger in older than younger adults (Hillman et al., 2006). However, evidence from both meta-analyses and narrative reviews also suggests that young adults might show regular PA-related improvement, either broadly or on specific performance components, on measures of cognitive control (Cox et al., 2015; Guiney & Machado, 2013).

One of the most commonly used cognitive control task used in the young adult PA literature is the Flanker task. A study supporting broad differences in cognitive control performance on the Flanker task showed that self-reported PA that induced sweating was linked to faster response times across all conditions (i.e., congruent and incongruent) in a sample of 15 to 71-year-old participants. No significant association with interference effects, however, was evident (Hillman et al., 2006).

In contrast, some studies administering the Flanker task to young adults have shown that regular PA is associated with interference effect performance indices and, in some cases, with particular neural indices. In a study of 64 healthy young adults (aged 20-30) Pérez, Padilla, Parmentier, and Andres (2014) found that habitually active participants (i.e., they performed aerobic activity for a period greater than 10 years for an average of 6 or more hours per week distributed across at least three days a week, and continued this activity at the time of testing) showed weaker interference effects than the habitually passive participants (i.e., they did not exercise more than 2 hours per week for the past 4 years).

Similarly, a study comparing younger (ages 35-48) and older middle-aged adults (55-65) explored differences in self-reported PA's association with both behavioral and neural responses during performance on neutral (i.e., Flankers were neutral, rather than the alternative response target) and incongruent trials (i.e., Flankers were the alternative response target; Winneke, Godde, Reuter, Vieluf, & Voelcker-Rehage, 2012). On neutral trials, regardless of participant age, interference effects were smaller among high active relative to low active individuals. The same behavioral findings emerged in the young middle-aged adult group on the incongruent trials, where there is greater conflict. Further, incongruent trials elicited larger N2 amplitude differences in the high-active compared to low-active young middle-aged adults, suggesting more attentional resources were allocated to resolving the perceptual conflict in the younger group. No behavioral or neuroelectric index differences on incongruent trials were observed between high and low active individuals in the group of older middle-aged adults. Taken together, these studies yield evidence of smaller interference effects in regularly active young adults, compared to those who are not regularly active, which is generally consistent with the findings in both child and older adult populations.

There is also evidence that high-fit, compared to low-fit, young adults demonstrate better cognitive control on the Flanker task based on differences in neural indices and coinciding behavioral indices that are more precise than overall response time or interference effects. For example, in a sample of 28 young adults (age: mean = 20.35 ± 2.05), high-fit young adults demonstrated greater post-error slowing in conjunction with smaller ERN and larger Pe, compared to low-fit young adults. This finding was interpreted as indicating reduced conflict and increased top-down cognitive control (Themanson & Hillman, 2006). Similarly, in another study of 72 young adults (ages 18-25), fit participants differed from their less fit counterparts on a Flanker task that emphasized response accuracy, as opposed to speed. The fit young adults demonstrated more post-error accuracy on items that immediately followed an error, as well as greater ERN amplitudes than their less-fit peers (Themanson, Pontifex, & Hillman, 2008). The authors suggested that these behavioral and neural findings point to better top-down modulation of responses and, thus, improved cognitive flexibility in order to meet task demands in fit adults.

Studies that use other cognitive control tasks similarly show that fitness is associated with better cognitive control. A recent study examined the link between fitness and Stroop task performance in young adult women (aged 19-34). In this study, Dupuy et al. (2015) found that high-fit, compared to low-fit, participants exhibited faster RT on incongruent trials, exclusively. Similarly, a study examining 93 both male and female young adults (aged: 23.01± 3.67) found that higher fitness was positively associated with smaller Flanker effects (Zhu & Castelli, 2014). Significant associations between fitness and cognitive control thus appear to extend beyond the Flanker task.

A few studies have assessed cognitive control using task switching paradigms, yet inhibitory processes incorporated into one of the tasks, rather than the task switching itself, appear to be the aspect of cognitive control that benefits most from PA/fitness. In one study, Themanson, Hillman, and Curtin (2006) compared behavioral and neuroelectric indices of cognitive control between 34 high and low physically active younger adults (18-21 years). Results revealed increased post-error response slowing and decreased ERN amplitude (i.e., reduced conflict) for physically active participants, compared to their less physically active counterparts; no differences in switching or accuracy were found between PA groups. These neurophysiological and behavioral results are consistent with the findings that emerged when researchers used the Flanker task to measure cognitive control (Themanson & Hillsman, 2006). In Cameron, Lucan, and Machado's (2015) study of 52 healthy young women (ages 18-30), results positively linked chronic physical activity level (CPAL) with better inhibition, but not better switching. A more recent study by the same research group using the same cognitive control task similarly showed that in a sample of 55 young adults (mean age: 21.8 ± 2.5) more frequent self-reported PA was related to better inhibitory control (Guiney, Lucas, Cotter, & Machado, 2015).

In another task-switching study, Kamijo and Takeda (2010) found that in a sample of 40 young adults (mean age = 21.4 ± 0.3), sedentary participants, compared to physically active ones, exhibited less efficient cognitive control on both behavioral and neuroelectric indices. First, the sedentary group showed more RT slowing than did the active group when switching between tasks. In addition, while the active group's P3 component was consistent across conditions (i.e., easy, hard, and switching), the sedentary group showed a decreased ERP P3 amplitude during the task that required switching when compared to that during the easier task, but not the hard task. This decrease in P3 amplitude commonly occurs in the face of increased memory load (Kok, 2001). Findings suggest that active participants were better able to efficiently modulate attention and cognitive resources to meet task demands in comparison to their sedentary peers. Further, the fact that differences in performance between the groups emerged only when the demands of the tasks differed greatly (i.e., easy vs. switching) suggests that cognitive control demands may need to be large in order to permit detection of effects of PA on performance.

Additional studies have yielded evidence that is consistent with the idea that regular PA/fitness-related effects on attentional control are only detectable in young adults when they are engaged in cognitively taxing tasks. In a study of 72 active and inactive healthy young adults (mean age = 23 ± 3), participants performed both standard and strategic versions of the Stop Signal Task (SST). The less-demanding standard version of the task requires participants to prioritize the speed of their response; the strategic version allows participants to adopt a more conservative approach by slowing their response speed to improve accuracy, which requires greater inhibitory processing demands. In this study, Padilla, Pérez, Andres, and Parmentier (2013) found that active participants were more efficient, or had faster response times, than did passive participants when inhibiting responses in the strategic version; there was no difference between groups in the standard condition. A study that sought to replicate these findings was successful and confirmed that regular exercise modulated strategic inhibitory processes in a sample of 58 young adults (mean age = 22.26 ± 3.26; Padilla, Pérez, & Andres, 2014).

Across the literature on PA and cognitive control as measured by various tasks in healthy young adults, findings provide suggestive evidence that cognitive control differences related to PA may emerge in specific situations, rather than manifesting globally. For example, results of two non-Flanker studies (Kamijo & Takeda, 2010; Padilla, Pérez, Andres & Parmentier, 2013) suggest that the cognitive demands, or amounts of cognitive control required by a task, seem to be important variables to consider when investigating differences in cognitive task performance. This is largely consistent with the findings in child and older adult literature suggesting selectively larger PA/fitness-related differences for performance on tasks or trials (e.g., incongruent Flanker trials) that require extensive amounts of cognitive control (Colcombe & Kramer, 2003; Hillman et al., 2006; Kramer et al., 1999, Kramer, Colcombe, McAuley, Scalf, & Erickson, 2005; Pontifex et al., 2011; Voss et al., 2011).

Moreover, in studies that have examined cognitive control in young adults, differences in performance between PA level or fitness groups seem to have been detected more readily when researchers focused on narrower performance indices, particularly when cognitive control demands are high, than those typically examined in studies of children or older adults. For example, research has often failed to detect differences between active/fit and inactive/less fit healthy young adults on broad cognitive control performance measures, such as indices of the interference effect (e.g., Hillman et al., 2006). However, group differences have been frequently identified when performance indices are more precise and reflect aspects of performance when cognitive control demands are high (e.g., post-error RT, or post-error accuracy when there are instructions to attend to accuracy) (Themanson & Hillman, 2006; Themanson, Hillman & Curtin, 2006; Themanson, Pontifex, & Hillman, 2008). Taken together, research findings suggest that there is more specificity in the cognitive control benefits conferred by regular PA in the young adult population than there is in regular PA's benefits for individuals at either end of the lifespan.

The importance of better understanding of the regular PA/fitness-cognitive control association in the young adult population has been highlighted in recent calls to closely examine how PA might affect cognition across the lifespan (Prakash, Voss, Erickson, & Kramer, 2015). Although studies yield general evidence that cognitive control is enhanced among those who engage in regular PA or have a high level of fitness, there is only a small body of research in this area. Further, evidence regarding how their performance benefits from regular PA or fitness is inconsistent across studies, ranging from general to very specific improvements.

There are potentially useful directions in which to extend the research on the regular PA-cognitive control link. In particular, manipulating the level of cognitive control that tasks demand could help to pinpoint benefits of regular PA that emerge for this cohort; integrating emotional processing into the task is one way of accomplishing such a manipulation. In addition, examining cognitive control with emotional processing should permit measurement of a level and aspect of cognitive control that has not been explored in the PA literature thus far; such work may provide additional insight into how regular PA confers emotional health benefits.

1.4 Physical Activity and Cognitive Control with Emotional Processing

A few studies within the PA literature have incorporated objective indices of behavior and cognitive processes that presumably contribute to mental health (Barnes, Coombes, Armstrong, Higgins, & Janelle, 2010; Shields, Larson, Swartz, & Smith, 2014; Tian & Smith, 2011; Heenan & Troje, 2014). Tian and Smith (2011), as well as Barnes, Coombes, Armstrong, Higgins, and Janelle (2010), for example, measured attention bias, which provides an index of attentional flexibility in the presence of emotionally salient stimuli, but does not place varying demands on inhibitory processes. Thus, whereas some aspects have been measured, other important cognitive processes, such as cognitive control have not been the focus of published studies to date.

Further, extant studies have examined the effects of acute exercise prior to or during performance on cognitive control tasks with emotional stimuli. Such research provides evidence of short-term changes in emotional processing and selective attention that may influence mood and adherence to exercise. However, examining the effects of acute PA does not provide insight into the long-term structural and functional brain changes engendered by regular PA (Dishman et al., 2006). That is, regular PA-related brain changes are more likely to result in more sustained benefits to cognitive and emotional functioning outside the immediate context of exercise.

There thus appears to be a gap in the PA literature that is worth exploring; there is evidence to suggest that cognitive control in the context of emotional stimuli is a plausible mechanism by which regular PA influences emotional functioning. Not only does research suggest cognitive control with emotional processing recruits regions of the brain influenced by PA, but performance on tasks that require such integration of cognition and emotional responses have been linked to emotional health and functioning.

For example, whereas healthy individuals have demonstrated an increase in cognitive control in the face of negative emotional stimuli, compared to neutral stimuli, individuals with symptoms of depression and anxiety have demonstrated reductions in cognitive control (Kanske, 2012). Altered cognitive control in the context of emotional stimuli in psychologically symptomatic individuals may be explained by the presence in such people of distinctive patterns of emotional processing, such as difficulty disengaging from distracting negative information (Koster et al., 2011; Pe, Vandekerckhove, & Kuppens 2013), as well as heightened detection of, orientation towards, and sensitivity to emotional stimuli (e.g., Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & Van Ijzendoorn, 2007; Mogg, Millar, & Bradley, 2000). These emotional processing differences are generally considered markers for a range of mental health problems and are correlated with poorer emotional functioning (Kalia, 2005; Li et al., 2008; Miskowiak & Carvalho, 2014; Zetsche, D'Avanzato, & Joormann, 2012). In sum, exploring associations between PA and cognitive control in the context of emotional stimuli, a variable that is linked to emotional health, may yield behavioral indices of cognitive processes that may underlie PA's emotional benefits.

Whereas performance on cognitive control tasks with neutral and emotional stimuli has been shown to be correlated (Cothran & Larsen, 2008), research suggests that the inclusion of emotional information alters the nature of the task, leading to subtle differences in performance between emotional and non-emotional versions. In particular, negatively-valenced stimuli appear to exert disproportionate power over attention. For example, on incongruent trials of the Flanker task, negatively-valenced flanking stimuli typically result in stronger interference effects than do neutral or happy distractors (Fenske & Eastwood, 2003). In addition, when a target is negatively valenced, neutral or happy flanking stimuli often interfere less with responses (Barratt & Bundesen, 2012; Fenske & Eastwood, 2003). Thus, something different occurs in the emotional and non-emotional versions, with the emotional version requiring that participants retain cognitive control even in the face of emotional information that is inherently distracting (i.e., negative cues).

Exploring performance on cognitive control tasks with and without emotional stimuli and its potential influence on the link between regular PA and emotional functioning could yield findings that further our understanding of mechanisms that underlie the emotional effects of regular PA. Studies focused on young adults are of particular importance, given that this population has received relatively little attention in research on PA, cognitive control, and emotion. Further, the small literature to date suggests that effects of PA on cognitive control may be more specific and subtle than those detected in child and older adult samples. There may thus be value in studies designed to maximize likelihood of detecting such subtle differences.

For example, differences in performance between young adults with regular PA/high fitness and those with no PA/low fitness may emerge most clearly when task demands are high. Thus, including a measure of cognitive control with emotional processing, which adds to the fundamental demands of a neutral cognitive control task, may better capture group differences in this population. Further, examining performance on both neutral and emotional versions of cognitive control tasks in tandem might prove to be a helpful step toward clarifying how regular PA supports adaptive responding in the face of emotional cues, which has been shown to be decreased in individuals with a range of mental health problems (Kanske & Kotz, 2012; Fales et al., 2008; Pe, Vandekerckhove, & Kuppens, 2013; Trivedi, 2006; Zetsche, D'Avanzato & Joormann, 2012). Overall, research in this area could provide evidence of at least one mechanism by which regular PA impacts emotional outcomes: changing cognitive control processes. Results could also contribute to the empirical base that guides public health decisions about who might benefit most from PA recommendations and why.

1.5 Study Aim and Hypotheses

The primary aim for the current study was to investigate the possibility that cognitive control mediates the widely-observed PA-emotional health association in health young adults. To achieve this aim, regular PA, cognitive control, and emotional functioning were assessed in a cross-sectional sample of healthy young adults. In light of known interrelationships among sleep, PA, cognitive performance, and emotional functioning (reviewed in Dishman et al., 2006), a measure of sleep quality was also assessed to allow for statistical control. Regular PA was estimated using both self-reported PA and aerobic fitness data. The construct of cognitive control was measured using neutral and emotional versions of the classic Flanker and Stroop tasks, performance on which has been shown to be affected by PA (Guiney & Machado, 2013), and emotional functioning (Kanske, 2012). Emotional functioning was assessed through self-report of current levels of depression, anxiety, and stress.

Given research evidence that regular PA affects brain structures and functions implicated in implementing the cognitive processes engaged during cognitive control, a core expectation was that regular PA would be positively linked not only with emotional health, but also with cognitive control performance in the present study. The novel question of interest was whether cognitive control would mediate the regular PA-emotional functioning relationship in young adults. More specifically, it was hypothesized that level of regular PA would indirectly influence emotional functioning through its effect on cognitive control, indexed by separate composites of neutral and emotional interference effects. Further, it was expected that there would be larger effects when the cognitive control task had emotional stimuli (emotional composite), compared to neutral stimuli (neutral composite). This expectation was grounded in the idea that the inclusion of emotional processing requirements would increase cognitive control demands, as well as in earlier findings that emotional cognitive control is more tightly related to emotional functioning than is neutral cognitive control. Hypotheses focused specifically on response time and interference effects during cognitive control tasks because, in the extant literature, PA level/fitness does not typically correlate with accuracy on cognitive control tasks in young adults (Guiney & Machado, 2013). In addition, because most researchers have conducted task-specific performance analyses, rather than generating composites of multiple task performances, exploratory mediation analyses were also conducted using task-specific interference effects as the mediator.

Possible findings from the current study were anticipated to help 1) clarify the associations between regular PA and performance on cognitive control tasks in young adults, 2) provide further understanding of cognitive mechanisms that might link regular PA and emotional health, and 3) guide future decisions about PA recommendations based on the processes that benefit from regular PA.

Table 1. Aerobic exercise and cognitive control studies (Stroop & Flanker tasks)

Task	Study	Ages	*N*	Exercise type or measures	Design	Results	Behavioral	*p*
CHILDREN								
Flanker Letter	Hillman et al. 2009	8-11	38	Aerobic fitness (PACER test)	CS	Compared low-fit (bottom 10 %ile), high-fit (top 10 %ile) children showed:	Higher accuracy rates across conditions and following commission errors	*
Flanker Arrow	Chaddock et al., 2010a	9-10	55	Aerobic Fitness ($VO_{2\ max}$ test)	CS	Compared low-fit (<30 %ile), high-fit (>70 %ile) children showed:	Smaller Flanker effects based on proportional interference scores	*
Flanker Arrow with neutral trials (fish)	Voss et al., 2011	9-10	36	Aerobic Fitness ($VO_{2\ max}$ test)	CS	Compared low-fit (<30 %ile), high-fit (>70 %ile) children showed:	Higher accuracy rates, particularly on incongruent trials (greater accuracy costs)	*
Flanker Arrow	Pontifex et al., 2011; Wu et al., 2011	8-11	48	Aerobic Fitness ($VO_{2\ max}$ test)	CS	Compared low-fit (<30 %ile), high-fit (>70 %ile) children showed:	Higher accuracy rates, and less variable response latencies	***
Flanker Arrow	Chaddock et al., 2012	9-10	32	Aerobic Fitness ($VO_{2\ max}$ test)	CS	Compared low-fit (<30 %ile), high-fit (>70 %ile) children showed:	Maintenance of accuracy rates, particularly on incongruent trials across test blocks	*
Stroop	Buck et al., 2008	7-12	74	Aerobic Fitness (PACER test)	CS	Association between aerobic fitness and:	Items reported in 45 sec and Interference effect	* n.s.
Stroop	Castelli et al. 2011	7-9	59	Aerobic exercise (various)- 75 min/day, 5 days/week, 9 months	RUT	Association between increased aerobic fitness and:	Items reported in 45 sec	n.s.
YOUNG ADULTS								
Flanker Letter	Themanson & Hillman, 2006	~20	28	Aerobic Fitness ($VO_{2\ max}$ test)	CS	Compared to low fit, high fit (>80th %ile) showed:	More post error slowing	**

Table 1. Aerobic exercise and cognitive control studies (Stroop & Flanker tasks)

Task	Study	Ages	*N*	Exercise type or measures	Design	Results	Behavioral	*p*
Flanker Arrow	Themanson, Pontifex, & Hillman, 2008	18-25	62	Aerobic Fitness ($VO_{2\,max}$ test)	CS	Association between $VO_{2\,max}$ and:	Greater post-error accuracy when instructed to maximize accuracy	*
Flanker Arrow with Neutral trials	Winneke, Godde, Reuter, Vieluf, & Voelcker-Rehage, 2012	35-48 & 55-65	49	Self-reported PA (German version of the Baecke Activity Questionnaire)	CS	Compared to low active, high active showed:	Smaller Flanker effects on incongruent condition in the younger middle-aged group only	*
Stroop	Hwang & Castelli, 2015	10-30	93	Cardiorespiratory fitness	CS	Association between fitness and:	Smaller interference effects	
Stroop	Dupuy et al., 2015	19-34	22	Aerobic Fitness ($VO_{2\,max}$ test)	CS	Compared to low fit, high fit showed:	Faster RT on incongruent trials	*
OLDER ADULTS								
Stroop	Dustman et al., 1984	55-70	13	Aerobic exercise (brisk walking) 60 min/day, 3 days/week, 4 months	RCT	After training, aerobic exercise group showed:	Reduced interference	***
Flanker Letter	Kramer et al., 2001	60-70	58	Aerobic exercise (brisk walking) 3 days/week, 6 months, compared to nonaerobic stretching and toning	RCT	After training, aerobic exercise group showed:	Smaller Flanker effects	*
Flanker Arrow	Colcombe et al., 2004 Study 1	55+	41	Aerobic Fitness ($VO_{2\,max}$ test, Rockport Test)	CS	Compared to low fit, high fit (median split) showed:	Smaller Flanker effects (% increase in RT)	*
Flanker Arrow	Colcombe et al., 2004 Study 2	58-77	29	Aerobic Exercise (walking): 40 min/day, 3 days/week, 6 months	RCT	After training, aerobic exercise group showed:	Smaller Flanker effects (11% RT reduction)	*
Flanker Letter	Hillman, Belopolsky, Snook, Kramer & McAuley (2004)	~67	24	Self-reported PA (Yale Survey for Older Adults)	CS	Comparison of low, moderate, and high fit showed:	No differences in RT or accuracy	n.s.

Table 1. Aerobic exercise and cognitive control studies (Stroop & Flanker tasks)

Task	Study	Ages	*N*	Exercise type or measures	Design	Results	Behavioral	*p*
Flanker Arrow	Hillman et al., 2006	15-71	241	Self-reported PA that induced sweating	CS	Association between frequency/week and:	Faster RT across all ages; Smaller Flanker effects in > 40 years old	**
Stroop	Smiley-Oyen et al., 2008	64-74	28	Aerobic exercise (brisk walking) 30 min/day, 3 days/week, 10 months	RCT	After training, aerobic exercise group showed:	Less interference Improved Accuracy	*** **
Flanker Letter	Voelcker-Rehage et al., 2010	62-79	72	Aerobic Fitness ($VO_{2\ max}$ test)	CS	Association between $VO_{2\ max}$ and:	RT on incompatible trials	**
Stroop	Prakash et al., 2011	60-75	70	Aerobic Fitness ($VO_{2\ max}$ estimate, Rockport test)	CS	Association between $VO_{2\ max}$ and:	Less interference Higher accuracy	* **
Flanker Letter	Voelcker-Rehage et al., 2011	62-79	44	Aerobic exercise (brisk walking), compared to relaxation and stretching, 3 times/week, 12 months	RCT	After training, aerobic exercise group showed:	Improved accuracy after 12 months	*
Stroop	Weinstein et al., 2012	Mean: 66.6	124	Aerobic Fitness ($VO_{2\ max}$ test)	CS	Association between $VO_{2\ max}$ and:	Less interference	*
Stroop	Gajewski & Falkenstein, 2015	65-87	40	Self –reported history of long-term PA: high active, low active	CS	Long term PA is associated with:	Reduced interference	*

Note. CS = cross-sectional; RCT = randomized controlled trial; LS = longitudinal study; PA = physical activity; VO_{2max} = maximal oxygen uptake; RT = response time; proportional interference scores = percent increase in RT to incongruent stimuli, over and above the average RT to congruent stimuli; n.s. = not significant

* = *p < .05.*

** = *p < .01*

*** = *p < .001*

2 METHODS

2.1 Participants

Participants in this IRB-approved study were 115 undergraduate students in the psychology department at Georgia State University. Their ages ranged from 18 to 30 years (*M* = 20.13, *SD* = 2.56), and the majority was female (69%, *n* = 76). The racial distribution of the sample was roughly consistent with that of the university study body and the local population, according to census data (U.S. Census Bureau, 2012): 19 participants (17%) identified as "White," 56 participants (50%) identified as "Black or African American," 27 participants (24%) identified as "Asian," and 9 participants (8%) identified as "Other. The majority of the sample was right handed (92%, *n* = 103) with the exception of 6 participants (5%) who reported being left hand dominant and 2 participants (3%) who reported using both hands. Only 1 participant (1%) endorsed having experienced a traumatic brain injury, and 4 (4%) had been diagnosed with Attention Deficit Hyperactivity Disorder. Removal of these participants did not affect results; thus these 5 participants were included in final analyses to increase power.

Participants, on average, had a normal body mass index (BMI: *M* = 24.43, *SD* = 5.47), but ranged from underweight to obese: 7 participants (6%) reported being underweight, 66 participants (60%) reported being normal weight, 27 participants (24%) reported being overweight, and 10 participants (9%) reported being obese. Reported levels of sedentary behavior (*M* = 6.50, *SD* = 3.41) were consistent with those of typical adults in the United States (Matthews, et al., 2007). Sleep varied across participants, with 55 participants (50%) indicating good sleep quality (PSQI ≤ 5) and 56 participants (50%) indicating poor sleep quality (PSIQ > 5; range 0-21). Nine participants (8%) reported exercising at some point during the day prior to their study visit.

2.2 Procedures

Participants were recruited through an online research management system for students enrolled in psychology courses. Participation included a one-time, 1.5-hour-long laboratory visit to complete questionnaires, cognitive tasks, and a fitness assessment. Participants received 1.5 course research credits for their participation. All study procedures were completed in the Urban Life building at Georgia State University after participants provided informed consent. The self-report questionnaires were completed in between the 4 cognitive tasks (i.e., task order: 2 cognitive tasks, self-report measures, 2 cognitive tasks) to minimize fatigue when completing the cognitive tasks. The order of cognitive tasks was counterbalanced and the order of self-report measures was randomized in the Qualtrics survey design. Given the established associations between acute exercise and subsequent cognitive performance (Hillman, Snook & Jerome, 2003), the fitness assessment was completed after all other tasks and measures.

2.3 Measures

2.3.1 Demographics

Participants completed a demographic questionnaire that comprised questions about age, gender, height, weight, handedness, race/ethnicity, education, major, parent education level, free time activities, changes in physical activity levels, traumatic brain injury history, diagnosis of Attention Deficit Hyperactivity Disorder, current medications, caffeine intake, and participation in exercise on the day of the lab visit (see Appendix A).

2.3.2 Sleep Quality

Pittsburgh Sleep Quality Index (PSQI: See Appendix B.2.). The PSQI (Buysse, Reynolds, Monk, Berman & Kupfer, 1989) is a widely-used 24-item self-report measure of sleep quality and disturbances over a 1-month period. The measure yields seven component scores that can be summed to provide a global score of sleep quality. Numerous studies using the PSQI provide support for the measure's reliability and validity in various populations (Buysse, Reynolds, Monk, Berman & Kupfer, 1989; Carpenter & Andrykowski, 1998; Grandner, Kripke, Yoon, & Youngstedt, 2006).

Participants respond to most items using a 4-point scale indicating frequency of sleep experiences: 0 *'Not during the past month,'* 1 *'Less than once a week,'* 2 *'Once or twice a week,'* and 3 *'Three or more times a week.'* Responses based on continuous rather than categorical scales (e.g., duration of sleep, sleep latency) are collapsed into categories. For sleep duration, for instance, responses are translated into a 4-point range of values (0-3) with higher scores reflecting worse sleep (e.g., ≥ 7 hours = 0, 6 hours = 1, 5 hours = 2, and < 5 hours = 3). The measure yields component scores for sleep quality, sleep latency, sleep duration, regular sleep efficiency, sleep disturbances, use of sleep medication, and daytime dysfunction. When component scores are summed, the global score can range from 0-21 with scores ≤ 5 associated with good sleep quality and scores > 5 associated with poor sleep quality.

2.3.3 Physical Activity

2.3.3.1 Physical Activity Level

Modified New Zealand Physical Activity Questionnaire Short Form (NZPAQ-SF: See Appendix C). The NZPAQ-SF is an 8-item self-report questionnaire that yields estimates of usual time spent on different types of PA in the past week. If the past week is not representative of a typical week, participants are also asked to respond based on a typical week. Questions 1-6 inquire about number of days and amount of time in the prior week spent engaged in brisk walking, as well as moderate and vigorous PA; these items provide an estimate of PA duration at each intensity level, which can be converted into MET minutes, a unit of measure that captures energy expenditure. An additional question was included to assess typical sedentary behavior. Question 7 asks about number of days in the prior week spent engaged in brisk walking or moderate activity for at least 30 minutes, or vigorous activity for at least 15 minutes, providing an estimate of PA frequency over the past week. Question 8 enquires about PA over the prior 6-month period relative to a specified criterion: at least 5 days a week spent engaged in brisk walking or moderate activity for at least 30 minutes or vigorous activity for at least 15 minutes. Responses to this item provide an estimate of chronic physical activity level (CPAL) based on recommended PA guidelines for adults. Response options include: 0 *‘Not physically active’,* 1 ‘*Physically active but not meeting criterion,’* 2 ‘*Meeting criterion for less than 6 months,’* or 3 *‘Meeting the criterion for greater than 6 months.’*

This CPAL item was used to create the variable that served as the core measure of PA in the present study. Responses to the CPAL item were used to divide participants into two groups (PA+ and PA-). The two groups were created to capture distinctions between PA levels that could result in brain changes in regions relevant to CC (Dishman et al., 2006). They were also based on PA level recommendations established by the Centers for Disease Control and Prevention (CDC; US Department of Health and Human Services, 2008). The PA+ group comprised participants who endorsed meeting PA recommendations for more than 6 months (CPAL = 4). The PA- group comprised those who did not meet PA recommendation criteria, as well as those who did, but had been active at the recommended level for less than 6 months (CPAL < 4). Responses to prior-week frequency and duration questions provided additional descriptive data regarding PA levels. This grouping approach was aimed at capturing distinctions between those who do and do not engage in physical activity that could engender enduring structural and functional brain changes in regions relevant to the cognitive processes under study.

The NZPAQ-SF was developed as a standardized measure that could be used for PA surveillance in general health surveys. It was adapted from the International Physical Activity Questionnaire—Short (IPAQ-short), a self-report measure of regular physical activity for use with individuals from different countries and socio-cultural contexts (IPAQ, 2005). The most notable change from the IPAQ-short was the reversal of the order in which questions are presented, such that the NZPAQ-SF first addresses brisk walking, then moderate- and vigorous-intensity PA. This change was made in an effort to reduce over-reporting of exercise levels; when the question regarding vigorous PA activity was asked first, individuals were sometimes misclassified into the vigorous intensity category. A “time spent sitting” question was removed and replaced by a “time spent active” and the “stage-of-behavior-change” question. The latter provides an index of chronicity of exercise behavior that was used as the predictor variable in the current study.

One study found correlations of data from PA questionnaires and various validation tools, including accelerometers, pedometers, and heart rate monitors, to range from .30 to .50, indicating moderate concurrent validity (Washburn, Heath, & Jackson, 2000). Other IPAQ validation studies have reported moderate correlations of overall PA questionnaire scores with data from pedometers (r = .47–.51; Bassett, Schneider, & Huntington, 2004; Macfarlane & Lee, 2004) and accelerometers (r = .30 to .39; Craig et al., 2003; Ekelund et al., 2006; Sjostrom, Bull, & Craig, 2002; Vandelanotte, De Bourdeaudhuji, Philippaerts, Sjostrom, & Sallis, 2005). Further, a validation study for the NZPAQ-SF, specifically, has shown that scores on the self-report questionnaire correlate significantly, if modestly, with heart rate monitoring data for brisk walking (r = .27-.43), vigorous-intensity activity (r = .27-.35), and total PA (r = .25). In this study, moderate-intensity PA was over-reported (Moy, Scragg, McLean, & Carr, 2008).

Despite their regular use in research, self-report PA questionnaires, including the NZPAQ-SF, often yield overestimates of PA level (McLean & Tobias, 2004; Boon, Hamlin, Steel, & Ross, 2008). There is also evidence of underestimation in specific types of activity (Maddison et al., 2007; Mackay, Schofield, & Schluter, 2007). Self-report measures of PA, although inexpensive and easy to administer, are clearly prone to yielding inaccurate data (Prince *et al*., 2008). This inaccuracy stems from multiple causes, including the inherent complexity of

PA behavior, inaccurate recall of activity intensity and duration, poor comprehension and/or interpretation of survey terminology, and social desirability bias (Matthews, 2002; Sallis & Saelens, 2000). Nevertheless, the NZPAQ-SF is useful for the current study because it captures various types of PA and ways of engaging in active behavior that may each contribute to overall PA level. Further, it allows distinction between individuals who report engagement in chronic PA at recommended levels and those who do not, which might be important for understanding PA's impact on cognitive processes.

2.3.3.2 Fitness

YMCA Three-Minute Step Test (TMST; See Appendix D). The YMCA Bench Step Test (Golding, 2000) is a convenient, low-cost 3-minute assessment that yields an estimate of aerobic fitness with minimal risk to the participant, as compared to maximal effort exercise tests, such as assessment of maximal oxygen consumption, or $VO_{2\ max}$ (American College of Sports Medicine, 2013). During the TMST, participants are fitted with a heart rate monitor and then step up and down on a 12-inch step for 3 minutes. Steps are synchronized to a 96 beats per minute metronome to the rhythm of up, up, down, down, which equates to 24 steps per minute. After 3 minutes of stepping, the participant is informed to stop immediately, sit down on the step, and a 1-minute post-exercise recovery heart rate is assessed. Heart rate was recorded using a Polar FT4 Heart Rate Monitor or an ActiGraph GT9X Link. There were a few instances in which heart rate was assessed manually (i.e., counting heartbeat for 10 seconds, and multiplying by 6) because the heart rate monitors did not successfully detect the participant's heart rate (n = 17). Aerobic fitness was estimated based on heart rate recovery following a short bout of exercise using published age- and gender- based norms. The aerobic fitness estimate was primarily used to validate the self-report of PA and verify fitness differences between PA level groups. Given the prevalent use of aerobic fitness as a PA variable in the existing literature, exploratory analyses will also be conducted using fitness instead of PA level groups.

2.3.4 Emotional Functioning

Depression Anxiety Stress Scale (DASS: See Appendix B.1). The DASS (Lovibond & Lovibond, 1995) is a 42-item self-report measure of negative affective states experienced in the preceding week. The instrument comprises three dimensional subscales designed to yield measures of depression, anxiety, and stress symptoms. The Depression scale assesses dysphoria, hopelessness, devaluation of life, self-deprecation, lack of interest/involvement, anhedonia, and inertia. The Anxiety scale assesses autonomic arousal, skeletal muscle effects, situational anxiety, and subjective experience of anxious affect. The Stress scale items are sensitive to levels of chronic non-specific arousal. This scale yields a measure of difficulty relaxing, nervous arousal, and being easily upset/agitated, irritable/over-reactive and impatient (Lovibond & Lovibond, 1995). Both reliability and validity have been well-established for all three subscales in both clinical and non-clinical populations (Antony et al., 1998; Brown et al., 1997; Clara et al., 2001; Crawford & Henry, 2003; Lovibond & Lovibond, 1995).

Participants respond to each item (e.g., “I found myself getting upset by quite trivial things”) using a 4-point scale: 0 *‘did not apply to me at all’*, 1 *‘Applied to me to some degree, or some of the time’,* 2 *‘Applied to me a considerable degree, or a good part of time’*, and 3 *‘Applied to me very much, or most of the time’*. The measure yields subscale scores for depression, anxiety, and stress. Each scale yields scores that can range from 0-42, with means (and standard deviations) in a normative sample of 6.34 (6.97), 4.7 (4.91), and 10.11 (7.91) for the depression, anxiety, and stress scales, respectively (Lovibond & Lovibond, 1995). The subscales can also be summed to produce a composite measure of negative emotional symptoms, which was used in the present study as a dependent variable in analyses focused on emotional functioning.

2.3.5 Cognitive Tasks

Participants in the current study completed neutral and emotional versions of the Flanker and Stroop tasks. Rather than a single task, two cognitive control task paradigms were administered in an effort to capture the construct of neutral and emotional cognitive control comprehensively. Of the many cognitive control tasks available, the Flanker and Stroop tasks were selected because they have been well-validated and are widely used in the existing literature. The Flanker task, in particular, which is part of the NIH toolbox (Weintraub et al. 2013), has been administered in numerous studies throughout the PA literature, providing the largest foundation of research across the lifespan. The Stroop task is among the cognitive control measures with the longest history of use (i.e., since 1935; MacLeod, 2015), and it has been regularly administered in studies that examine links between cognitive control and emotional functioning (e.g., Williams, Mathews, & MacLeod, 1996). Standardized composite scores for neutral cognitive control and emotional cognitive control were created by calculating the z-score of the correct trial response time (RT) interference effects for each task and then averaging the standardized scores for neutral Flanker and Stroop tasks and, separately, those for emotional Flanker and Stroop tasks. In addition, a score of median baseline RT across all tasks was created for use as a covariate reflecting general mental speed/motivation/task engagement. The median was calculated, rather than the mean, because it is less affected by outliers (Petrie & Sabin, 2009).

2.3.5.1 Neutral Flanker Task

The Flanker task used in the present study (Eriksen & Eriksen, 1974) requires individuals to indicate as quickly and as accurately as possible the direction of a central stimulus that is embedded in an array of other stimuli. Arrays consist of white stimuli (commonly arrows that point to the right or the left) that appear against a black background on a computer screen. There are 3 types of stimuli arrays or trials presented throughout the task. During baseline trials, only a center target stimuli is presented on the screen. In congruent trials, the target stimulus is flanked by stimuli that are target-consistent (i.e., same as target). Lastly, during incongruent trials, the target stimulus is flanked by target-inconsistent stimuli, which are oriented in the opposite direction from the target. Participants press a key with their right index finger when central stimuli are oriented to the right and press a key with their left index finger when central stimuli point to the left (see Figure 3 for examples of the stimulus displays). Many Flanker tasks use arrows or letters as stimuli. However, in the current study, scrambled face stimuli, consistent with those used in previous modified versions of the Flanker task (Fenske & Eastwood, 2003), were used. This modification increased consistency between the neutral Flanker and emotional Flanker stimuli in their complexity, thereby reducing differences between tasks.

Participants complete 20 practice trials before beginning the task. During the task, participants in the present study completed 320 trials that were divided into 4 task blocks with 80 trials each. In between each block, an optional 1-minute rest break was encouraged. Across the blocks, the list-wise proportion of trials was 20% baseline, 60% congruent, 20% incongruent, a ratio that was selected in order to maximize conflict and, thus, the interference effect (Tillman and Wiens, 2011). Trial types were randomly ordered within task blocks. All participants were presented with the same sequence of trial types. During each of the 320 trials, stimuli were presented in the center of the computer screen for 200 milliseconds (ms), followed by a response window of 1500 ms, during which nothing appeared on the screen (see Figure 2). Trials were separated by fixation crosses (+) presented during an inter-stimulus interval (ISI) that varied randomly among 1000, 1200, and 1400 ms to reduce expectancy effects. Participants were instructed to respond as quickly and accurately as possible for each trial. Task duration was approximately 10 minutes.

This task yields measures of response time (time in ms from the presentation of the stimulus to key press for each correct response) and response accuracy (percent correct). Interference scores are obtained by calculating the difference in mean scores between correct congruent and incongruent task conditions (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005). Mean response time and response accuracy for each condition, as well as interference scores, were calculated. Lower RT interference scores were interpreted as reflecting stronger cognitive control abilities (Ridderinkhof, Van Den Wildenberg, Segalowitz, & Carter, 2004).

2.3.5.2 Neutral Stroop Task

The color Stroop task is a widely-used test of two key components of executive function: selective attention and inhibitory control (MacLeod, 1991, 1992). Participants were asked to name the ink color in which a stimulus was printed by pressing one of two buttons on the key-board. The color Stroop task involved three types of trials: baseline, congruent, and incongruent (See Figure 4). Baseline trials are those in which a nonword is presented (i.e., "******"). Congruent trials are those in which the stimulus word names the ink color in which it is printed (e.g. "green" in green ink). Incongruent trials are those in which the stimulus word names a different color than the ink in which it is printed (e.g. "green" in yellow ink). On incongruent trials, when they are instructed to ignore the word and indicate the ink color, people are typically slower to respond than they are during congruent trials. This effect is termed interference, or the color Stroop effect (Gilboa-Schechtman, Revelle, & Gotlib, 2000). Overall, the neutral Stroop task used in the study was designed to maintain procedural consistency with the other cognitive control tasks.

Participants in the present study completed 20 practice trials prior to 4 blocks of 80 trials each (i.e., 320 task trials total). An optional 1-minute rest break was encouraged in between blocks. Across blocks, the list-wise proportion of trials was set at 20% baseline, 60% congruent, and 20% incongruent, in order to maximize the interference effect (Tillman & Wiens, 2011). Stimuli were presented in the center of the computer screen for 200 milliseconds (ms), followed by a response window of 1500 ms during which nothing appeared on the screen (See Figure 2). Trials were set apart by fixation crosses (+) presented during an inter-stimulus interval (ISI) that varied randomly from 1000, to 1200, to 1400 ms to reduce expectancy effects. Mean response time and response accuracy for each condition, and RT interference scores were calculated. Lower interference scores were interpreted as reflecting stronger cognitive control abilities (Ridderinkhof, Van Den Wildenberg, Segalowitz, & Carter, 2004).

2.3.5.2.1 Neutral Stroop Task Design

Color Stroop tasks often vary in the numbers and types of colors used. Two colors—green and yellow—were selected for use in this study's color Stroop task in order to retain consistency with the Flanker task, which permitted two possible responses (neutral Flanker: right or left; emotional Flanker: happy or sad). Further, the color words were selected to match the lexical characteristics of the words used in the emotional Stroop task (described below), which were selected from a normed database (Warriner, Kuperman, & Brysbaert, 2013) (See Figure 4). Lexical characteristics of the color words were determined using an orthographic wordform database (Medler & Binder, 2005).

A one-way analysis of variance (ANOVA) indicated that the color Stroop task words did not differ from the emotional Stroop task words with regard to length, $F(3, 30) = 0.76$, $p = .526$, number of syllables, $F(3, 30) = 0.91$, $p = .128$, orthographic neighbors (i.e., words of the same length that differs from the original word by only one letter, $F(3, 30) = 0.07$, $p = .977$, or averaged frequency of orthographic neighbors, $F(3, 30) = 0.910$, $p = .450$. However, there was a significant difference in frequency, which is how often a word is encountered in 1,000,000 presentations of text, across word types, $F(3, 30) = 3.26$, $p = 0.035$. A Tukey post-hoc test revealed that the frequency of color Stroop words ($M = 109.62$, $SD = 62.81$) was greater than each of the word types used in the emotional Stroop task: neutral ($M = 27.66$, $SD = 30.91$, $p = .021$), negative ($M = 32.62$, $SD = 28.08$, $p = .046$), and positive words ($M = 29.93$, $SD = 44.25$, $p = .037$).

A standardized composite score for neutral cognitive control was created by calculating the z-scores for the interference effects for the Flanker and Stroop tasks and then averaging the standardized scores.

2.3.5.3 Emotional Flanker Task

This alternate version of the Flanker task (Eriksen & Eriksen, 1974) was identical to the task described above, except that the stimuli were replaced with emotional face icons that had been used in a previous modified version of the Flanker task (Fenske & Eastwood, 2003). Participants were asked to indicate, as quickly as possible via key press, whether a target face presented expressed positive or negative affect. As in the non-emotional task version, trials are considered baseline if no flanking faces are present, congruent if the flanking faces are target-consistent and share the same expression as the target, and incongruent if the flanking faces are target-inconsistent and show the opposite expression from the target (See Figure 3 for examples of the stimulus displays). Participants in the current study were instructed to press a key with their left index finger for a positive face (e.g., ☺☺☺, ☹☺☹) and to press a different key with their right index finger for a negative face (e.g., ☹☹☹, ☺☹☺).

Participants completed 20 practice trials, followed by 320 task trials divided into 4 blocks with 80 trials each. In between each two blocks an optional 1-minute rest break was encouraged. Across blocks, the list-wise proportion of trials was 20% baseline, 60% congruent, and 20% incongruent, in order to maximize the interference effect (Tillman and Wiens, 2011). There were equal numbers of positive and negative targets within each type of trial. Trial types were randomly ordered within the task block. All participants completed the task with the same order of trial types. During each of the 320 trials, stimuli were presented in the center of the computer screen for 200 milliseconds (ms) with a response window of 1500 ms, during which nothing appeared on the screen (See Figure 2). Trials were separated by fixation crosses (+) presented during an inter-stimulus interval (ISI) that varied randomly from 1000, to 1200, to 1400 ms to reduce expectancy effects. Participants were instructed to respond as quickly and accurately as possible throughout the task. Task duration was approximately 10 minutes. Mean response time and response accuracy for each condition, as well as RT interference scores for positive target trials were calculated. Positive target trials were the focus of analyses, because they capture one's ability to inhibit distraction from negative Flankers, which is a feature that has been shown to relate to emotional functioning (Kanske, 2012). However, relying solely on negatively-valenced distracting information limits our ability to evaluate the influence of positively-valenced emotional content on cognitive control abilities. Lower RT interference scores were considered to reflect better cognitive control abilities.

2.3.5.4 Emotional Stroop Task

Participants were asked to name the ink color in which each stimulus was printed by pressing one of two buttons on the keyboard. The emotional Stroop task involves 3 types of trials: baseline, neutral, and emotional. Baseline trials are those in which a nonword is presented (i.e., ******). Neutral trials are those in which the word is non-emotional in meaning (See Figure 5). Emotional trials are those in which the word is emotionally-laden, either positively or negatively. The emotional context of the word is thought to interfere with color naming, causing the respondent to be slower to name the colors of the emotional words than the colors of the neutral words (Williams, Mathews, & MacLeod, 1996; Algom, Chajut, & Lev, 2004). Further, performance seems to be generally slower when participants name the colors of negative words than when they name the colors of positive words (Estes & Adelman, 2008). This slowed reaction to name the color of emotionally relevant or negative words is referred to as interference and is frequently termed the emotional Stroop effect (MacLeod & MacDonald, 2000).

Participants in the present study completed 20 practice trials followed by a subsequent 320 trials broken into 4 blocks of 80 trials each. In between each block an optional 1-minute rest break was provided. Across the blocks the list-wise proportion of trials was 20% baseline, 60% neutral, and 20% emotional (10% positive, 10% negative). Stimuli were presented in the center of the computer screen for 200 milliseconds (ms), with a response window of 1500 ms during which nothing appeared on the screen (See Figure 2). Trials were separated by fixation crosses

(+) presented during an inter-stimulus interval (ISI) that varied randomly from 1000, to 1200, to 1400 ms to reduce expectancy effects. Mean response time and response accuracy for each condition, and interference scores for negative emotional word trials were calculated. Negative emotional word trials were the focus of analyses because they permit capture of one's ability to inhibit distraction from negative words, which is a feature that has been shown to relate positively to adaptive emotional functioning (Williams, Mathews, & MacLeod, 1996). Yet, relying solely on negatively-valenced distracting information restrains our ability to determine the influence of positively-valenced emotional content on cognitive control abilities. Smaller negative word RT interference scores were considered to reflect greater cognitive control abilities.

2.3.5.4.1 <u>Emotional Stroop Task Design</u>

The color and emotional Stroop task paradigms can differ in several respects; thus, the emotional Stroop used in the present study was designed to minimize these differences. For example, whereas the color Stroop task uses color words printed in colored inks, the emotional Stroop task uses words with some emotional connotation that are also printed in colored inks. Words are thus identical across congruent and incongruent trials in the color Stroop, but are never the same across the neutral and emotional trials on the emotional Stroop task. Therefore, it is important that neutral and emotional words be carefully matched on all lexical features that could influence word recognition, such as length, frequency of use, and number of orthographic neighborhoods (Larsen, Mercer, & Balota, 2006). For example, if the emotional words are greater in length than non-emotional words, then any observed slowing might be due to the additional visual processing time needed for more complex stimulus words.

Words were selected for the emotional Stroop task from a database of nearly 14,000 English words with normative information regarding valence and arousal (Warriner, Kuperman, & Brysbaert, 2013), which are critical features for obtaining the emotional Stroop effect (Dresler, Meriau, Heekeren, & van der Meer, 2009). Positive and negative words were matched on arousal, but were selected to have opposing valences; neutral words that were low arousal and were neither high nor low on valence were selected. A subset of positive, negative, and neutral words selected according to arousal and valence that were matched based on lexical characteristics, including length, frequency of use, orthographic neighbors, and averaged frequency of orthographic neighbor, which was determined using an orthographic wordform database (Medler & Binder, 2005), composed the final stimulus set.

A one-way ANOVA confirmed optimal valence, arousal, and lexical characteristics of the wordtype lists (i.e., positive, negative, neutral). As expected, there was a significant difference in arousal across wordtype lists, $F(2, 29) = 112.26$, $p < .001$. A post-hoc Tukey's test revealed that arousal for negative ($M = 5.86$, $SD = 0.92$) and positive ($M = 6.29$, $SD = 0.27$) wordtype lists did not differ ($p = .261$), but that arousal for the neutral word list ($M = 3.31$, $SD = 0.36$) was significantly lower than arousal levels for both emotional word lists (negative: M =5.86, $SD = 0.91$, p = <.001; positive: $M = 6.29$, $SD = 0.27$, p = <.001). There was also an expected significant difference in valence across word type lists, $F(2, 29) = 298.23$, $p < .001$. A post-hoc Tukey's test revealed that valence differed significantly among negative ($M = 2.36$, $SD = 0.41$), positive ($M = 8.03$, $SD = 0.31$), and neutral ($M = 5.01$, $SD = 2.05$) word lists, in expected directions. Word type lists did not significantly differ with regard to frequency, $F(2, 29) = 0.06$, $p = .940$, length, $F(2, 29) = 0.89$, $p = .421$, syllables, $F(2, 29) = 2.54$, $p = .096$, orthographic frequency, $F(2, 29) = 0.02$, $p = .981$, or averaged frequency of the orthographic neighbors, $F(2, 29) = 0.28$, $p = .758$.

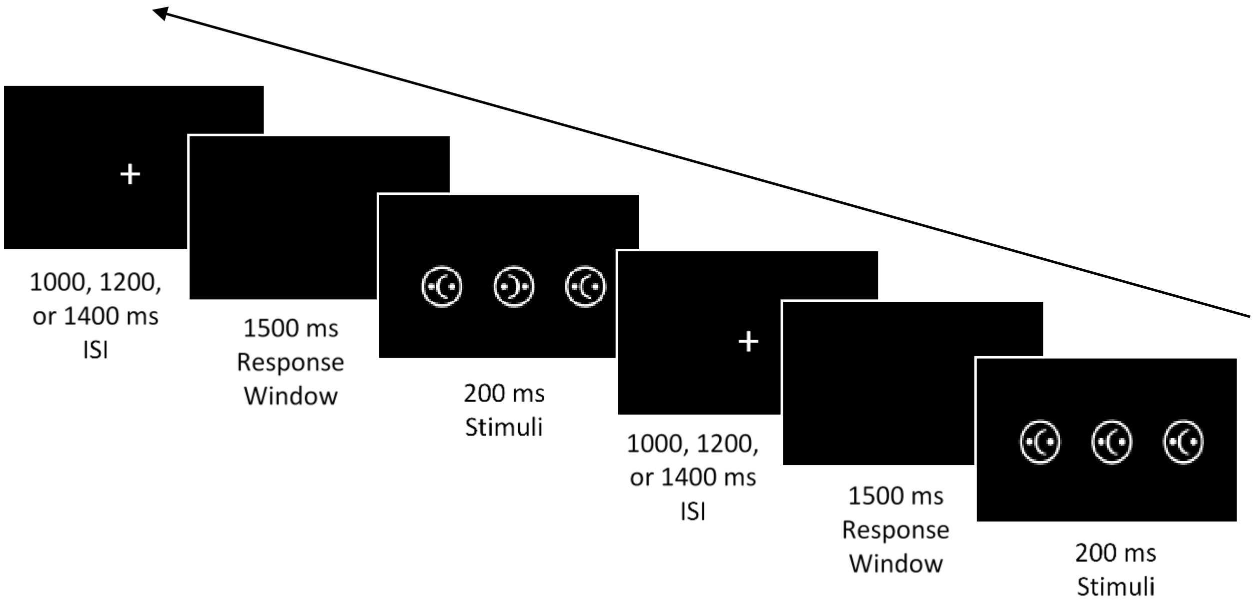

Figure 1. Task procedure for cognitive tasks (Neutral Flanker stimuli shown).

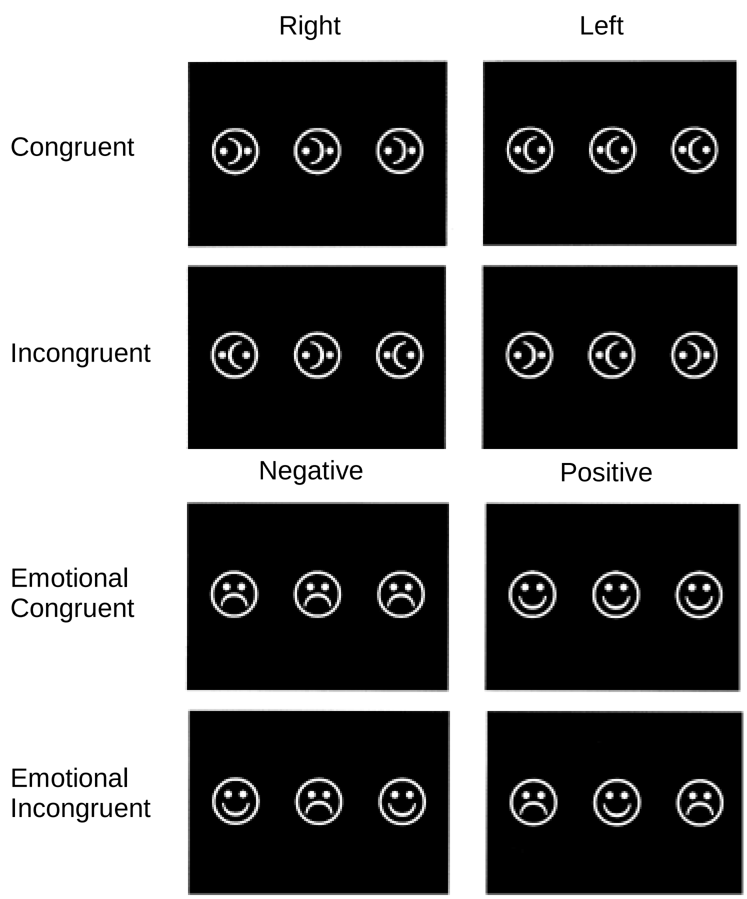

Figure 2. Example of the stimulus displays for the Flanker tasks.

Neutral Stroop Task			Emotional Stroop Task			
Nonword	Congruent	Incongruent	Nonword	Neutral	Emotional	
					Positive	Negative
******	**green**	**green**	******	carpet	amazing	danger
******	**yellow**	**yellow**		crisp	awesome	worry
				latent	celebrate	hopeless
				lumbar	fantastic	panic
				plastic	fun	scream
				region	happy	tragedy
				snout	hilarious	stress
				copy	excite	horrific
				wig		
				decade		
				graph		
				toothpaste		
				carpet		
				orifice		
				minute		
				council		

Figure 3. Wordtype lists for Stroop tasks.

3 DATA ANALYSES

The IBM Statistical Package for the Social Sciences, version 23 (SPSS; IBM Corporation, USA) was used for data entry, storage of deidentified data, and analyses.

3.1 Preliminary Analyses

Prior to conducting analyses, data were inspected for errors, normality, skewness, excessive missing cases, and outliers. On the cognitive tasks, outlier trials were excluded from analyses if response time (RT) was < 200 ms and/or the RT exceeded 3 standard deviations above the participant's mean RT across conditions (Whelan, 2008). Also, participants were excluded if performance on any cognitive task was < 50% accurate (Themanson, Pontifex, & Hillman, 2008), suggesting reduced understanding of the task instruction and/or reduced task engagement. Data were also tested to confirm that all regression assumptions were met (Field, 2009). Where needed, data were transformed to better approximate normality of distributions.

Means and standard deviations were computed for all variables to characterize the sample. Correlations, t tests, and one-way (ANOVAs) were conducted to examine associations among demographic, sleep, cognitive task performance, and the emotional functioning outcome variables to determine whether any covariates should be included in analyses and to examine associations among study variables. Between subjects t-test were conducted to determine whether the PA groups differed on any study variables and to confirm fitness differences between PA groups determined by self-report.

3.2 Primary Analyses

In order to determine whether neutral cognitive control and/or emotional cognitive control mediated the relation between PA level and emotional functioning, bootstrapping (a non-parametric resampling technique to assess indirect effects) was performed using published SPSS macros (Preacher & Hayes, 2014). The same data analytic approach was used for exploratory analyses.

4 RESULTS

4.1 Preliminary Analyses

Four participants were removed from analyses due to insufficient accuracy on the neutral Flanker task due to poor task engagement. It is unlikely that participants performed poorly because they misunderstood the task, because they had been trained, had been questioned about their understanding of the task, and had completed practice trials. Further, 3 out of the 4 participants with poor accuracy data had completed the emotional Flanker task with sufficient accuracy prior to completing the neutral Flanker task. The remaining 111 participants were included in analyses. The distribution of the DASS total score was positively skewed ($Skewness_{DASS}$ = 1.51, *SE* = 0.23); therefore, these data were square root transformed to normalize the distribution ($Skewness_{DASS\_transformed}$ = 0.50, *SE* = 0.23). Similarly, the distribution of the interference scores on the neutral Stroop task was positively skewed ($Skewness_{NeutralStroop}$ = 1.55, *SE* = 0.23) and the data were square root transformed with a constant added prior to transformation ($Skewness_{NeutralStroop\_transformed}$ = 0.50, *SE* = 0.25). Demographic variable transformations due to skewness are documented in Table 2. All other assumptions of regression analysis were met.

Descriptive statistics for demographic and study variables are provided in Table 2 and 3. Thirty-one participants (28%) reported engaging in recommended levels of PA for more than 6 months (PA+ group); among the 80 participants (72%) that reported not meeting this criteria (PA- group), 12 (11%) reported engaging in recommended levels of PA for less than 6 months, 45 (41%) reported engaging less than recommended levels of PA, and 23 (21%) reported that they were not physically active. According to t-tests, PA groups differed with regard to fitness, $t(109) = -3.26$, $p = .009$, and self-reported MET minutes per week, $t(109) = -2.67$, $p = .009$. Participants in the PA+ group had higher fitness and physical activity level (fitness: *M* = 3.55, *SD* = 1.79; MET minutes per week: *M* = 1752.65, *SD* = 4633.84), than those in the PA- group (*M* = 4.78, *SD* = 1.79; PA level: *M* = 4264.84, *SD* = 3895.88), which serves to validate the self-report data. Based on score ranges from the DASS manual (depression: *M* = 6.34, *SD* = 6.97; anxiety: *M* = 4.7, *SD* = 4.91; stress: *M* = 10.11, *SD* = 7.91), participants on average endorsed normal emotional functioning, as reflected in total DASS scores (*M* = 18.68, *SD* = 16.64).

Correlations between demographic and study variables are provided in Table 4. Sleep quality was significantly and positively related to emotional functioning, r (109) = .45, p < .001, indicating that better sleep quality was associated with better emotional functioning. Similarly, when sleep quality was dichotomized into good and poor sleep quality, a t-test showed that emotional functioning varied by sleep quality, t(109) = -2.62, p = .010. Individuals with poor sleep quality (*M* = 22.66, *SD* = 18.65) had significantly worse emotional functioning than individuals with good sleep quality (*M* = 14.64, *SD* = 13.04). Given its association with emotional functioning, sleep quality was included as a covariate in analyses. Emotional functioning was not associated with any other demographic or study variables.

T-tests were conducted to determine if study variables differed according to demographic variables. A significantly larger percentage of men reported engaging in recommended levels of PA for greater than 6 months (15/35 = 43%), than did women (16/76 = 21%), χ^2 (1, *N* = 111) = 5.66, p < .017. Otherwise, PA groups did not differ significantly based on race or handedness (*p*'s > .05). Moreover, emotional functioning and cognitive task performance did not differ based on any demographic variables assessed.

4.1.1 Cognitive Task Behavioral Data

Table 5 as well as Figures 4 and 5 present mean response latency and accuracy (Table only) for the neutral and emotional Stroop and Flanker tasks. On the neutral Flanker task, participants were generally accurate (*M* = 89.60, *SD* = 9.95). According to paired sample t-tests, accuracy did not differ between baseline (*M* = 89.74, *SD* = 10.69) and congruent trials (*M* = 90.55, *SD* = 9.89, p = .090). Participants were less accurate, however, on incongruent (*M* = 86.59, *SD* = 14.68), compared to baseline (p = .007) and congruent trials (p = .001). A one sample t-test indicated there was a significant accuracy interference effect when compared to zero (*M* = 3.97, *SD* = 11.87), *t*(110) =3.52, *p* = .001. With regard to neutral Flanker mean RT, baseline trials (*M* = 459.79, *SD* = 69.51) were significantly faster than congruent trials (*M* = 466.26, *SD* = 68.76, *p* < .001) and incongruent trials (*M* = 481.20, *SD* = 71.55, *p* < .001). Further, incongruent trials were significantly slower than congruent trials (*p* < .001), resulting in a significant interference effect in the expected direction (*M* = 14.94, *SD* = 20.04), *t*(110) = 7.85, *p* <.001. Overall RT and accuracy on the neutral Flanker task were not significantly correlated, *r* (111) = 0.02, *p* = .838, suggesting no notable speed-accuracy tradeoff on this task.

On the neutral Stroop task, participants were generally accurate (*M* = 91.76, *SD* = 6.62). Paired samples t-tests indicated that accuracy did not differ between baseline (*M* = 93.36, *SD* = 6.23) and congruent trials (*M* = 93.63, *SD* = 6.49, *p* = .501), but participants were less accurate on incongruent (*M* = 84.54, *SD* = 13.26) compared to baseline (*p* < .001) and congruent trials (*p* < .001). A one sample t-test indicated there was a significant accuracy interference effect when compared to zero (*M* = 9.08, *SD* = 11.93), *t*(110) = 8.02, *p* < .001. Mean RT differed across trial type; baseline trials (*M* = 437.11, *SD* = 70.23) were significantly slower than congruent trials (*M* = 418.79, *SD* = 64.72, *p* < .001). As expected, incongruent trials (*M* = 449.67, *SD* = 93.70) were significantly slower than both baseline (*p* < .001) and congruent trials (*p* < .001), resulting in a significant interference effect in the expected direction (*M* = 30.87, *SD* = 38.61), *t*(110) = 8.43, *p* < .001. However, because congruency between the word and the color on congruent trials seems to facilitate responding, an interference effect using the baseline trial RT, rather than congruent trial RT, was also calculated. This interference from baseline was also significantly different from zero (*M* = 12.56, *SD* = 40.84), *t*(110) = 3.24. *p* = .002. Overall RT and accuracy on the neutral Stroop task were not significantly related, *r* (111) = 0.11, *p* = .232, suggesting no notable speed-accuracy tradeoff on this task.

On the emotional Flanker task, participants were generally accurate (*M* = 90.29, *SD* = 7.16). Accuracy did not differ between positive-target baseline (*M* = 91.19, *SD* = 8.12) and positive-target congruent trials (*M* = 90.63, *SD* = 6.70, *p* = .252), but participants were less accurate on positive-target incongruent (*M* = 83.84, *SD* = 12.31) compared to positive-target baseline (*p* < .001) and positive-target congruent trials (*p* < .001). A one sample t-test indicated that there was a significant accuracy interference effect when compared to zero (*M* = 7.35, *SD* = 10.33, *t*(110) = 7.50, *p* < .001). In regard to mean RT time, positive-target baseline trials (*M* = 453.92, *SD* =78.08) were significantly faster than positive-target congruent trials (*M* = 466.10, *SD* = 71.58, *p* < .001) and positive-target incongruent trials (*M* = 507.63, *SD* = 85.21, *p* < .001). As expected, positive-target incongruent trials were significantly slower than the positive-target congruent trials, resulting in a significant interference effect in the expected direction (*M* = 41.53, *SD* = 35.93), *t*(110) = 12.18, *p* < .001. Bivariate correlations indicated that overall RT and accuracy on the emotional Flanker task were not significantly related, *r* (111) = 0.17, *p* = .082, indicating no notable speed-accuracy tradeoff on this task.

On the emotional Stroop task, participants were generally accurate (*M* = 92.58, *SD* = 6.18). Accuracy did not differ among baseline (*M* = 92.88, *SD* = 6.55), neutral (*M* = 92.23, *SD* = 6.33, *p* = .070), and negative emotional trials (*M* = 93.24, *SD* = 8.76, *ps* = .070-.537). A one sample t-test indicated there was a no significant accuracy interference effect when compared to zero (*M* = -0.37, *SD* = 6.22), *t*(110) = -0.62, *p* = .537. With regard to mean RT, baseline (*M* = 404.48, *SD* = 64.77) and neutral trials (*M* = 403.57, *SD* = 64.96) did not differ (*p* = .498). In contrast, negative emotional trials (*M* = 399.02, *SD* = 68.94) were significantly faster than both the nonword (*p* = .009) and neutral trials (*p* = .014), which, in striking contrast to findings for the emotional Flanker task, resulted in a significant negative interference effect (*M* = -4.55, *SD* = 19.23), *t*(110) = -2.49, *p* = .014. Bivariate correlations indicated that overall RT and accuracy on the emotional Stroop task were not significantly related to one another, *r* (111) = 0.11, *p* = .233, suggesting no notable speed-accuracy tradeoff on this task.

4.1.1.1 Comparing Cognitive Control Task Performance

4.1.1.1.1 The Addition of Emotional Processing

Comparisons between tasks as a function of stimuli can be seen in Table 5, as well as in Figures 4 and 5. According to a paired-samples t-test, mean RT on baseline and congruent trials did not differ between the neutral and emotional versions of the Flanker task (p = .374, p = .978, respectively), but mean RT on incongruent trials did significantly differ, $t(110) = -3.68$, $p < .001$). Mean RT was greater on the emotional Flanker task (M = 507.63, SD = 85.21) than the neutral version of the task (M = 481.20, SD = 71.55). Further comparison revealed that the interference effects for the two tasks were significantly different, $t(110) = -6.87$, $p < .001$, with a greater interference effect when the task had emotional stimuli (M = 41.53, SD = 35.93), rather than neutral stimuli (M = 14.94, SD = 20.04).

Paired-samples t-test comparing performance on the neutral and emotional Stroop tasks suggested that mean RT for baseline, $t(110) = 7.39$, $p < .001$, congruent, $t(110) = 3.89$, $p < .001$, and incongruent trials, $t(110) = 8.14$, $p < .001$, differed significantly between tasks. Participants demonstrated faster responding across all trial types on the emotional version of the task (baseline M = 404.48, SD = 64.77; congruent: M = 403.57, SD = 64.96; incongruent: M = 399.02, SD = 68.94) compared to neutral (baseline M = 437.11, SD = 70.23; congruent: M = 418.79, SD = 64.72; incongruent: M = 449.67, SD = 93.70). Analyses also indicate that the interference effect between the two types of Stroop tasks was significantly different, $t(110) = 8.62$, p = < .001. In contrast to the pattern observed on the Flanker tasks, the neutral Stroop task interference effect (M = 30.87, SD = 38.61) was significantly greater than that for the emotional Stroop task (M = -4.55, SD = 19.23).

4.1.1.1.2 Within Cognitive Control Composites

Mean accuracy and response time for each condition of each cognitive control task are displayed in Figures 4 and 5. Paired samples t-tests assessed differences between performance on neutral task conditions that were combined to create the neutral cognitive control composite. Results indicated that performance on baseline, $t(110) = 3.62$, $p < .001$, congruent, $t(110) = 8.38$, $p < .001$, and incongruent trials, $t(110) = 4.07$, $p < .001$, all differed significantly between the two neutral tasks. More specifically, responding on the neutral Stroop task (baseline *M* = 437.11, *SD* = 70.23; congruent: *M* = 418.79, *SD* = 64.72; incongruent: *M* = 449.67, *SD* = 93.70) was consistently faster than that on neutral Flanker task (baseline *M* = 459.79, *SD* = 69.51; congruent: *M* = 466.26, *SD* = 68.76; incongruent: *M* = 481.20, *SD* = 71.55). Further, the interference effects for the two tasks were not significantly correlated, $r(109) = -0.16$, $p = .105$, and were significantly different, $t(110) = -3.64$, $p < .001$. Along with faster responding overall, there were greater interference effects on the neutral Stroop task, (*M* = 30.87, *SD* = 38.61) compared to the neutral Flanker task (*M* = 14.94, *SD* = 20.04).

Paired samples t-tests also assessed differences between performances on the two emotional tasks that were combined to create the emotional cognitive control composite. Similar to the neutral tasks, mean RT on baseline, $t(110) = 9.10$, $p < .001$, congruent, $t(110) = 13.19$, $p < .001$, and incongruent trials, $t(110) = 16.96$, $p < .001$, were all significantly different between the emotional Flanker and Stroop tasks. There were consistently faster mean RTs on the emotional Stroop task trials (baseline: *M* = 404.48, *SD* = 64.77; congruent: *M* = 403.57, *SD* = 64.96; incongruent: *M* = 399.02, *SD* = 68.94), compared to the emotional Flanker task trials (baseline: *M* = 437.11, *SD* = 70.23; congruent: *M* = 418.79, *SD* = 64.72; incongruent: *M* = 449.67, *SD* = 93.70). Moreover, the interference effects for the two tasks were not significantly correlated, $r(109) = -0.05$, $p = .595$, and were significantly different, $t(110) = 11.67$, $p < .001$, with greater interference on the emotional Flanker task (*M* = 41.53, *SD* = 35.93) than the emotional Stroop task (*M* = -4.55, *SD* = 19.23).

4.2 Power Analysis

A post hoc power analysis (G*Power, Germany) indicated that with 111 participants and error probability of α = .05, power = .93, suggesting that this study had adequate power to detect an effect of f^2 = .15 or larger. (Themanson & Hillman, 2006; Themanson, Pontifex, & Hillman, 2008; Winneke, Godde, Reuter, Vieluf, & Voelcker-Rehage, 2012). In addition, based on empirical estimate the sample size was sufficient to detect the mediated effect using bias-corrected bootstrapping analyses. Based on empirical estimates, to test for mediation, the sample size was sufficient (Fritz & MacKinnon, 2007).

4.3 Primary Analyses

4.3.1 Neutral Cognitive Control

According to a simple mediation analysis conducted using ordinary least squares path analysis with sleep quality as a covariate, PA level did not have a significant indirect influence on emotional functioning through its effect on neutral cognitive control abilities. As can be seen in Figure 6 and Table 6, there was no evidence that participants reporting longstanding PA at recommended levels performed differently on neutral cognitive control tasks than those reporting a lack of longstanding PA at recommended levels (a = -0.035, p = .872), or that participants' demonstrated cognitive control was associated with their reported emotional functioning (b = -0.236, p = .521). A bias-corrected bootstrap confidence interval for the indirect effect (ab = 0.008) based on 10,000 bootstrap samples was not entirely above or below zero (-0.105-0.153). Further, there was no evidence that PA level influenced emotional functioning independently of its effect on cognitive control performance (c' = -0.230, p = .521).

4.3.2 Emotional Cognitive Control

Similarly, a simple mediation analysis conducted using ordinary least squares path analysis with sleep quality as a covariate showed that PA level did not have a significant indirect influence on emotional functioning through its effect on emotional cognitive control abilities. As can be seen in Figure 7 and Table 7, there was no evidence that participants reporting longstanding PA at recommended levels performed differently on emotional cognitive control tasks than those reporting a lack of longstanding PA at recommended levels (*a* = 0.053, *p* = 802), or that participants' demonstrated emotional cognitive control was associated with their reported emotional functioning (*b* = -0.111, *p* = .497). A bias-corrected bootstrap confidence interval for the indirect effect (*ab* = -0.006) based on 10,000 bootstrap samples was not entirely above or below zero (-1.153-0.057). Further, there was no evidence that PA level influenced emotional functioning independent of its effect on emotional cognitive control performance (*c'* = -0.216, *p* = .550).

4.4 Exploratory Analyses

4.4.1 Neutral Flanker Task

According to a simple mediation analysis conducted using ordinary least squares path analysis with sleep quality as a covariate, PA level did not indirectly influence emotional functioning through its effect on neutral Flanker task interference effects. There was no evidence that participants reporting longstanding PA at recommended levels performed differently on the neutral Flanker task than those reporting a lack of longstanding PA at recommended levels (*a* = 2.327, *p* = .586), or that neutral Flanker task interference effects were associated with reported emotional functioning (*b* = 0.001, *p* = .929). A bias-corrected bootstrap confidence interval for the indirect effect (*ab* = 0.002) based on 10,000 bootstrap samples was not entirely above or below zero (-0.073-0.085). Further, there was no evidence that PA level influenced emotional functioning independent of its effect on neutral Flanker task interference (*c'* = -0.223, *p* = .537).

4.4.2 Neutral Stroop Task

Findings from a simple mediation analysis conducted using ordinary least squares path analysis with sleep quality as a covariate indicated that PA level did not indirectly influence emotional functioning through its effect on neutral Stroop task interference effects. There was no evidence that participants reporting longstanding PA at recommended levels performed differently on neutral cognitive control tasks than those reporting a lack of longstanding PA at recommended levels (a = -0.418, p = .545). In contrast, Stroop task interference effects were negatively associated with reported emotional functioning (b = -0.126, p = .043), such that smaller neutral Stroop interference effects (better cognitive control) were related to poorer emotional functioning. A bias-corrected bootstrap confidence interval for the indirect effect (ab = 0.053) based on 10,000 bootstrap samples was not entirely above or below zero (-0.042-0.262). Further, there was no evidence that PA level influenced emotional functioning independent of its effect on neutral Stroop task interference (c' = -0.274, p = .441).

4.4.3 Emotional Flanker Task

Results of a simple mediation analysis conducted using ordinary least squares path analysis with sleep quality as a covariate were inconsistent with the prediction that PA level would indirectly influence emotional functioning through its effect on emotional Flanker task interference effects. There was no evidence that participants reporting longstanding PA at recommended levels performed differently on the emotional Flanker task than those reporting a lack of longstanding PA at recommended levels (a = 9.387, p = .222), or that emotional Flanker task interference effects were associated with reported emotional functioning (b = -0.005, p = .304). A bias-corrected bootstrap confidence interval for the indirect effect (ab = -0.044) based on 10,000 bootstrap samples was not entirely above or below zero (-0.349-0.042). Further, there was no evidence that PA level influenced emotional functioning independent of its effect on emotional Flanker task interference (c' = -0.178, p = .623).

4.4.4 Emotional Stroop Task

Lastly, a simple mediation analysis conducted using ordinary least squares path analysis with sleep quality as a covariate indicated that PA level did not indirectly influence emotional functioning through its effect on emotional Stroop task interference effects. There was no evidence that participants reporting longstanding PA at recommended levels performed differently on the emotional Stroop task than those reporting a lack of longstanding PA at recommended levels (a = -3.608 p = .378), or that emotional Stroop task interference effects were associated with reported emotional functioning (b = 0.001, p = .930). A bias-corrected bootstrap confidence interval for the indirect effect (ab = -0.003) based on 10,000 bootstrap samples was not entirely above or below zero (-0.111-0.068). Further, there was no evidence that PA level influenced emotional functioning independent of its effect on emotional Stroop task interference (c' = -0.219, p = .546).

4.4.5 Fitness as a proxy for PA

Multiple simple mediation analyses conducted using ordinary least squares path analysis with sleep quality as a covariate indicated that fitness level did not indirectly influence emotional functioning through its effect on composite or task-specific interference effects. There was no evidence that participants with various fitness levels performed differently across cognitive control task indices (neutral composite: a = -0.043, p = .413; emotional composite: a = -0.010, p = .844; neutral Flanker: a = -0.384, p = .712; neutral Stroop: a = -0.095, p = .473; emotional Flanker: a = 0.957, p = .609; emotional Stroop: a = -0.783, p = .432), or that any cognitive control abilities were associated with reported emotional functioning. The one exception to this pattern of null findings emerged for neutral Stroop task interference effects (neutral composite: b = -0.257, p = .115; emotional composite: b = -0.122, p = .457; neutral Flanker: b = 0.001, p = .930; neutral Stroop: b = -0.141, p = .027; emotional Flanker: b = -0.005, p = .272; emotional Stroop:

b = 0.001, *p* = .939). A bias-corrected bootstrap confidence interval for the indirect effects (neutral composite: *ab* = 0.011; emotional composite: *ab* = 0.001; neutral Flanker: *ab* = -0.000; neutral Stroop: *ab* = 0.013; emotional Flanker: *ab* = -0.005; emotional Stroop: *ab* = -0.001) based on 10,000 bootstrap samples was not entirely above or below zero when using any of the cognitive control indices (neutral composite: -0.009-0.056; emotional composite: -0.017-0.040; neutral Flanker: -0.024-0.016; neutral Stroop: -0.019-0.056; emotional Flanker: -0.081-0.017; emotional Stroop: -0.029-0.016). Further, there was no evidence that fitness level influenced emotional functioning independent of its effect on any index of cognitive control abilities (neutral composite: *c'* = -0.067, *p* = .443; emotional composite: *c'* = -0.057, *p* = .514; neutral Flanker: *c'* = -0.056, *p* = .527; neutral Stroop: *c'* = -0.069, *p* = .421; emotional Flanker: *c'* = -0.051, *p* = .558; emotional Stroop: *c'* = -0.055, *p* = .529).

Table 2. Descriptive statistics for demographic variables (*N* = 111).

Variables	*M*	*SD*	*Skew*	*Variables*	*n*	*%*
Age	20.13	2.56	1.83	ADHD		
Age^t	1.30	0.05	1.53	Yes	4	4
BMI	24.43	5.47	1.97	No	107	96
BMI^t	1.38	0.09	0.88	TBI		
Sedentary Hours	6.50	3.41	1.09	Yes	1	1
Sedentary Hours^t	2.67	0.60	0.47	No	110	1
Sleep Quality (PSQI)	6.24	3.19	3.19	BMI		
Sleep Quality^t (PSQI)	2.42	0.62	0.62	Underweight	7	6
Baseline RT (ms)	444.99	66.74	0.83	Normal	66	60
				Overweight	27	24
	n	*%*		Obese	10	9
Gender				Sleep Quality (PSQI)		
Female	76	69		Good	55	50
Race				Poor	56	50
White	19	17		Day of visit exercise	9	8
Black	56	51		Yes	9	8
Asian	27	24		No	101	92
Other	9	8				
Handedness						
Right	103	93				
Left	6	5				
Both	2	2				

Note. Where needed data were transformed to better approximate normality of distributions; both raw and transformed data are presented; ^{t} = transformed; BMI = Body mass index calculated based on height and weight; PSQI = Pittsburgh Sleep Quality Inventory; ms = milliseconds.

Table 3. Descriptive statistics and Cronbach's alpha in and between study variables (*N* = 111).

Study Variables	*M*	*SD*	*Skew*	*Misc*	*Study Variables*	*n*	*%*
PA level (NZPAQ-SF)	2454.25	4565.35	5.74		PA level (NZPAQ-SF)		
PA level^t (NZPAQ-SF)	2.92	0.76	-0.79		PA+	31	28
Fitness (Heart rate recovery)	111.60	23.92	0.85		PA-	80	72
Interference					Fitness (TMST)		
Neutral Flanker (ms)	14.94	20.04	-0.01		Excellent	9	8
Neutral Stroop (ms)	30.87	38.61	1.55		Good	13	12
Neutral Stroop^t (ms)	6.57	2.59	0.50		Above Average	13	12
Emotional Flanker (ms)	41.53	35.93	0.63		Average	17	15
Emotional Stroop (ms)	-4.55	19.23	0.41	*range*	Below Average	16	14
Neutral CC Composite	0.00	0.65	-0.16	-2.48-2.37	Poor	28	25
Emotional CC Composite	0.00	0.69	0.40	-2.76-3.37	Very Poor	14	13
				α			
Emotional Functioning (DASS)	18.68	16.54	1.51	0.94			
Emotional Functioning^t (DASS)	3.92	1.82	0.50				
Depression	4.84	6.27	.091				
Anxiety	5.44	5.25	1.40				
Stress	8.41	7.04	1.36				

Note. Where needed data were transformed to better approximate normality of distributions; both raw and transformed data are presented; ^{t} = transformed; PSQI = Pittsburgh Sleep Quality Inventory; NZPAQ-SF = Modified New Zealand Physical Activity Questionnaire Short Form; PA level = MET minutes/week; ms = milliseconds; DASS = Depression Anxiety Stress Scale; Depression = depression subscale of DASS; Anxiety = anxiety subscale of DASS; Stress = stress subscale of DASS; TMST = Three Minute Step Test.

Table 4. Pearson product correlations among unadjusted raw scores for all continuous variables (*N* = 111).

	Variable	1	2	3	4	5	6	7	8	9	10	11	12
1.	Age	---											
2.	BMI	0.01	---										
3	Sedentary hours	-0.05	-0.26*	---									
4.	Sleep Quality (PSQI)	0.01	-0.05	-0.06	---								
5.	Baseline RT (ms)	0.12	0.03	-0.03	-0.04	---							
6.	PA level (NZPAQ-SF)	-0.07	-0.04	0.04	0.15	0.01	---						
7	Fitness (HR recovery)	0.09	-0.03	-0.31**	0.07	0.02	0.14	---					
8..	Neutral CC	-0.00	-0.05	-0.08	-0.02	0.36**	0.00	-0.08	---				
9.	Emotional CC	-0.07	0.10	-0.07	-0.09	0.15	0.11	-0.02	0.09	---			
10.	Emotional Fx (DASS)	-0.02	-.153	0.17	.45**	-0.01	0.07	-0.02	-0.12	-0.10	---		
11.	Depression	-0.02	-0.16	0.22*	0.41**	0.00	-0.04	-0.08	-0.15	-0.06	0.86**	---	
12.	Anxiety	0.02	-0.18	0.18	0.44**	0.12	0.13	-0.00	0.01	-0.14	0.90**	0.67**	---
13.	Stress	-0.05	-0.09	0.08	0.35**	-0.11	0.10	0.02	-0.15	-0.09	0.91**	0.64**	0.77**

Note. BMI = Body mass index calculated based on height and weight; PSQI = Pittsburgh Sleep Quality Inventory; NZPAQ-SF = Modified New Zealand Physical Activity Questionnaire Short Form; PA level = MET minutes/week; HR = heart rate; CC = cognitive control; Fx = Functioning; DASS = Depression Anxiety Stress Scale; Correlations were computed using raw unadjusted variables.
*$p < .05$, **$p < .01$

Table 5. Descriptive behavioral data for the Stroop and Flanker tasks as a function of stimuli

	Stimuli							
	Flanker		*Stroop*					
Task	*M*	*SD*	*M*	*SD*	*r*	*p*	*t*	*p*
Neutral								
Accuracy baseline (%)	89.74	10.69	93.36	6.23	0.46**	<.001	-3.97	<.001
Accuracy congruent (%)	90.55	9.89	93.63	6.49	0.62**	<.001	-4.15	<.001
Accuracy incongruent (%)	86.59	14.68	84.54	13.26	0.30**	.001	1.30	.196
Accuracy interference (%)	3.97	11.87	9.08	11.934	0.03	.783	-3.24	.002
RT baseline (ms)	459.79	69.51	437.11	70.23	0.55**	<.001	3.62	<.001
RT congruent (ms)	466.26	68.76	418.79	64.72	0.60**	<.001	8.38	<.001
RT incongruent (ms)	481.20	71.55	449.67	93.70	0.54**	<.001	4.07	<.001
RT interference (ms)	14.94	20.04	30.87	38.61	-0.16	.105	-3.64	<.001
RT interference baseline (ms)	--	--	12.56	40.84	-0.15	.113	-0.52	.603
Emotional								
Accuracy baseline (%)	91.19	8.12	92.88	6.55	0.33**	<.001	-2.07**	.040
Accuracy congruent (%)	90.63	6.70	92.23	6.33	0.47**	<.001	-2.50*	.014
Accuracy incongruent (%)	83.84	12.31	93.24	8.76	0.47**	<.001	-8.78	<.001
Accuracy interference (%)	7.35	10.33	-0.37	6.22	0.20*	.032	7.44	<.001
RT baseline (ms)	453.92	78.08	404.78	64.77	0.69**	<.001	9.10**	<.001
RT congruent (ms)	466.10	71.58	403.57	64.96	0.74**	<.001	13.19**	<.001
RT incongruent (ms)	507.63	85.21	399.02	68.94	0.64**	<.001	16.96**	<.001
RT interference (ms)	41.53	35.93	-4.55	19.23	-0.05	.595	11.67**	<.001

Note. *M* = mean; *SD* = standard deviation, *r* = Pearson product correlation; *t* = t-statistic; *p* = p-value.
*$p < .05$, **$p < .01$

Table 6. Model coefficients for neutral cognitive control mediation model.

		Consequent						
		M (Neutral CC)				*Y* (Emotional Functioning)		
Antecedent		*Coeff.*	*SE*	*p*		*Coeff.*	*SE*	*p*
X (PA level)	*a*	-0.035	0.214	.872	*c'*	-0.230	0.357	.521
M_1 (Neutral CC)		---	---	---	*b*	-0.236	0.160	.145
Constant	i_1	-0.04	0.39	.918	i_2	1.176	0.646	.071
Covariate (Sleep Quality)		0.021	0.155	.895		1.162	0.258	<.001
		R^2 = <.001				R^2 = 0.173		
		$F(2, 108) = 0.020$; $p = .980$				$F(3, 107) = 7.446$; $p < .001$		

	Indirect Effect			
	Effect	*SE(boot)*	*LLCI*	*ULCI*
ab	0.008	0.0598	-0.1051	0.1532

Note. *Coeff* = slope; *SE* = standard error; *p* = p-value; *LLCI* & *ULCI* = lower and upper levels for confidence interval

Table 7. Model coefficients for emotional cognitive control mediation model.

		Consequent						
		M (Emotional CC)				*Y* (Emotional Functioning)		
Antecedent		*Coeff.*	*SE*	*p*		*Coeff.*	*SE*	*p*
X (PA level)	*a*	0.053	0.213	.802	*c'*	-0.216	0.360	.550
M_2 (Emotional CC)		---	---	---	*b*	-0.111	0.162	.497
Constant	i_1	0.364	0.386	.347	i_2	1.226	0.654	.063
Covariate (Sleep Quality)		-0.157	0.154	.312		1.139	0.261	<.001
		R^2 = .01				R^2 = 0.16		
		$F(2, 108) = 0.53$; $p = .589$				$F(3, 107) = 6.78$; $p < .001$		

	Indirect Effect			
	Effect	*SE(boot)*	*LLCI*	*ULCI*
ab	-0.006	0.048	-0.1528	0.0572

Note. *Coeff* = slope; *SE* = standard error; *p* = p-value *LLCI* & *ULCI* = lower and upper levels for confidence interval

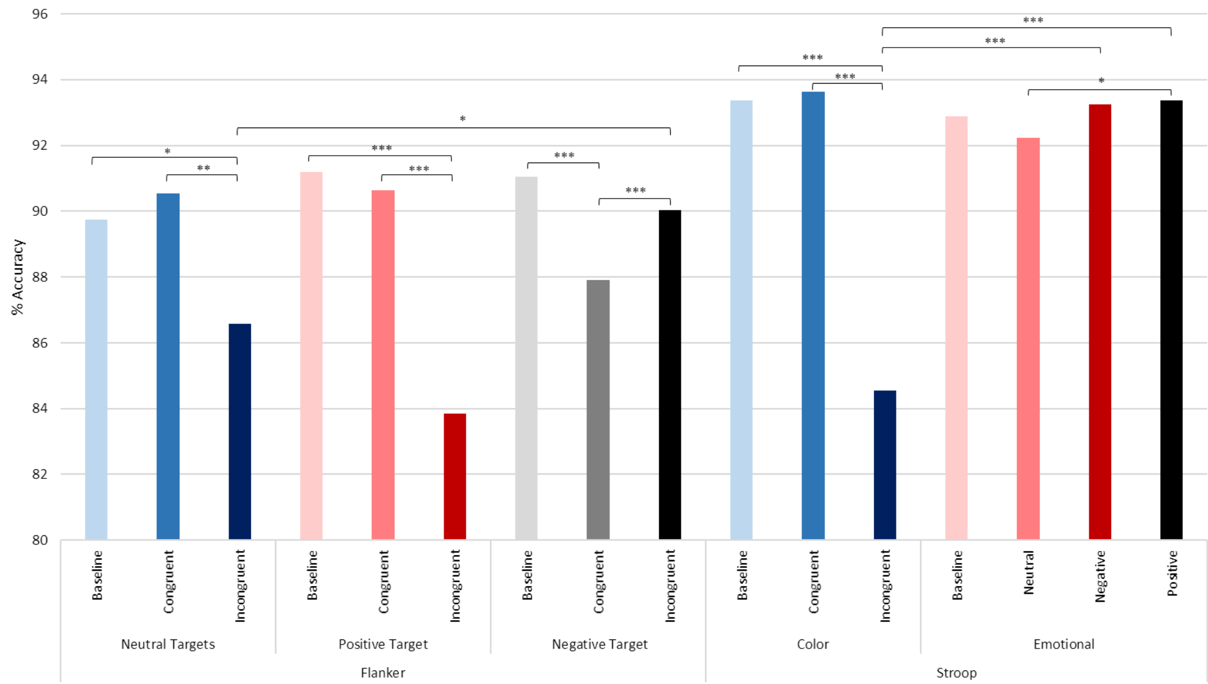

Figure 4. Cognitive control task accuracy data.
Blue bars = neutral cognitive control task; red bars = emotional cognitive control tasks; black bars = not included in study analyses, but included in graph for reference.
* = *p* < .05; ** = *p* < .01; *** = *p* < .001

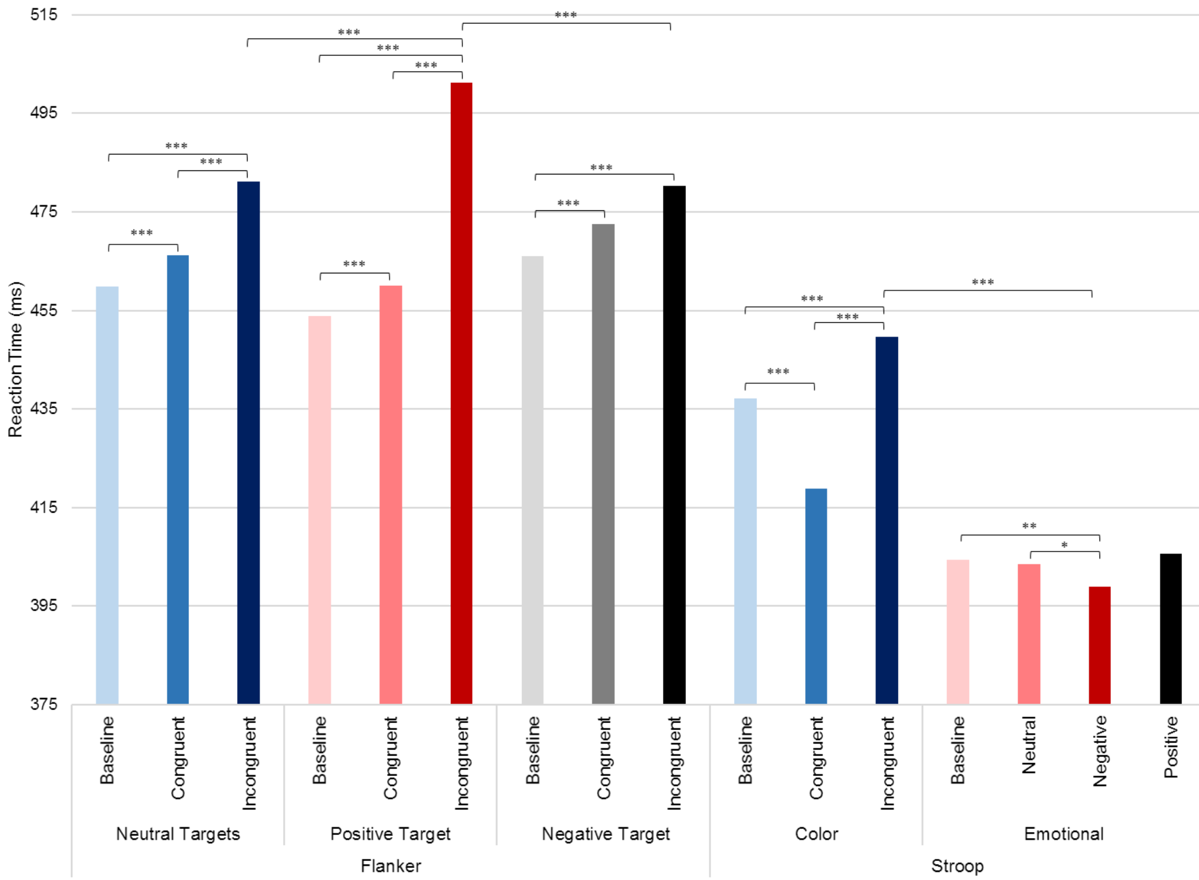

Figure 5. Cognitive control task response time data.
Blue bars = neutral cognitive control task; red bars = emotional cognitive control tasks; black bars = not included in study analyses, but included in graph for reference
* = *p* < .05; ** = *p* < .01; *** = *p* < .001

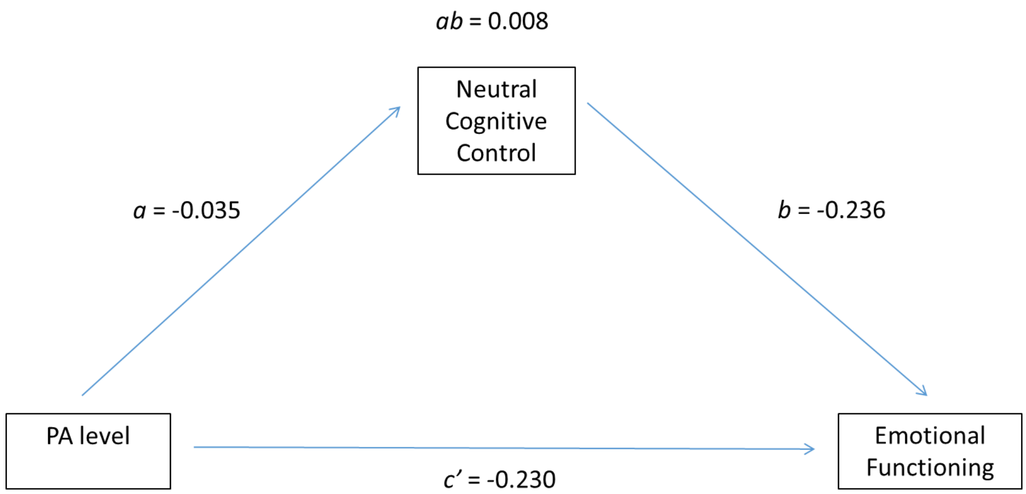

Figure 6. Neutral cognitive control mediation model.

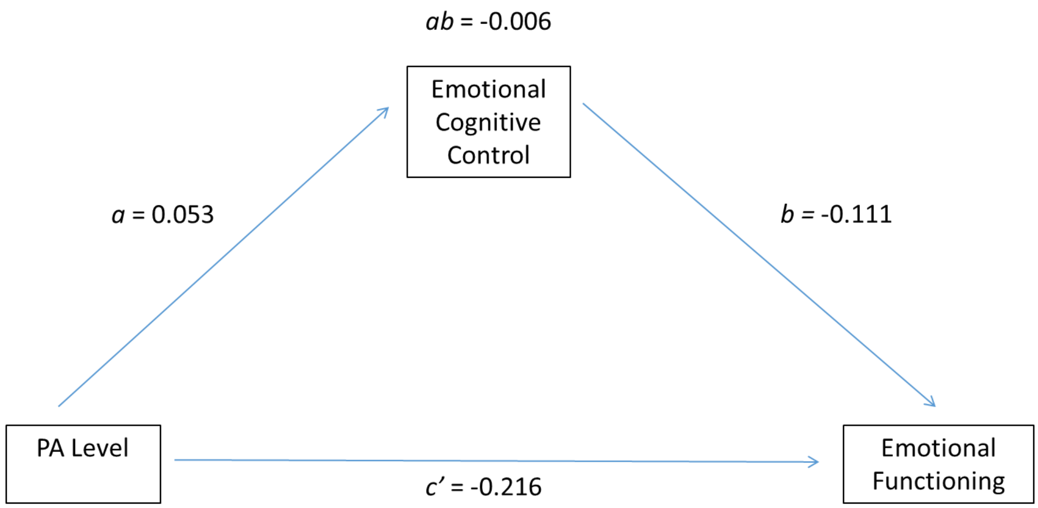

Figure 7. Emotional cognitive control mediation model.

5 DISCUSSION

The purpose of the present study was to evaluate whether neutral cognitive control and/or emotional cognitive control mediated the association between regular PA and emotional functioning. Recent evidence has yielded support for the idea that young adults who are aerobically fit or regularly active might incur benefits with regard to certain aspects of psychological function, such as cognitive control and emotional functioning (Guiney & Machado, 2013; Ströhle, 2009). However, it has remained unclear whether cognitive control might serve as a mechanism by which PA is linked to better emotional functioning. To address this question, the present study was designed to test two hypotheses: 1) PA level would indirectly influence emotional functioning through its effect on neutral and emotional cognitive control abilities in healthy young adults, and 2) there would be larger effects when the cognitive control task used emotional stimuli, because such stimuli were expected to increase the task's cognitive control demands and because tasks with emotional stimuli were anticipated to more effectively tap processes relevant to emotional functioning.

5.1 Summary of Results

Results of the present study yielded no significant support for either of the two hypotheses. Specifically, bias-corrected bootstrap confidence intervals did not indicate indirect effects of regular PA on emotional functioning through its effects on either neutral or emotional cognitive control. Moreover, the present study's findings provided no evidence that participants reporting longstanding PA at recommended levels performed differently on neutral or emotional cognitive control tasks or self-reported different levels of emotional functioning than those not reporting longstanding PA at recommended levels. In addition, neither neutral nor emotional cognitive control was associated with participants' self-reported emotional functioning. Exploratory analyses indicated that findings were comparable when task-specific interference effects were used as indices of cognitive control and when fitness level was used instead of the PA level variable.

This pattern of findings stands in contrast to those obtained in much of the prior research on regular PA/fitness and how it relates to cognitive and emotional functioning.

The hypotheses for the current study were based on an extant literature in which researchers have typically examined links among different subsets of the three core study variables (regular PA, cognitive control, and emotional functioning) rather than studying the three in concert. Only one published study to date has taken the latter approach; Lott and Jensen (2016) used structural equation modeling to evaluate direct and indirect associations among aerobic fitness, cognitive control, and emotion regulation in a community sample of preadolescent children. In this study, the researchers used a multi-modal approach to assessing cognitive control, with both Stoop task performance and parent questionnaire responses serving as indices. This approach yielded evidence that cognitive control mediated the association between aerobic fitness and emotional regulation in children. However, tasks did not all load well onto a cognitive control factor, and the observed significant mediation effects appeared to have been largely driven by parent questionnaire responses. Thus, taken together with the current study's null findings, Lott and Jensen's (2012) results raise the possibility that patterns of associations among PA, cognitive control, and emotional health vary across development. In other words, although cognitive control mediates the regular PA emotional health association in children, comparable associations cannot be detected in a healthy young adult population with generally strong cognitive control abilities and healthy emotional functioning. Lott and Jensen's findings also suggest that heterogeneity in the cognitive control construct may lead to different outcomes depending on the way in which the construct is measured.

It is plausible that cognitive control, specifically, is not a robust mechanism by which regular PA influences emotional functioning in healthy young adults. The path from regular PA to emotional functioning is complex and is likely multi-factorial, comprising several biological and psychological mechanisms. It is possible that other mechanisms, such as neurotransmitters (Nicastro & Greenwood, 2016), neurotrophic factors (Zoladz & Pilc, 2010), neuroimmunological changes (Eyre & Baune, 2012), inflammation (Moylan et al., 2013), stress resilience (Hegberg & Tone, 2015), distraction (Guszkowska, 2003), self-efficacy (Gaudlitz, von Lindenberger, Zschucke, & Strohle, 2013), or social engagement (Penedo, F. J., & Dahn, J. R. (2005), may better explain possible links between regular PA and emotional functioning in young adults.

Given the limited research exploring regular PA, cognitive control, and emotional functioning in tandem, the following discussion considers associations between each two of the three study variables separately. The results will be discussed with particular attention to empirical and theoretical considerations that might help interpret findings or the lack thereof and to methodological distinctions among studies.

5.2 Regular PA and Emotional Functioning

5.2.1 Empirical and Theoretical Considerations

Although numerous studies have yielded evidence of a link between PA level/fitness and better emotional functioning (e.g., Dunn, Trivedi & O'Neal, 2001; Galper, Trivedi, Barlow, Dunn & Kampert, 2006; Hamer, Stamatakis & Steptoe, 2009; Kim et al., 2012), the current study produced results that were inconsistent with this established literature. In particular, there were no significant findings indicating that there is a relationship between longstanding regular PA and self-reported emotional functioning in the healthy young adult participants.

Notably, the null findings align with assertions that regular PA might not have a clear association with emotional health benefits in healthy, non-clinical populations, where research findings have been mixed (Paluska & Schwenk, 2000). On the one hand, several studies have shown that exercise training interventions improve depressive symptoms in healthy, non-depressed samples (Conn, 2010a; Conn, 2010b; DiLorenzo et al., 1999). For example, DiLorenzo et al. (1999) found that healthy, non-depressed individuals who engaged in exercise training, compared to a wait-list control group, showed larger decreases in depressive symptomology. On the other hand, some research has failed to detect such effects. King, Taylor, Haskell, and

DeBusk (1989), did not find that 6 months of aerobic training, compared to a control condition, generated significant changes in depressed mood among healthy adults.

One possible explanation for the mixed findings with regard to improvement of emotional functioning with exercise training is that a floor effect truncates the range of scores in young adult samples. In other words, healthy, non-clinical samples do not have much room for improvement in emotional functioning, so there is not much to gain in terms of regular PA's emotional benefits. This floor effect may be relevant to the current study sample and findings, as the sample generally reported normal emotional functioning, with a notable positive skew in the distribution of responses and 88% of participants reporting distress below clinically meaningful levels. In future studies there may thus be value in exploring the link between PA and emotional functioning in non-clinical samples with a wider range of emotional functioning. Ensuring that both distress-free and mildly distressed adults are included in research of this type may help us to better identify and understand the emotional benefits of regular PA.

The present study's unexpected failure to detect an association between regular PA and emotional functioning might also reflect a tendency for young adults to use effective coping strategies other than regular PA. These alternative coping strategies might include, but are not limited to, spirituality, meditation, journaling, social engagement, a good support system, and a healthy diet, each of which has been shown to support healthy emotional functioning (Baikie & Wilhelm, 2005; Currie et al., 2009; Goyal et al., 2014; Jacka, Mykletun, Berk, Bjelland, & Tell, 2011; Koenig, 2010; Turner & Brown, 2010). In other words, regular PA is not the only viable path to healthy emotional functioning; it is very possible that sedentary young adults achieve or maintain sound emotional health with alternate coping strategies. The current study did not assess the use of coping strategies beyond exercise and maintenance of good sleep hygiene, so it is unknown whether and the degree to which participants in the current study use alternate effective coping approaches. Given that college students endorse the use of social support, deep breathing, journaling, and listening to music to cope with distress or stress, it is plausible that PA is only one of many tools that the current participants use to maintain emotional health (Aselton, 2012). Nevertheless, it is possible that the use of alternate coping strategies might help explain the nonsignificant association between regular PA and emotional functioning in the current study.

The current study tested for a main effect of regular PA on emotional functioning, which studies have detected. However, it is possible that in healthy young adult populations, a moderation model that includes moderator variables left unexamined in the present work may better describe associations between PA and emotional health. That is, maybe not all healthy young adults obtain equivalent mental health benefits from regular PA.

There is evidence, for example, that person and contextual factors that place individuals at risk for developing mental health problem might modulate the association between regular PA and emotional functioning in healthy young adult populations (Hegberg & Tone, 2015; Mata, Thompson, & Gotlib, 2010; Smits, Tart, Rosenfield, & Zvolensky, 2011). One study found that PA level was only associated with emotional functioning in a healthy sample among those individuals endorsing high levels of trait anxiety, which is a tendency to respond to situations with anxiety (Hegberg & Tone, 2015). Similarly, Smits, Tart, Rosenfeld, and Zyolensky (2011) found evidence that emotional health benefits of PA might be more evident among individuals at increased risk of developing anxiety disorders due to heightened anxiety sensitivity, a construct reflecting fear of physiological arousal.

There are also biological markers detectable in members of at-risk populations that could potentially influence the association between regular PA and emotional functioning. For example, in a healthy, adolescent sample, regular PA was only found to protect against depression among girls with a Brain Derived Neurotrophic Factor (BDNF) polymorphism that has been linked to risk for depression (Mata, Thompson, & Gotlib, 2010). Lastly, the experience of stress may be an important factor to consider in examinations of the regular PA/emotional functioning relationships. A recent RCT found that daily PA for 5 weeks effectively reduced worrying in a sample of young adults with elevated stress levels (de Bruin, van der Zwan, & Bögels, 2016), suggesting that the association between regular PA and emotional functioning might be more readily detectable in the context of unusually high stress. Individual differences among participants across a variety of domains may thus be important to consider in research exploring the association between regular PA and emotional functioning. The lack of attention in the current study of healthy young adults to these personal and contextual factors may have contributed to the failure to detect a significant association between regular PA and emotional functioning.

The types of regular PA in which individuals engage might also influence the emotional health benefits that they accrue. For instance, when sedentary adults were randomly assigned to 10 weeks of high intensity exercise, moderate intensity exercise, attention-placebo or waiting list, significant improvements in psychological responses were only seen in the moderate intensity exercise group (Moses, Steptoe, Mathews, & Edwards, 1989). The researchers proposed that the high intensity exercise may have been too demanding for the participants, thus attenuating its emotional benefits. Additional research suggests that physical activity, when excessive, can be associated with impaired mental health (Peluso & Andrade, 2005). Similarly, one study showed that PA motivated by enjoyment and/or competence, but not body-related motives, was related to positive psychological outcomes (Frederick & Ryan, 1993). The important of motivations aligns with the self-determination theory, which emphasizes that the satisfaction of three psychological needs—competence, autonomy, and relatedness— yields enhanced self-motivation and mental health (Ryan & Deci, 2000). Thus, it is possible that select participants in the PA+ group in the present study may have been engaging in highly intense levels of regular PA that were deleterious to their emotional functioning, or were motivated by factors that might mitigate the emotional benefits of regular PA. If this was the case, the inclusion of participants with these types of regular PA might have attenuated a positive association between regular PA and emotional functioning in the sample as a whole. Future research might benefit from distinguishing these types and levels of PA with measures that include questions about type, intensity, duration, exercise-specific stress and motives of PA,

In summary, the lack of an observed significant association between regular PA and emotional health among young adults in the present study may reflect tendencies for members of this population to have less room for improvement in emotional functioning as a function of regular PA and/or to use alternative coping strategies that facilitate healthy emotional functioning. Further, it is possible that unmeasured characteristics cause some participants to obtain more emotional health benefits from regular PA than do others, or that not all types of regular PA are associated with better emotional functioning.

5.2.2 Methodological Considerations

The ways in which regular PA and emotional functioning constructs were measured in the current study may have also influenced the pattern of results in unexpected ways. Regular PA can be measured using many different approaches. The current study sought to capture distinctions between those who do and those who do not report engaging in longstanding regular PA, which is thought to engender enduring structural and functional brain changes in regions relevant to the cognitive processes under study (Dishman et al., 2006). However, at least one study has linked levels of regular PA that are as low as 20 minutes per week with mental health benefits (Hamer, Stamatakis, & Steptoe, 2009). Thus, it is possible that the criteria used to create the dichotomous PA variable in the current study did not yield a variable that was optimal for capturing group differences in emotional functioning and the use of this method of categorization obscured individual differences in the sample (MacCallum, Zhang, Preacher, & Rucker, 2002). For example, the PA- group comprised individuals who reported a wide variety of PA levels, ranging from no PA to regular recommended levels of PA for less than 6 months; this within-group heterogeneity may have diluted our ability to detect important emotional health differences between the PA- group and the PA+ group.

Thus, whereas the dichotomization strategy was selected to correspond meaningfully to PA's brain-related changes, it may not have been the best choice for distinguishing between individuals likely to obtain high versus low emotional health benefits. An alternative dichotomization strategy might have been to compare emotional functioning between participants who endorsed being sedentary and those who reported longstanding engagement in recommended levels of PA. Use of such an extreme groups approach would still allow for the distinction of a PA level and chronicity that is in line with CDC recommendations and that is also thought to lead to changes in the brain. It would also, theoretically, increase the likelihood that group differences in emotional functioning would be large, and thus confer greater power to detect effects (Preacher, Rucker, MacCallum, & Nicewander, 2005). This approach, however, also has disadvantages, such as loss of information, magnification of results or increased risk of false positive results, potentially spurious grouping of individuals with considerable variability, and obscuring findings about individuals with scores that fall between the extremes (Altman & Royston, 2006; Preacher, MacCallun, Rucker, & Nicewander, 2005).

Although recommended levels of PA released by the CDC are often used as a logical starting point in research, the dose of regular PA required to confer emotional health benefits is unclear. Some studies indicate that any regular PA, regardless of intensity, is associated with fewer indicators of poor emotional functioning (e.g., Harvey, Hotopf, Øverland, & Mykletun, 2010), while others suggest that specific intensities or doses are necessary (e.g., Dunn, Trivedi, Kampert, Clark, & Chambliss, 2005). Future research is encouraged to measure regular PA in ways that allows for greater distinction among its many different types and levels; such work would be useful in providing a firmer foundation for recommendations regarding optimal PA for mental health. Such studies might, for example, gather data on type, intensity, energy expenditure, frequency, duration, and chronicity of activity to better understand which aspects of PA may be more reliably associated with emotional health benefits.

It is also important to consider ways in which the choice of an emotional functioning measure may have influenced results in the current study. In particular, it is possible that regular PA could be associated with emotional functioning in ways that are not reflected in scores on the emotional functioning questionnaire used in the present research. Research linking regular PA/fitness and mental health commonly uses questionnaires designed to measure depressive or anxious symptoms (e.g., Conroy et al., 1982; Morgan et al., 1970,) mood, (e.g., Steptoe et al., 1989) or general wellbeing or mental health status (e.g., Bhui & Fletcher, 2000; Greist et al., 1978; Steptoe & Butler, 1996). The DASS, a measure that includes questions about depression, anxiety, and stress in the preceding week, shows good convergent validity with other measures of depression and anxiety (Lovibond & Lovibond, 1995; Nieuwenhuijsen, De Boer, Verbeek, Blonk, & Van Dijk, 2003). However, its focus on negative emotional symptoms in the past week, which may be easily influenced by situational factors during that time frame, may set it apart from measures that cover longer periods of time. It is plausible that emotional functioning during the relatively brief reference period of one week may not be consistent with more enduring aspects of participants' general emotional health status, which might be differentially associated with the effects of regular PA and/or cognitive control performance (Rutherford, MacLeod, & Campbell, 2010). Further, past-week self-report questionnaires may be more suitable for longitudinal studies that explore differences in emotional functioning across two or more time points (e.g., before and after engaging in regular PA). Cross-sectional studies, on the other hand, might be better served by the use of trait-based measures that inquire about how the respondent views their emotional functioning in general to assess emotional health.

5.3 Cognitive Control

5.3.1 The Addition of Emotional Processing

In line with a number of previous studies using the Flanker task, the performance data in the current study were consistent with a significant interference effect during neutral and emotional Flanker tasks, with incongruent stimuli eliciting longer RTs than congruent ones (Alguacil et al., 2013; Chen et al., 2014; Ochsner et al., 2009). Further, whereas the emotional Flanker interference effect was larger than the neutral Flanker interference effect, participants showed comparable mean RTs on baseline and congruent trials of both the neutral and emotional versions of the task. This pattern suggests that responses slowed significantly more when negative emotional stimuli flanked positive targets than when neutral cues served as distracting stimuli. Further, it is consistent with the idea that the addition of an emotional processing component to the Flanker task increases the cognitive control required to perform well (Chiew & Braver, 2011; Fenske & Eastwood, 2003).

In contrast, the addition of an emotional processing component to the Stroop task did not result in larger interference effects. In fact, the observed interference effects on the emotional Stroop task differed strikingly from those on all of the other three cognitive control tasks, with participants responding faster on incongruent than on congruent trials. In other words, negatively-valenced emotional information appeared to enhance processing rather than to interfere with it. Further, participants responded more quickly during trials across all conditions of the emotional Stroop task than they did on similar conditions of the neutral Stroop task. This pattern of performance suggests that the inclusion of emotional stimuli (positive and negative) in the emotional Stroop task enhanced response speed on the task as a whole. It also suggests that responding was further facilitated when participants were presented with negatively-valenced emotional words. Thus, the negatively-valenced emotional stimuli did not appear to interfere with responding or increase cognitive control demands in the same way that the negative flanking information did in the emotional Flanker task. Moreover, the presence of emotional stimuli in the Stroop task actually appears to have enhanced the use of cognitive control.

The failure of an emotional overlay to increase interference during the Stroop task was surprising, given findings in previous studies (Algom, Chajut, & Lev, 2004; Estes & Adelman, 2008; Egner, Etkin, Gale, & Hirsch, 2008; Etkin, Egner, Peraza, Kandel, & Hirsch, 2006; MacLeod & MacDonald, 2000; Williams, Mathews, & MacLeod, 1996). However, characteristics of the study sample and of the emotional Stoop stimulus words may have played roles in the unexpected pattern of task performance. For instance, previous studies showing that negative emotional information slows down responding have largely recruited clinical samples (i.e., adults with significant depression or anxiety). The current study, in contrast, focused on young adults drawn from a non-clinical, healthy population. In light of evidence that individual differences in anxiety and depression may modulate how emotion effects responding on cognitive control-type tasks (see review: Kanske, 2012), the absence of a clinical group may have contributed to the failure to elicit interference.

Additionally, differences between the words used in past and current emotional Stroop tasks may have influenced results in important ways. For example, Larsen, Mercer, and Balota (2006) reported that the often-replicated slowdown in color naming of emotional words may be due, in part, to lexical differences between the emotional and control words used in many studies. In an effort to avoid such confounding of emotional and lexical effects, the current study matched neutral and emotional words based on multiple lexical characteristics in addition to the more standard matching on valence, arousal, and word length. Thus, it is possible that the facilitation, rather than interference, found in the current study reflects a more valid estimation of the effect of emotional stimuli on color naming and cognitive control than those obtained in research with stimuli that had not been as closely matched on their lexical features. Further research understanding emotional Stroop performance with psychometrically sound tasks is warranted to better understand the effect of emotional stimuli on Stroop performance.

Although the discrepancy between the effects of emotional stimuli in the Flanker and Stroop tasks was unforeseen, it aligns with research suggesting that emotional stimuli may affect performance in different ways, depending on the way in which they are used in a task, as well as on their relevance to successful performance (see Figure 8; Kanske, 2012). Kanske (2012) argued that if the emotional stimuli are task-relevant, which means they are the stimuli that participants need to process and react to in order to solve the task, then emotion should speed up cognitive conflict processing rather than slow it down. If, however, emotional stimuli are task-irrelevant and serve merely as distracters or ancillary cues, the dual competition model proposed by Pessoa (2009) suggests they may instead impede cognitive conflict processing because the cognitive resources needed are shared and diverted to negative emotional stimuli.

It could be argued that the emotional stimuli in the emotional Stroop tasks are task-relevant, in that emotional information is integrated into the target stimuli (MacLeod, 1991) and thus might be expected to enhance the exercise of cognitive control. The emotional Flanker task presents a more complicated picture; although there are emotional stimuli that are task-relevant stimuli (i.e., positive target faces), there are also emotional task-irrelevant distracters (e.g., negative flanking faces) that are spatially adjacent to the target and that could act to slow down responding. The cognitive control task paradigms used in the current study incorporate emotion in different ways and yield different patterns of outcomes. These divergent outcomes across paradigms suggests that emotional cognitive control is not purely driven by the presence of emotional content, but that it also depends on the way in which an individual engages with the emotional content. If this is the case, tasks that vary the role of emotional information should be grouped together with caution. Further, it is possible that varied indices of emotional cognitive control might differentially relate to the onset and maintenance of various mental health problems; individual consideration of discrete task performance patterns could help to characterize and possibly inform treatment of the underlying cognitive biases that contribute to select mental health problems.

5.3.2 Neutral and Emotional Composites

Unlike most prior research on PA, cognitive control, and emotion, the current study was designed to capture a broad construct—cognitive control with and without emotional processing—rather than to parse this construct according to task-specific patterns of performance. To accomplish this goal, I created composite scores that reflected performance on neutral and emotional cognitive control task paradigms that have been shown to activate shared brain regions and networks (Nee, Wager, & Jonides, 2007).

It is unclear how well these composite scores yielded useful information, because performance on the tasks that were combined to create the neutral and emotional cognitive control composites varied substantially in important ways. Although mean RT for each trial-type was significantly and positively correlated across neutral and emotional cognitive control tasks, RT interference scores did not show significantly associations across tasks. In fact, performance on the emotional versions of the cognitive control tasks resulted in interference effects in opposite directions. Such inconsistencies between performance indices from different cognitive control task paradigms suggests that each task may be tapping a slightly different subset of cognitive control processes. If this suggestion is accurate, the present findings are consistent with the idea that cognitive control is a coherent, but multidimensional construct (Diamond, 2013; Duckworth & Kern, 2011; Nee, Wager, & Jonides, 2007).

5.4 Regular PA and Cognitive Control

5.4.1 Empirical and Theoretical Considerations

Much prior research has provided evidence that regular PA relates positively to cognitive control as measured using a variety of cognitive control tasks and indices (Dupuy et al., 2015; Pérez, Padilla, Parmentier, & Andres, 2014; Winneke, Godde, Reuter, Vieluf, & Voelcker-Rehage, 2012; Zhu & Castelli, 2014), (Cameron, Lucan, & Machado's, 2015; Guiney, Lucas, Cotter, & Machado, 2015; Kamijo & Takeda, 2010; Themanson, Hillman, & Curtin, 2006). The present study, however, is not the first to fail to detect a significant association between PA level/fitness and interference effects in a young adult population (Hillman et al., 2006). Moreover, there has been a recent shift in the literature toward reporting more precise indices of post-error performance and omitting interference effects as a performance index on cognitive control tasks (Themanson & Hillman, 2006; Themanson, Pontifex, & Hillman, 2008). It is not clear why this shift occurred, but one possibility is that findings emerge more robustly and consistently when performance is indexed in very specific ways that focus on performance when cognitive control demands are the highest. Future research regarding PA and cognitive control might thus benefit from assessing post-error performance in the finely-grained ways that Themanson and colleagues did.

Measurement issues offer one potential explanation for the lack of an evident association between regular PA and cognitive control in the present study. However, despite increased interest in this area of research in young adults, there are also viable reasons why a link between regular PA and cognitive control may simply not be present at a detectable level in a healthy young adult population. First, it could be there is no association because healthy young adults are at a peak level of cognitive control abilities, leaving little room for regular PA to lead to enhanced cognitive control task performance (Friedman, Nessler, Cycowicz, & Horton, 2009).

Thus, regular PA may be disproportionately valuable in populations where cognitive control abilities are not at their prime. For instance, younger and older samples might preferentially benefit from the cognitive benefits of regular PA because they are at stages of life associated with age-related development or decline in cognitive control (Prakash et al., 2009; Voelcker-Rehage, & Niemann, 2013). Moreover, individuals with clinical levels of depression and anxiety often present with altered cognitive control abilities; thus, even young adults with clinically significant symptoms may benefit from the cognitive benefits of regular activity in ways that healthy peers do not (Kubesch, 2003). The current study's null findings, taken together with Hillman et al.'s (2006) results, suggest that there is room for question about the idea that PA should benefit cognition in healthy young adults in the same ways that it does in more vulnerable groups.

A second possible reason is that it may not be necessary to meet longstanding recommendations regarding PA levels in order to obtain cognitive control benefits. Recent research in the PA-health literature suggests that smaller doses of regular PA than are recommended by CDC guidelines can improve cardiometabolic health (Gillen et al., 2016). The same may be true for cognitive health, where exact doses of PA needed for cognitive benefits are unclear. It is plausible that participants in both the PA+ and PA- groups were engaging in levels or types of PA that conferred cognitive benefits, resulting in an absence of significant differences between the two PA level groups created in the current study.

Third, it is also possible that there is a publication bias favoring studies that find associations between PA and cognitive functioning (Franco, Malhotra, & Simonovits, 2014). Meta-analysis of existing work on PA and cognition could yield useful information about the robustness of effects. In the context of meta-analytic research, calculation of estimates of the number of studies with null findings needed to mitigate effects to a non-significant level would also be useful.

5.4.2 Methodological Considerations

Some inconsistencies between findings from the present study and those from prior work could reflect differences in the ways that regular PA/fitness is conceptualized across studies. The present study's null findings are inconsistent with results from two studies that used very similar approaches to measurement and conceptualization of PA level and found significant negative associations between CPAL and performance on a measure of cognitive inhibition (Cameron, Lucas, & Machado, 2015; Guiney, Lucas, Cotter, Machado, 2015). In contrast to the current study's dichotomous variable, both previous studies broke participants into more categories (not physically active, physically active but not meeting recommendation criteria, meeting the criterion for less than 6 months, and meeting the criterion for longer than 6 months). This multicategorical variable was more sensitive to different levels of PA and allowed for a more nuanced examination of PA that does not reach recommended levels, which may have been where beneficial cognitive effects emerged (Gillen et al., 2016; Hamer, Stamatakis, & Steptoe, 2009).

In addition, the dichotomization approach used in the current study did not permit the examination of extreme groups, which may have increased the power to detect differences in cognitive control (Preacher, Rucker, MacCallum, & Nicewander, 2005). For example, Pérez, Padilla, Parmentier, and Andres (2014) recruited participants into their study who represented one of two extreme groups. Habitually active participants had performed aerobic activity for a period greater than 10 years for an average of 6 or more hours per week distributed across at least three days a week, and continued this activity at the time of testing. Habitually passive participants did not exercise more than 2 hours per week for the past 4 years). This approach may have enabled the researchers to detect differences in cognitive control abilities that might be obscured in groups that do not represent population extremes (Preacher, Rucker, MacCallum, & Nicewander, 2005).

The current study took a different approach to measuring the PA-related construct than that used in much prior work on PA and cognitive control in young adults. Most published studies have found significant relationships between cardiorespiratory fitness, based on $VO_{2\ max}$, and cognitive control performance (Dupuy et al., 2015; Themanson & Hillman, 2006; Themanson, Pontifex, & Hillman, 2008), rather than self-reported PA level groups. Even though the PA level groups in the current study were verified to have fitness differences based on heart rate recovery following a validated step test procedure (TMST), which provides an objective and norm-based categorization of fitness that is more reliable than self-reported PA and has been shown to be correlated with VO_{2max} (Dimkpa, 2009), heart rate recovery is not as reliable as $VO_{2\ max.}$ It is possible that aerobic fitness and its relation to other study variables would have been better captured by assessing VO_{2max}.

In summary, there are many ways that PA and fitness can be measured and conceptualized. The PA level dichotomization method used in the current study could have led to imprecise grouping of individuals with high or low likelihood to benefit from PA, which could, in turn, have affected power to detect significant effects (MacCallum, Zhang, Peacher, & Rucker, 2002). Measurement of fitness also diverged from the approach used in many earlier studies, which may have contributed to discrepant findings. It will be useful for future research to try to replicate previous findings with consistent measures, and to group individuals with different levels of PA in a manner that is theory-driven and optimizes the likelihood of detecting hypothesized effects.

5.5 Cognitive Control and Emotional Functioning

In at least two studies, emotional health has been linked positively to performance on cognitive control tasks (Kanske, 2012; Pe, Vandekerckhove, & Kuppens, 2013); further, emotional disorders have been shown to relate to atypical processing of negative emotional stimuli (Li, Paller, & Zinbarg, 2008; Mercado, Carretié, Tapia, & Gómez-Jarabo, 2006; Scott, Mogg, & Bradley, 2001). Contrary to predictions, no such associations were detected between neutral or emotional cognitive control and emotional functioning in the present study. When task-specific performance indices were examined in exploratory analyses as potential correlates of emotional health, few significant results emerged. However, the neutral Stroop task interference effect was associated with emotional functioning, in an unexpected direction: smaller interference effects (better cognitive control) on the neutral Stroop task were linked to poorer emotional functioning. Further, there was no consistent evidence that performance on cognitive control tasks with emotional stimuli had a stronger relationship with emotional functioning than did performance on neutral tasks.

Although numerous studies document altered cognitive control abilities in clinically depressed and anxious subjects (Demeyer, De Lissnyder, Koster, & De Raedt, 2012; Fales, et al., 2008; Pe, Vanderkerckhove, & Kuppens, 2013) or healthy individuals with high state anxiety (Dresler, Meriau, Heekeren, & van der Meer, 2009), it is possible that such relationships are generally weak or absent in healthy young adult populations. Findings from at least one other study are partially consistent with this possibility; Kanske and Kotz (2012) failed, as the present study did, to find a significant relationship between subclinical anxiety and depression symptoms and neutral cognitive control task performance in a sample of young adults. However, subclinical depression and anxiety were associated in Kanske and Kotz's (2012) study with emotional conflict, a variable calculated by subtracting neutral trial interference from emotional trial interference. This finding suggests that the inclusion of emotional stimuli in cognitive control tasks may have differentially affected task performance in participants who reported more distress. Clearly further research is needed to resolve inconsistencies in the small literature on cognitive control and emotional functioning in healthy young adults; use of consistent measures and indices across studies would be of value in such work. In the interim, the present study's finding of a positive association between interference on the neutral Stoop task and emotional health should be interpreted with caution.

5.6 Strengths and Limitations

The current study was marked by a few notable strengths. The aim of the study was novel, exploring a mediation model that had not been previously tested. This aim also integrated into a single parsimonious model findings from studies that had focused on individual links between subsets of the 3 study variables. Methodologically, the cognitive control task designs were empirically driven (i.e., Stroop task words were matched on many important characteristics), and PA assessment was multimodal, in that it encompassed both subjective and objective measures.

Despite these strengths, the present study yielded null findings that must be interpreted in the context of several limitations. First, the use of self-report questionnaires to gather data regarding PA is potentially problematic (Adam et al., 2005). Although this measurement approach has the advantage of yielding scores that permit ready classification of respondents according to their activity categories or levels, retrospective PA questionnaires may not provide as accurate or precise an assessment of absolute time spent at different exercise intensity levels and the associated energy expenditure as do real-time data collection methods such as accelerometers (Slootmaker, Schuit, Chinapaw, Seidell, & Van Mechelen, 2009; Welk, 2002). In addition, the questionnaire used in the current study does not collect information regarding type or mode (e.g., group exercise class, team sport, individual activity) or motives for PA, which can influence the psychological outcomes. Future studies may benefit from assessing regular PA with objective, reliable, and valid measures, such as physical activity trackers that capture intensity, duration, and frequency of exercise (e.g., Actigraph; Hermann, 2011), and also gathering self-report data on psychological and contextual factors related to PA engagement.

Another possible limitation that is important to note is that participant recruitment was blind to PA level, which resulted in unequal group sizes when participants were clustered according to PA and thus may have diminished power to detect significant associations. An alternate approach that might have proven more fruitful is sampling from extreme groups (Preacher, Rucker, MacCallum, & Nicewander, 2005). Such an approach is common in the PA literature; many studies that have found significant links between regular PA/fitness and cognitive and emotional benefits have compared sedentary individuals to those who are regularly active or low-fit to high-fit individuals (e.g., Gajewski, & Falkenstein, 2015; Voss et al., 2011). There may thus be value in embedding group placement in recruitment procedures to ensure that groups are equal and in sampling from extreme groups to maximize the power of analyses.

In addition, it is not clear if the findings can be generalized to individuals who fall outside the sample's characteristics on variables such as age, emotional functioning and cognitive control. For instance, the null findings may or may not apply to a clinical sample of individuals with anxiety or depressive disorders, or other populations that are vulnerable to poorer cognitive control abilities and/or are at-risk for higher levels of emotional problems (e.g., older adults, history of diabetes, severe brain injury; Braver & Barch, 2002; Perlstein, Larson, Dotson, & Kelly, 2006; Tran, Baxter, Hamman, Grigsby, 2014). Future studies could address this generalizability issue by assessing regular PA, cognitive control, and emotional functioning in various populations that might be more likely to benefit from the emotional and cognitive benefits of regular PA. Conducting these types of studies would not only potentially allow for benefits of regular PA to be detected, but findings would also provide useful data regarding the use of regular PA as a treatment for specific populations.

5.7 Future Research

Although the lack of significant support for the hypotheses in the current study is disappointing, there are several ways in which this work can nonetheless inform research moving forward. As a starting point, there may be value in retesting the current study hypotheses in young adults, 1) with more extreme and/or distinct PA level groups, 2) in samples with a wider range of emotional functioning or using measures that captures general emotional functioning, rather than just the past week, and 3) with additional cognitive control indices that tap cognitive control abilities when demands are high (e.g., post-error incongruent trials).

More broadly, continued research to clarify paths via which regular PA confers emotional health benefits is warranted (Cerin, 2010). The null results of the current study suggest that there are alternative populations worth exploring when considering cognitive control as a mediator, as healthy young adults may not accrue detectable benefits. In addition, it would be fruitful to incorporate imaging techniques during cognitive task administration to better understand the functional cognitive changes that may be associated with regular PA and emotional functioning that may or may not be apparent when examining behavioral indices. The literature would also be strengthened by a controlled intervention study that could provide evidence for whether improvements in cognitive control abilities are a key pathway linking regular PA to emotional functioning. Lastly, future research is encouraged to explore not only cognitive processes that might explain regular PA's emotional benefits, but alternative mechanisms as well.

There are also recommendations for the broader PA-emotional functioning literature. One recommendation for future studies would be to use objective measures of regular PA to improve the reliability and validity of estimates of regular PA. Additionally, there may be value in research that explores what types or modes and levels (e.g., frequency, duration, intensity, chronicity) of PA provide emotional health and/or cognitive benefits. Specifically, PA intervention studies with different PA types, levels, and durations will help clarify whether there is a dose-response relationship between PA and cognitive and/or emotional health and if there is an optimal type or amount of regular PA that will confer benefits.

All in all, research targeting whether, how much, and how regular PA confers emotional health benefits will help shape specific recommendations and programs geared towards prescribing PA with optimal effects. Further, if we can clearly describe how PA may prompt better emotional functioning, we will be better able prescribe and develop alternative treatments to help those individuals with poorer emotional functioning.

5.8 Summary

Results of the current study failed to support the hypothesis that neutral and emotional cognitive control, based on composites and individual task performance, would have a mediating effect on the association between regular PA and emotional functioning in healthy young adults. They are thus in line with the idea that healthy young adults at peak cognitive functioning may not readily benefit from the emotional and cognitive effects of regular PA because they do not have much room for improvement in these areas. However, the lack of support for study hypotheses does not necessarily preclude the possibility that regular PA confers emotional health benefits in young adults or that cognitive control abilities are a mechanism at play in this or other populations. Future research is warranted to clarify how and for whom regular PA provides emotional health benefits.

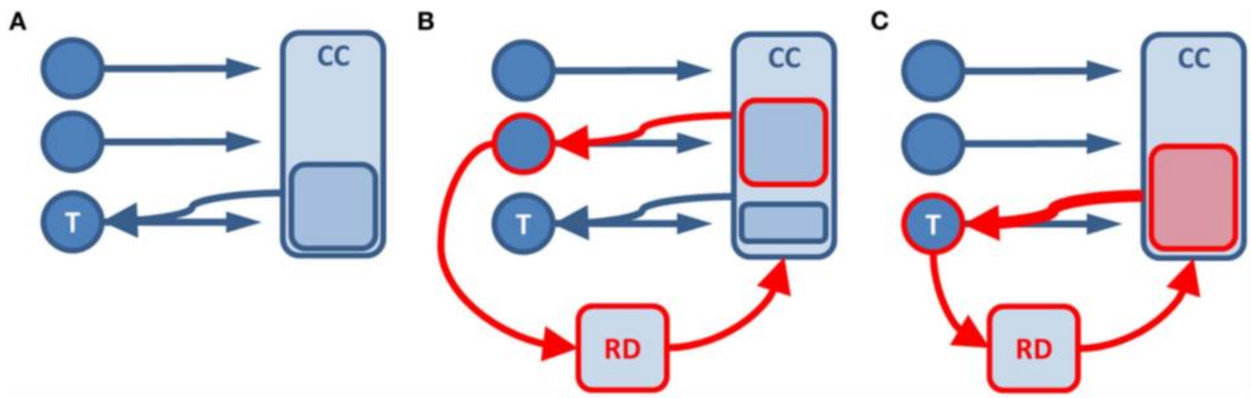

Figure 8. Illustration of the functional integration of emotion and cognitive control in conflict processing. The situation for neutral (A) and emotional task-irrelevant (B) or task-relevant stimuli (C) is displayed. Circles represent stimuli. Rectangles stand for processing units. Red frame color indicates an emotional stimulus or emotion induced processing. T, task-relevant stimulus; CC, cognitive control; RD, relevance detector. Figure from Kanske, P. (2015). On the influence of emotion on conflict processing. *Current Research and Emerging Directions in Emotion-Cognition Interactions, 457*.

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APPENDICES

Appendix A: Demographics

Gender:

- ☐ Male
- ☐ Female
- ☐ Other

Date of Birth: _____________________
Age: _____________________
Height: ___ feet ___inches
Weight: _____(pounds)
Dominant Hand (Circle one): Left Right Both
Race:

- ☐ Caucasian
- ☐ African American
- ☐ Asian
- ☐ American Indian or Alaskan Native
- ☐ Native Hawaiian or other Pacific Islander
- ☐ Other (Please Specify: _________)

College Major: _____________________
Current Year in College:

- ☐ Freshman
- ☐ Sophomore
- ☐ Junior
- ☐ Senior
- ☐ Other: _____________________

What is the highest level of education achieved by your *father* or *male guardian*?

- ☐ Middle school or less
- ☐ High school
- ☐ Junior college
- ☐ Four-year college
- ☐ Graduate school, Master's degree or equivalent
- ☐ Graduate school, PhD level or equivalent
- ☐ Other: _____________________

What is the highest level of education achieved by your *mother* or *female guardian*?

- ☐ Middle school or less
- ☐ High school
- ☐ Junior college
- ☐ Four-year college
- ☐ Graduate school, Master's degree or equivalent
- ☐ Graduate school, PhD level or equivalent
- ☐ Other: _____________________

Free time activities (aside from physical activity):

____

Since attending college your physical activity levels have:

- ☐ Increased
- ☐ Decreased
- ☐ Remained the same
- ☐ Other: _____________________

Have you ever had a traumatic brain injury?

- ☐ Yes
  - If yes, please describe: ____
- ☐ No

Have you ever been diagnosed with ADHD?

- ☐ Yes
  - If yes, at what age: _______
- ☐ No

Please list current medications and duration of use: ________

How much caffeine have you consumed today (i.e., coffee, tea, caffeinated soda, etc.): ________

Appendix B: Pittsburgh Sleep Quality Index

Subject's Initials________________ID#__________________Date_______________Time_____AM/PM

PITTSBURGH SLEEP QUALITY INDEX

INSTRUCTIONS:
The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. Please answer all questions.

1. During the past month, what time have you usually gone to bed at night?

   BED TIME ___________

2. During the past month, how long (in minutes) has it usually taken you to fall asleep each night?

   NUMBER OF MINUTES ___________

3. During the past month, what time have you usually gotten up in the morning?

   GETTING UP TIME ___________

4. During the past month, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spent in bed.)

   HOURS OF SLEEP PER NIGHT ___________

For each of the remaining questions, check the one best response. Please answer all questions.

5. During the past month, how often have you had trouble sleeping because you . . .

a) Cannot get to sleep within 30 minutes

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

b) Wake up in the middle of the night or early morning

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

c) Have to get up to use the bathroom

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

d) Cannot breathe comfortably

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

e) Cough or snore loudly

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

f) Feel too cold

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

g) Feel too hot

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

h) Had bad dreams

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

i) Have pain

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

j) Other reason(s), please describe____

____

How often during the past month have you had trouble sleeping because of this?

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

6. During the past month, how would you rate your sleep quality overall?

Very good ___________

Fairly good ___________

Fairly bad ___________

Very bad ___________

7. During the past month, how often have you taken medicine to help you sleep (prescribed or "over the counter")?

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

8. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

9. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?

No problem at all __________

Only a very slight problem __________

Somewhat of a problem __________

A very big problem __________

10. Do you have a bed partner or room mate?

No bed partner or room mate __________

Partner/room mate in other room __________

Partner in same room, but not same bed __________

Partner in same bed __________

If you have a room mate or bed partner, ask him/her how often in the past month you have had . . .

a) Loud snoring

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

b) Long pauses between breaths while asleep

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

c) Legs twitching or jerking while you sleep

Not during the past month Less than once a week Once or twice a week Three or more times a week

d) Episodes of disorientation or confusion during sleep

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

e) Other restlessness while you sleep; please describe___________________________________

____

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

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Appendix C: Modified New Zealand Physical Activity Questionnaire- Short Form

I am going to ask you about the time you spent being physically active in the last 7 days. Do not include activity undertaken today.

By active I mean doing anything using your muscles. Think about activities at work, school or home, getting from place to place, and any activities you did for exercise, sport, recreation or leisure. I will ask you separately about brisk walking, moderate activities, and vigorous activities.

Please answer these questions even if you do not consider yourself to be a physically active person.

Walking		
1	During the last 7 days, on how many days did you walk at a brisk pace- a brisk pace is a pace at which you are breathing harder than normal? This includes walking at work or school, while getting from place to place, at home and at any activities that you did solely for recreation, sport, exercise, or leisure. Think only about brisk walking done for at least 10 minutes at a time	____ days per week (GO TO 2) None (GO TO 3)
2	How much time did you typically spend walking at a brisk pace on each of those days	Hours : minutes __:__
Moderate physical activity		
3	During the last 7 days, on how many days did you do moderate physical activities? Moderate activities make you breathe harder than normal, but only a little- like carrying light loads, bicycling at a regular pace, or other activities like these. Do not include walking of any kind. Think only about those physical activities done for at least 10 minutes at a time.	___ days per week (GO TO 4) None (GO TO 5)
4	How much time did you typically spend on each of those days going moderate physical activities?	Hours : minutes __:__
Vigorous physical activity		
5	During the last 7 days, on how many days did you do vigorous physical activities? Vigorous activities make you breathe a lot harder than normal ('huff and puff')- like heavy lifting, digging, aerobics, fast bicycling, or other activities like these. Think only about those physical activities done for at least 10 minutes at a time.	____ days per week (GO TO 6) None (GO TO 7)
6	How much time did you typically spend on each of those days going vigorous physical activities?	Hours : minutes __:__
Frequency of Activity		
7	Think about all your activities over the last 7 days (including brisk walking), on how many days did you engage in:	Number of days ___ None

- At least 30 minutes of moderate activity that made you breathe a little harder than normal, OR
- At least 15 minutes of vigorous activity that made you breathe a lot harder than normal

State of Change

8	Describe your regular physical activity over the past six months. Regular physical activity means at least 15 minutes of vigorous activity (makes you 'huff and puff') or 30 minutes of moderate activity (makes you breathe slightly harder than normal) each day for 5 or more days each week. Include brisk walking**.**	- I am not regularly physically active and do not intend to be so in the next 6 months - I am not regularly physically active but am thinking about starting in the next 6 months - I do some physical activity but not enough to meet the description of regular physical activity - I am regularly physically active but only began in the last 6 months - I am regularly physically active and have been so for longer than 6 months
9	Was your activity over the past 7 days representative of a typical week?	Yes (GO TO 17) No (GO TO 11)

Typical Walking

10	In a typical week, on how many days do you walk at a brisk pace- a brisk pace is a pace at which you are breathing harder than normal? This includes walking at work or school, while getting from place to place, at home and at any activities that you did solely for recreation, sport, exercise, or leisure. Think only about brisk walking done for at least 10 minutes at a time	__ days per week (GO TO 11) None (GO TO 12)
11	How much time do you typically spend walking at a brisk pace on each of those days	Hours : minutes __:__

Typical Moderate physical activity

12	In a typical week, on how many days did you do moderate physical activities? Moderate activities make you breathe harder than normal, but only a little- like carrying light loads, bicycling at a regular pace, or other activities like these. Do not include walking of any kind.	__ days per week (GO TO 13) None (GO TO 14)

	Think only about those physical activities done for at least 10 minutes at a time.	
13	How much time do you typically spend on each of those days going moderate physical activities?	Hours : minutes __:__
Typical Vigorous physical activity		
14	In a typical week, on how many days do you do vigorous physical activities? Vigorous activities make you breathe a lot harder than normal ('huff and puff')- like heavy lifting, digging, aerobics, fast bicycling, or other activities like these. Think only about those physical activities done for at least 10 minutes at a time.	__ days per week (GO TO 15) None (GO TO 16)
15	How much time do you typically spend on each of those days going vigorous physical activities?	Hours : minutes __:__
Typical Frequency of Activity		
16	Think about all your activities in a typical week (including brisk walking), on how many days do you engage in: - At least 30 minutes of moderate activity that made you breathe a little harder than normal, OR - At least 15 minutes of vigorous activity that made you breathe a lot harder than normal	Number of days ___ None

Sedentary behavior

The following question is about sitting or reclining at work, at home, getting to and from places, or with friends including time spend sitting at a desk, sitting with friends, reading, watching television, but do not include time spend sleeping.

17	How much time do you usually spend sitting or reclining on a typical day?	Hours : minutes __:__

SHOWCARD FOR NZPAQ-SF

Moderate Physical Activity

Badminton (Social)
Ballroom dancing
Bowls - Indoor
Bowls - Outdoor/Lawn
Carrying light loads
Cricket - outdoors (batting and bowling)
Cycling - recreational (not mountain biking) - less than 15 km/hr
Deer hunting
Doubles tennis
Electrical work
Exercising at home
Farming
Golf
Gardening
Heavy gardening
Heavy cleaning
Horse riding/Equestrian
House renovations
Kayaking - slow
Machine tooling - operating lathe, punch press, drilling, welding
Manual lawnmower
Massage
Motor sports (motorcycling/trail biking, motor racing)
Plastering
Plumbing
Raking/planting
Skate boarding
Surfing/body boarding
Vacuuming
Yachting/sailing/dingy sailing

SHOWCARD FOR NZPAQ-SF

Vigorous Physical Activity

Boxing	Race walking
Aerobics	Running/jogging/cross-country
Kayaking – fast	Judo, karate etc.
Athletics (track and field)	Softball (running/pitching only)
Aquarobics	Squash
Skiing	Surf life saving
Badminton (Competitive)	Swimming
Basketball	Table tennis
Mountain biking	Tennis
Cricket - indoors (batting and bowling)	Touch football
Cycling - competitive	Tramping
Cycling - recreational (not mountain biking) - more than 15 km/hr	Triathlon
	Volleyball
Rock climbing	Water polo
Exercise classes/going to the gym (other than aerobics work)/weight training	Carrying heavy loads
	Forestry
Netball	Horse racing
Soccer	Heavy construction
Rowing	Digging ditches
Rugby League	Chopping or sawing wood
Rugby Union	
Hockey	

Appendix D: YMCA Bench Step Test

YMCA Bench Step Test for Cardiovascular Fitness

Testing for cardiovascular fitness can be costly, time consuming, and also require elaborate equipment. Luckily there is an easy Do-It-Yourself assessment that can easily be completed at home.

The YMCA 3-minute Bench Step Test is based on how quickly your heart rate recovers following a short bout of exercise.

Below are the essentials to perform the test on your own:

- 12-inch tall step, bench, or box (as close to 12 inches as you can find)
- Stopwatch, timer, or clock with a secondhand
- Metronome (free – www.metronomeonline.com)
- Heart rate monitor (optional)
- Partner to assist with cadence and form (optional)

Procedures:

1. Set the metronome to 96 beats per minute and turn the volume up loud enough that you can hear each beat.
2. Stand facing your step.
3. When ready to begin start the stopwatch or timer and begin stepping on and off the step to the metronome beat following a cadence of up, up, down, down.
4. Continue for 3 minutes.
5. As soon as you reach 3 minutes, stop immediately and sit down on your step.
6. Perform a manual pulse reading and count the number of beats for an entire **60 seconds** - http://www.webmd.com/heart/taking-a-pulse-heart-rate - If wearing a heart rate monitor record your heart rate 1 minute from when you sit down.
7. Record your pulse when you have reached 1 minute and then locate your score on the rating scale below.

Results: Age-adjusted standards based on guidelines published by YMCA.

Ratings for Women, Based on Age

	18-25	26-35	36-45	46-55	56-65	65+
Excellent	52-81	58-80	51-84	63-91	60-92	70-92
Good	85-93	85-92	89-96	95-101	97-103	96-101
Above Average	96-102	95-101	100-104	104-110	106-111	104-111
Average	104-110	104-110	107-112	113-118	113-118	116-121
Below Average	113-120	113-119	115-120	120-124	119-127	123-126
Poor	122-131	122-129	124-132	126-132	129-135	128-133
Very Poor	135-169	134-171	137-169	137-171	141-174	135-155

Ratings for Men, Based on Age

	18-25	26-35	36-45	46-55	56-65	65+
Excellent	50-76	51-76	49-76	56-82	60-77	59-81
Good	79-84	79-85	80-88	87-93	86-94	87-92
Above Average	88-93	88-94	92-88	95-101	97-100	94-102
Average	95-100	96-102	100-105	103-111	103-109	104-110
Below Average	102-107	104-110	108-113	113-119	111-117	114-118
Poor	111-119	114-121	116-124	121-126	119-128	121-126
Very Poor	124-157	126-161	130-163	131-159	131-154	130-151

Appendix E: Depression Anxiety Stress Scale (DASS)

Please read each statement and circle a number 0, 1, 2 or 3 that indicates how much the statement applied to you *over the past week*. There are no right or wrong answers. Do not spend too much time on any statement.

The rating scale is as follows:

0 Did not apply to me at all
1 Applied to me to some degree, or some of the time

2 Applied to me to a considerable degree, or a good part of time
3 Applied to me very much, or most of the time

1	I found myself getting upset by quite trivial things	0	1	2	3
2	I was aware of dryness of my mouth	0	1	2	3
3	I couldn't seem to experience any positive feeling at all	0	1	2	3
4	I experienced breathing difficulty (e.g., excessively rapid breathing, breathlessness in the absence of physical exertion)	0	1	2	3
5	I just couldn't seem to get going	0	1	2	3
6	I tended to over-react to situations	0	1	2	3
7	I had a feeling of shakiness (e.g., legs going to give way)	0	1	2	3
8	I found it difficult to relax	0	1	2	3
9	I found myself in situations that made me so anxious I was most relieved when they ended	0	1	2	3
10	I felt that I had nothing to look forward to	0	1	2	3
11	I found myself getting upset rather easily	0	1	2	3
12	I felt that I was using a lot of nervous energy	0	1	2	3
13	I felt sad and depressed	0	1	2	3
14	I found myself getting impatient when I was delayed in any way (e.g., elevators, traffic lights, being kept waiting)	0	1	2	3
15	I had a feeling of faintness	0	1	2	3
16	I felt that I had lost interest in just about everything	0	1	2	3
17	I felt I wasn't worth much as a person	0	1	2	3
18	I felt that I was rather touchy	0	1	2	3
19	I perspired noticeably (e.g., hands sweaty) in the absence of high temperatures or physical exertion	0	1	2	3

20	I felt scared without any good reason	0	1	2	3
21	I felt that life wasn't worthwhile	0	1	2	3
22	I found it hard to wind down	0	1	2	3
23	I had difficulty in swallowing	0	1	2	3
24	I couldn't seem to get any enjoyment out of the things I did	0	1	2	3
25	I was aware of the action of my heart in the absence of physical exertion (e.g., sense of heart rate increase, heart missing a beat)	0	1	2	3
26	I felt down-hearted and blue	0	1	2	3
27	I found that I was very irritable	0	1	2	3
28	I felt I was close to panic	0	1	2	3
29	I found it hard to calm down after something upset me	0	1	2	3
30	I feared that I would be "thrown" by some trivial but unfamiliar task	0	1	2	3
31	I was unable to become enthusiastic about anything	0	1	2	3
32	I found it difficult to tolerate interruptions to what I was doing	0	1	2	3
33	I was in a state of nervous tension	0	1	2	3
34	I felt I was pretty worthless	0	1	2	3
35	I was intolerant of anything that kept me from getting on with what I was doing	0	1	2	3
36	I felt terrified	0	1	2	3
37	I could see nothing in the future to be hopeful about	0	1	2	3
38	I felt that life was meaningless	0	1	2	3
39	I found myself getting agitated	0	1	2	3
40	I was worried about situations in which I might panic and make a fool of myself	0	1	2	3
41	I experienced trembling (e.g., in the hands)	0	1	2	3
42	I found it difficult to work up the initiative to do things	0	1	2	3