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## Executive Function, Eating, and Exercise Duration in Adolescents

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Executive Function, Eating, and Exercise Duration in Adolescents

Robyn C. Blackburn

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

Doctor of Philosophy

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## ABSTRACT

### **Executive Function, Eating, and Exercise Duration in Adolescents**

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Doctor of Philosophy

Adolescence is an important developmental period for executive function as well as establishing lifelong health habits like diet and exercise. However, connections between exercise, executive function and dietary behaviors have not yet been adequately studied in adolescents, especially in terms of exercise duration. This research seeks to establish how 30 versus 60 minutes of exercise affects the association between executive function, calorie consumption and food-specific inhibition. The current research uses a within-participant design and linear mixed modeling to test the impact of exercise bout duration and executive function on calorie consumption and food-specific inhibition (food Go/No-Go accuracy and reaction time). This paper concludes that for adolescents, there may be a small impact of EF on dietary behaviors. It also concludes that 30 versus 60 minutes of non-cognitively demanding exercise (i.e., treadmill running) does not affect these associations in meaningful ways. Overall, the practical advantages of 30 minutes versus 60 minutes of exercise may make this a better recommendation for teens, but additional research on the impact of exercise is needed to inform these recommendations.

Keywords: adolescence, exercise, executive function, dietary behavior, calorie consumption, food-specific inhibition

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### **Executive Function, Eating, and Exercise Duration in Adolescents**

This study aimed to explore the impact of exercise duration on various elements of executive function (EF) and dietary outcomes in adolescence. Adolescence may be an especially sensitive time for observing the impact of exercise, since the prefrontal cortex, which is implicated in various aspects of EF including inhibitory control, is still developing during this period. This research provides important insights into this population, who are establishing health habits that will affect the rest of their lives. This research contributes to reducing rates of overweight and obesity in the current “obesity epidemic”. In the United States, currently 20.6% of 12- to 19-year-olds are obese (Center for Disease Control and Prevention, 2019a). Both overweight and obesity are associated with food specific inhibition and regulating food behavior, which can be improved with EF training. Although the connection between exercise and EF, and EF and dietary outcomes has been well documented in various populations, a non-clinical adolescent population has yet to receive adequate attention. Additionally, research has yet to establish whether exercise bout duration matters for these associations. Specifically, this study contributes to the current research exploring whether there is a difference in the associations between EF/food specific inhibition and food consumption when aerobic exercise bout is 30 versus 60 minutes. Put another way, I searched to find out if there was a “sweet spot” for exercise duration that maximizes the favorable associations that have been observed between EF and dietary behaviors. This research was also meant to shed light on the validity of the Center for Disease Control and Prevention’s current aerobic exercise recommendations for teens. Currently, the recommendation is that adolescents should engage in 60 minutes of moderate- or vigorous-intensity aerobic physical activity six days a week (Center for Disease Control and Prevention, 2019b). Uniquely, this study used diverse measures including cognitive and behavioral measures

to establish EF, food specific inhibition and food consumption, which gave a more complete look at these concepts.

## **Literature Review**

### ***Exercise improves executive functioning throughout different phases of life***

Recent literature has shown the impact of exercise on EF throughout a lifetime. This research is valuable since it allows us to take a lifespan approach to the topic at hand and understand the context of the adolescent research that I will cover and to which the current study contributes. Thus, this literature review reviews the life span, though the purpose of the current study was to address the impact of exercise on multiple facets of EF and dietary outcomes during the unique developmental period of adolescence. Research is included about adults and children to show the concept over the lifespan and where there may be insufficient literature on adolescents. One of the main topics I discuss is executive function (also known as EF or cognitive control), which is an umbrella term that incorporates the inter-related processes that are responsible for purposeful, goal-oriented cognition and behavior that develop over childhood and adolescence (Best, 2010; Diamond, 2013; Isquith, 2001). EF is a set of processes that are necessary when trying to concentrate or pay attention, particularly when automatic responses are insufficient (Diamond, 2013). Thus, using EF requires effort and is essential for success in school and life (Diamond, 2013). EF has three main components: inhibitory control, working memory and cognitive flexibility (Diamond, 2015). These core elements of EF are essential features of cognition and are crucial to an individual's reasoning, planning and creative problem-solving (Diamond, 2015).

A review by Best (2010) showed support for both acute and chronic exercise improving EF in children. Specifically, school-aged children showed improvements in working memory, selective attention and inhibitory control that were linked to exercise (Guiney & Machado,



2013). Inhibitory control can be defined as “thinking before we act (i.e., giving considered responses rather than impulsive ones), resisting temptations, resisting distractions, and staying focused” (Diamond, 2015, p. 2). During adolescence and young adulthood, individuals experience life-long peaks in EF, meaning that EF matures sometime during adolescence or early adulthood and is highest during this developmental period compared to any other time in the life span (Best et al., 2009). These highs in EF during young adulthood have been shown to be accentuated by aerobic exercise, and regular exercise in this group was associated with quicker reaction times and error detection (Guiney & Machado, 2013).

In regard to EF, adolescence is a crucial development period since the prefrontal cortex matures late in adolescence and this neural circuitry within the prefrontal cortex is crucial to EF (Gogtay et al., 2004; Luria, 2012; O’Hare & Sowell, 2008; Shimamura, 2000; Stuss & Benson, 1984). Additionally, during adolescence, these brain changes (such as myelination and synaptic pruning) are driven by experience (O’Hare & Sowell, 2008). EF develops over an extended developmental period, and its developmental trajectory could help us understand why children’s EF is sensitive to aerobic exercise (Best, 2010). For instance, since both EF and the underlying neural circuitry are immature, experiences (like aerobic exercise) during this time may enhance EF (Best, 2010).

However, it may not only be during childhood and adolescence that EF is improved by aerobic exercise. Some studies have shown that older adults also showed improvements in EF (i.e., attention, task switching, working memory) after exercise, which normally deteriorates with age (Guiney & Machado, 2013). Aerobic exercise in this population increased both grey and white matter significantly compared to strength or flexibility training (Guiney & Machado, 2013). However, in contrast to these findings, there have also been a number of studies that show

the impact of exercise on EF improvement does not appear to exist after a certain age, perhaps after age 60 (Diamond, 2015). Historically, the majority of these studies have focused on the effects of acute aerobic exercise on inhibition (a specific aspect of EF) using the Stroop Task (Barella et al., 2010; Hogervorst et al., 1996; Lambourne & Tomporowski, 2010; Sibley et al., 2006; Yanagisawa et al., 2010). These studies have shown EF improvement in both young and older adults (Barella et al., 2010; Hogervorst et al., 1996; Sibley et al., 2006; Yanagisawa et al., 2010).

It is well documented that EF in children improved both after short-term moderate-to-vigorous aerobic exercise (Budde et al., 2008; Elleberg & St. Louis-Deschênes, 2010; Hillman et al., 2009; Pesce et al., 2009) and chronic training (Davis et al., 2007; Davis et al., 2011; Hinkle et al., 1993). For instance, Tuckman and Hinkle (1986) found better post-test performance on a measure of EF in children who engaged in aerobic running versus a control group of standard physical education. It is important to note that initial research examining the beneficial effects of exercise on EF was conducted with adults, and this research concluded that the effect depended on the intensity and duration of the exercise (Brisswalter et al., 2002; Kamijo et al., 2004; Tomporowski, 2003). It was determined that the benefits to EF came from a sub-maximal aerobic intensity (i.e., 20-80% of maximum heart rate) maintained during a 20-40-minute bout of exercise.

After these studies, researchers began exploring the effects during other developmental stages (i.e., childhood) that included better research methods, such as consistently controlling for heart rate (Elleberg & St. Louis-Deschênes, 2010). The Elleberg and St. Louis-DeDeschênes (2010) study used the exercise duration prescription previously shown to improve EF in adults and used an experimental design to test performance on reaction time tasks in 7- and 10-year-old

boys both before and after their randomly assigned condition. The tasks included a simple reaction time task and choice response time task aimed at capturing certain aspects of EF such as flexibility and inhibition. The experimental group engaged in 30 minutes of exercise (with an additional 5 minute warm up and cool down) on a stationary bike, while watching an age-appropriate children's show. The control group sat still on the stationary bike watching the same show for 40 minutes. For the experimental group, heart rate was monitored using telemetry during the exercise bout and heart rate was kept around 60% of maximum heart rate for the 30 minutes of cycling. The 10-minute choice response time task asked participants to press a key or withhold a response each time particular shapes appeared on a screen. Analysis looked at the response time for correctly identified targets and response accuracy. The results of this study indicate that both the 7- and 10-year-old children in the exercise group were significantly faster on both the simple reaction time task and the choice response task than the children in the control group, showing that exercise benefited both of these age groups equally in terms of reaction time compared to the no exercise condition. However, there was no significant difference in accuracy between the two experimental groups, which may indicate that it is not a measure of cognitive change that is sensitive to exercise. The enhancement on the choice response time task was 2.2 times greater than for the simple reaction time task, suggesting that exercise improves cognitive function, not just sensory and motor responses.

Additionally, not all forms of aerobic exercise are equal. Exercise that is "cognitively engaging" has a stronger effect on children's EF than "non-cognitively engaging" exercise (Best, 2010). It has been suggested that exercises that improves bimanual and hand-eye coordination or involves rhythmic movement may be especially beneficial for improving EF (Diamond, 2015). For instance, children engaging in Taekwondo, a traditional martial art, showed improvement on

all aspects of EF studied (Lakes & Hoyt, 2004). Also, children randomly assigned to practice yoga improved more and performed better post-test on the Tower of London EF task compared to their peers assigned to physical exercise (Manjunath & Telles, 2001). Children who consistently engaged in aerobic games that required them to think (i.e., basketball and soccer) for 40 minutes (43 hours total) showed EF improvements compared to those who only engaged in the games for 20 minutes (22 hours total; Davis et al., 2011). This finding suggests that the cognitive elements of exercise may, in part, account for the EF benefits, especially when more time is spent engaging in cognitively demanding exercise (Diamond, 2015).

Importantly, in computerized cognitive training of adults there has been support that the more time spent training to improve EF, the more EF improves (Basak et al., 2008; Jaeggi et al., 2008). In an experimental study of adolescents, 13 to 16-year olds were randomly assigned to either an experimental or control group and given an attention and concentration test called the d2-test before and after a short bout of one of two types of exercise (Budde et al., 2008). The control group engaged in 10 minutes of normal sport lesson exercise and the experimental group engaged in 10 minutes of coordinative exercise. The experimenters controlled for heart rate, meaning that the two groups' exercise intensity was equally vigorous. This study revealed that both groups improved significantly from pre- to post-test, but that the group who participated in the coordinative exercise had greater improvement compared to the control group. The researchers concluded that since heart rate was controlled for, the significant differences in concentration and attention were due to the coordinative character of the exercise. Additionally, the researchers proposed that coordinative exercise may lead to pre-activation in parts of the brain that mediate functions such as attention. This research is consistent with the previously reviewed literature indicating that exercise improves EF while continuing to clarify those

findings by showing cognitively demanding exercise may increase EF more than non-cognitively demanding exercise. Taken together, this body of research suggests that acute exercise improved short-term EF across the developmental spectrum, with well-established effects for children and adolescents.

### ***EF and Food-Specific Inhibition***

Research assessing the impact of EF on food-specific inhibition has focused on adult clinical populations, especially in individuals with loss of control eating and binge eating disorder (Manasse et al., 2015a; Manasse et al., 2015b). In contrast to these studies, the current study will focus on a non-clinical population. Also, although some of this previous research has focused on early adolescence (Groppe & Elsner, 2014), the entire developmental period of adolescence has not been studied extensively in this research. In adulthood (i.e., ages 18+), individuals with loss of control eating show worse EF (i.e., planning and self-regulatory control) than those without loss of control eating (Manasse et al., 2014).

Similarly, adults (ages 18+) with binge eating disorder needed more time to inhibit an ongoing response and displayed more difficulty inhibiting responses elicited by food stimuli relative to those without binge eating disorder (Svaldi et al., 2014). Adults with binge eating disorder have also displayed significantly poorer performance on problem-solving and inhibitory control tasks as higher prioritization of immediate versus delayed rewards (Manasse et al., 2015b). Taken together, these studies show that EF and food-specific inhibition are positively correlated. From these studies we can see that individuals with loss of control eating or binge eating also have problems with various aspects of EF. As a side note, when hedonic hunger in adults was low, poor EF increased the likelihood of an individual being categorized into a binge eating group (Manasse et al., 2015a). This shows that even when individuals are not hungry, poor EF can contribute to

binge eating. These studies clearly show support for the positive relationship between EF and food-specific inhibition in adulthood, but further research is needed to extend these findings to adolescents.

### *Aspects of EF and Food-Specific Inhibition*

EF, especially inhibitory control, has been shown to be related to food-specific inhibition, which is inhibitory control in the context of dietary behavior. These terms have been differentiated in order to make clear the difference between inhibitory control, which is one of the three main aspects of EF, and food-specific inhibition, which is specifically used in the context of self-regulating or inhibiting a response to food (Houben & Jansen, 2015). Inhibitory control is being able to control one's attention, behavior, thoughts and emotions while overriding impulses or distractions (Diamond, 2013). Recently, there has been support which suggests that overweight and obesity may be related to food-specific inhibition specifically rather than simply inhibitory control deficits in children, young adults and adults (Houben et al., 2014; Nederkoorn et al., 2012). These findings appear to imply that food-specific inhibition may be more predictive of dietary behavior than inhibitory control.

Additionally, the term food-specific inhibitory control training is commonly used when referring to training individuals to reduce food intake (Koningsbruggen et al., 2013; Veling et al., 2013). Self-regulation in eating and inhibitory control in children ages 3-9 have been shown to be strongly positively correlated,  $r=.54$  (Tan & Hulob, 2011). Children who self-regulate when eating as well as children who show high inhibitory control are less likely to be overweight than children who show poorer inhibitory control (Tan & Hulob, 2011). In this study, parents reported on their children's self-regulation in eating, inhibitory control, and their own feeding practices (Tan & Hulob, 2011). These findings suggest that inhibitory control and food-specific inhibition

are positively correlated and that both may play a role in preventing overweight in children. This study explored how inhibitory control, as well as other less-studied aspects of EF, affect food-specific inhibition. We explored these associations after short and long bouts of exercise.

Though there has not been adequate research about how other aspects of EF besides inhibitory control affect food-specific inhibition, this study explored how these other aspects (such as emotional control, working memory and task completion) may play a role.

### ***EF and Eating***

EF has been shown to influence health behaviors, such as regulation or control of eating behavior in emerging adults (Allom & Mullan, 2014; Calvo et al., 2014). Better EF has been associated with healthier eating behavior, specifically, superior updating capacity (an aspect of EF that refers to an individual's ability to update and monitor their goals) was related to greater fruit and vegetable consumption (Allom & Mullan, 2014). Similarly, decreased EF has been linked to unhealthy eating behaviors and weight outcomes, such as obesity, in older children and adults (Pieper & Laugero, 2013). One study of preschool age children, ages 3-6 (mean age = 4.4 years), found that children with lower cognitive development scores had higher eating in the absence of hunger (Pieper & Laugero, 2013). Some research has even shown the causal role of EF in modulating cravings for, and consumption of, high-calorie food (Hall, 2016). Similarly, EF, especially planning ability, has been shown to be helpful in predicting the breakfast eating habits of emerging adults (mean age = 19.46 years) by moderating the association between intention and behavior (Wong & Mullan, 2009). It is important to note that in young adults (mean age = 21.13 years) uncontrolled eating and other maladaptive eating behaviors are associated with obesity (Calvo et al., 2014).

Obesity is, in turn, related to reduced EF (Calvo et al., 2014). An extensive review of the literature revealed that obese children performed significantly worse than non-obese children in various tasks measuring EF and, specifically, inhibitory control (Reinert et al., 2013). Higher body mass index (BMI) in adolescents was strongly associated with deficits in the orbitofrontal cortex, an area that, along with the limbic system, is associated with the inhibitory dimension of EF (Reinert et al., 2013). Further, orbitofrontal cortex volume has been shown to be positively associated with high quality food choices and performance on measures of EF (Reinert et al., 2013). Along the same lines as these findings, in adults, disinhibition has been shown to be significantly correlated with BMI, specifically, obesity has been associated with disinhibited eating, decreased cortical gray matter volume, and lower performance on cognitive assessments (Maayan et al., 2012). Similar to these findings in adults, in adolescents, obese individuals had significantly higher ratings of disinhibition, lower orbitofrontal cortex volume and lower performance on cognitive tests compared to non-obese adolescents (Maayan et al., 2012). As further support, a review of the literature by Fitzpatrick and colleagues (2013) showed that obese individuals demonstrate impaired performance on behavioral tasks aimed at examining EF compared to healthy weight individuals, although some inconsistencies in these findings exist within the literature. In summary, it is clear that obese individuals show difficulties in a number of aspects of EF, such as decision-making, planning and problem-solving when compared to healthy-weight controls (Fitzpatrick et al., 2013). However, these ideas have not been well-studied in adolescents.

### *Aspects of EF and Eating*

Many aspects of EF have yet to be thoroughly studied in relation to eating. However, we do have information about eating and inhibitory control, which is one of three core components



comprising EF. Inhibitory control has been shown to be associated with unhealthy eating in young adults (mean age = 20.20 years), such that poor inhibitory control predicts unhealthy snack food intake (Kakoschke et al., 2015). For example, poorer inhibitory control is related to higher saturated fat intake in young adults (mean age = 19.79 years; Allom & Mullan, 2014). Furthermore, during young adulthood, response inhibition, a measure of impulsivity, has been linked to food intake (as measured by caloric intake), showing the connection between inhibitory control and eating (Nederkoorn et al., 2009). There may in fact be a feedback loop when it comes to eating and inhibitory control. Specifically, excess energy intake can contribute to overweight or obesity and research has shown that obese adults (ages 18-65) are more impulsive than lean people and that impulsive people eat more than less impulsive people (Lawrence et al., 2015; Nederkoorn et al., 2009). Indeed, obese individuals report higher levels of uncontrolled eating and exhibited slower performance on an inhibitory control task (Calvo et al., 2014). However, it is important to note that because much of the research examining the relationship between obesity and EF is cross-sectional rather than longitudinal, the question of directionality remains to be answered (Reinert et al., 2013).

However, training individuals to inhibit simple motor responses (key presses) to highly energy dense food pictures reduced their food intake in laboratory studies (Lawrence et al., 2015). This result also carries over to real-world eating, such that participants who were trained to inhibit their response to food in an online task showed significant reductions in daily energy intake, rated liking of high energy density foods less and significant weight loss (Lawrence et al., 2015). This means that eating may be modifiable with inhibitory control training.

In line with these findings, it has been suggested that inhibitory control plays an important role in dietary self-restraint in adults (Guerrieri et al., 2009; Hall, 2012; Hall & Fong, 2013; Houben & Jansen, 2011; Nederkoorn et al., 2009; Rotenberg et al., 2005) and also that

enhancements in inhibition induced by acute aerobic activity may facilitate self-control (i.e., inhibition) in the dietary domain (Lowe et al., 2014). One study that supports this idea randomly assigned thirty-four undergraduate students to one of three exercise conditions: (1) minimal exercise; (2) moderate intensity exercise, which was defined at 30% heart rate reserve; or (3) vigorous intensity exercise (50% heart rate reserve; Lowe et al., 2014). Participants' heart rates were continuously monitored during their bout of exercise and participants were asked about their current hunger level (Lowe et al., 2014). After their bout of exercise, the participants took standardized EF tasks then a bogus "taste test" of three snack foods (milk chocolate, regular potato chips and flavored potato chips) and two control foods (dark chocolate and soda crackers) in which they were instructed to consume as much as they would like (Lowe et al., 2014). The researchers covertly measured the amount of food that was consumed. Concerning the effect on EF, the results of this study showed a significant main effect of treatment condition on the Stroop task performance, but not on the Go/No-Go and Stop Signal task performance (Lowe et al., 2014). Concerning the effect on eating, there was no significant difference in energy intake following the exercise, which was consistent with a few other studies of adults (Deighton et al., 2012; George & Morganstein, 2003; King et al., 1997a; King et al., 1997b; Lowe et al., 2014). This study supported the idea that aerobic exercise improves EF in general but shows the continuing lack of a conclusion about its effect specifically on dietary inhibition and dietary behavior (Lowe et al., 2014).

### ***The Impact of Exercise***

The impact of exercise frequency on cognitive functioning, including aspects of EF such as cognitive flexibility, has been well studied in adults. Specifically, one study explored the impact of exercising 0-2 days a week (minimal aerobic exercise), 3-4 days a week (moderate

aerobic exercise) or 5-7 days a week (high aerobic exercise) on cognition and frontal lobe activity in 91 healthy adults ages 18 to 70 over a 10-week period (Masley et al., 2009). The three exercise groups were compared, and results showed improvements in mental speed ( $p = .03$ ), attention ( $p = .047$ ), and cognitive flexibility ( $p = .002$ ) with increased exercise frequency (Masley et al., 2009). However, once the researchers controlled for age, gender, education, and changes in psychomotor speed, just cognitive flexibility showed significant improvements ( $p = .002$ ; Masley et al., 2009). This study shows that increasing frequency of aerobic exercise is associated with cognitive flexibility, a measure of EF (Masley et al., 2009).

Further confirming these findings, a recent meta-analysis showed that even acute bouts of exercise positively benefited cognition with a small but significant and reliable effect size ( $ES = 0.20$ ,  $p < .04$ ; Lambourne & Tomporowski, 2010). However, in terms of EF, results have been varied: some studies have shown moderate-to-large effects for adults (Chang & Etnier, 2013; Chang et al., 2011; Pontifex et al., 2009), while other have shown no benefit of exercise on EF (Coles & Tomporowski, 2008; Tomporowski & Ganio, 2006). These inconsistencies may be due to a variety of factors, including study design, aspect of EF being studied, and type of exercise (Lowe et al., 2014).

Exercise may result in a number of positive outcomes such as reducing symptoms of depression and anxiety, reducing diastolic and systolic blood pressure, triglycerides, fasting glucose, and reducing risk for cardiovascular disease, dyslipidemia, hypertension, metabolic syndrome, diabetes mellitus, abdominal obesity, reducing waist circumference and increasing skeletal muscle mass, positive attitude and quality of life (Agarwal, 2012; Craft & Perna, 2004; DiLorenzo et al., 1999; Durstine et al., 2001; Hagberg et al., 2000; Ivy, 1997; King et al., 2012; Lampman & Schteingart, 1991; North et al., 1990; Ross & Bradshaw, 2009; Lee et al., 2008;

Stice et al., 2006; Takata et al., 2010). A systematic review showed that when combined with changes in diet, using exercise in a weight loss intervention helped to reduce obesity (Stice et al., 2006). However, it still remains to be seen how much exercise is necessary to see these aforementioned benefits in teens. It has also been argued that longer exercise bout will generate increased appetite and subsequent increased calorie consumption (i.e., compensatory eating) but there may be considerable individual variation in this and a number of studies have not supported this theory, instead finding that individuals tend not to compensate for the energy expended during exercise by altering food intake (Hopkins et al., 2010; Hopkins et al., 2014; King et al., 2012; Mayer, 1953; Schubert et al., 2013; Tsofliou et al., 2003; Unick et al., 2010). Specifically for 30 versus 60 minutes of exercise, calorie consumption following exercise may not vary. Indeed, Rosenkilde et al. (2012) found that after 13 weeks accumulated energy balance between individuals who exercised for either 30 or 60 minutes did not differ, even though energy expenditure was twice that in the 60-minute exercise group.

It is also crucial to point out that one of the biggest obstacles to exercising for adolescents is time. Indeed, when asked what their top barriers to exercising were, adolescents said, “having no time to exercise” and “wanting to do other things with my time” were their top barriers to exercising (Tergerson & King, 2002). There has not been ample evidence thus far to show that 30 or 60 minutes of exercise is superior for teens, but one study found that just 30 minutes of exercise still resulted in increased cognition for teens (Harveson et al., 2016). Thus, if 30 minutes of exercise is more attainable for teens since it is less demanding on their schedules, and if a shorter bout of exercise can provide similar benefits to the individual (such as disease prevention and health promotion) then this would provide valuable information to know (Sothorn et al., 1999). Thus, it is imperative to provide evidence that provides information about the impact of exercise

bout as related to eating and EF in order to inform policy, assist clinicians and doctors and help teens and their families know how much exercise to recommend for teens.

### **The Current Study**

The current study aimed to increase the understanding about how EF/food-specific inhibition and calorie consumption and are related, as well as how exercise duration affects these relationships. This research answers the questions “How does EF affect calorie consumption and food-specific inhibition in adolescents?” and “How does exercise duration affect these relationships?”. Though associations between exercise and eating have been studied previously, duration of exercise bout has yet to be explored sufficiently. Thus, this study aimed to fill in the holes in the current body of research by examining the associations between EF/food-specific inhibition and eating. Understanding whether exercise bout duration influences food-related executive functioning may influence clinical recommendations for exercise duration. Further, this topic has not been extensively studied in a non-clinical, adolescent population which the current study does.

In terms of a single, short bout of exercise, the current research outlined previously showed that 30 minutes of exercise was sufficient to increase food-specific inhibition and may not increase subsequent calorie consumption. It is also more attainable for individuals since it requires less of a time commitment. In previous research with similar intensity levels, individuals who maintained sub-maximal aerobic intensity (20-80% of maximum heart rate) for an exercise bout around 30 minutes showed improvement in EF and reaction time (Brisswalter et al., 2002; ElleMBERG & St. Louis-Deschênes, 2010; Kamijo et al., 2004; Tomporowski, 2003). Though the findings are not completely clear, it has also been postulated that longer exercise bout (i.e., 60 minutes in the case of this study) will lead to increased calorie consumption, while shorter

exercise duration may not (Hopkins et al., 2010; Hopkins et al., 2014; King et al., 2012; Mayer, 1953; Tsofliou et al., 2003; Schubert, et al., 2013; Unick et al., 2010). Based on these findings, my hypotheses were based on the idea that 30 minutes of exercise would benefit food-related inhibition (accuracy and reaction time on a food Go/No-Go task) and healthy eating (eating less of a high calorie food). However, this current study was novel in that we are looking at how the interaction of EF and exercise duration impacted food-specific inhibition and calorie consumption, something that had not yet been studied. Thus, my hypotheses for the interaction effects were based on the idea that 30 minutes of exercise (rather than 60) would benefit food-related inhibition and healthier eating.

### **Study Aims/Hypotheses**

#### ***Aim 1***

The first aim of this study was to examine the association between EF and calorie consumption and to determine whether exercise duration influenced this association. This aim was evaluated using three separate models corresponding to the three indicators of EF (See Table 1 for model descriptions). The first model used the BRIEF2-SR GEC as the independent variable. The second model used the three BRIEF2-SR index scores as the independent variables. The third model used seven BRIEF2-SR scale scores as the independent variables. My hypotheses were informed by previous research which suggested that EF modulates the consumption of high calorie foods and that we may see these effects after 30 minutes of exercise. It is important to note that higher scores on the BRIEF2-SR indicated higher levels of EF dysfunction, whereas lower scores on the BRIEF2-SR indicated lower levels of EF dysfunction. Thus, lower scores on this measure are indicative of superior EF.

**Hypothesis 1.** Because greater EF has been shown to be associated with lower calorie consumption of high calorie foods in previous research, I hypothesized that there would be a positive association between measures of EF (BRIEF2-SR, GEC, index scores, scale scores) and calorie consumption.

**Hypothesis 2.** I hypothesized significant interaction effects of EF\*exercise duration on calorie consumption (specifically, the BRIEF2-SR GEC\*exercise duration, index scores\*exercise duration and scale scores\*exercise duration interactions). I predicted that there would be a significant association between EF and calorie consumption in the 30-minute exercise condition but not in the 60-minute exercise condition. This hypothesis was derived from research suggesting that shorter exercise bout may lead to better regulation of high calorie food consumption while not leading to compensatory eating.

### *Aim 2*

The second aim of this study was to evaluate whether EF was associated with food-specific inhibition and whether this association was affected by exercise duration bout. This aim was evaluated with six statistical models corresponding to the three indicators of EF: (1) the BRIEF2-SR GEC, (2) the three BRIEF2-SR index scores, and (3) the seven BRIEF2-SR scale scores and the two measures of food-specific inhibition (food-specific Go/No-Go accuracy and mean reaction time). While previous research has examined the influence of exercise on EF and inhibition, limited research has explored the association between EF and food-specific inhibition.

**Hypothesis 3.** Because extant research has shown an association between EF and food-specific inhibition, I hypothesized an inverse association between measures of EF (BRIEF2-SR GEC, index scores, scale scores) and food-specific Go/No-Go accuracy and a positive association between EF scores and mean reaction time (RT).

**Hypothesis 4.** For the measures of EF\*exercise duration interaction effects (specifically, the BRIEF2-SR GEC\*exercise duration, index scores\*exercise duration and scale scores\*exercise duration interactions), I predicted a significant association between EF and food-specific inhibition (Go/No-Go accuracy and RT) in the 30-minute exercise condition but no such effect in the 60-minute exercise condition. This hypothesis was derived from literature suggesting that short exercise bouts produce improvements in reaction time and some aspects of EF (which we may compare to food-specific inhibition) which are not present for longer bouts of exercise.

## Method

### Participants

Thirty-four normal weight (BMI percentile  $\geq 5$  and  $< 85$ ) adolescent participants (ages 12 to 18) were recruited for this study (53% female, M age = 14.76, SD = 1.60). This study was part of a larger study that looked at the impact of exercise duration on brain response to food images and dietary behavior. Participants were recruited using flyers distributed at high schools in the Utah Valley area during school lunch times and through parents from flyer distribution at Brigham Young University. Eligibility requirements were (1) the adolescent was between ages 12 and 18, (2) the adolescent's BMI was in the normal weight category (BMI percentile  $\geq 5$  and  $< 85$ ), (3) the adolescent's parents consented to their child's participation if under the age of 18, (4) the adolescent was able to exercise at a moderate intensity for up to 60 minutes as determined by the Physical Activity Readiness Questionnaire (Thomas et al., 1992), and (5) the adolescent was able to participate in magnetic resonance imaging (MRI), as determined by an MRI screening form. Exclusion criteria included cardiovascular, metabolic, or pulmonary disorders, use of weight loss medication, history of bariatric surgery, use of medications that affect salivation (e.g.,



antihistamines, antidepressants), binge eating, left-handedness, psychiatric conditions (e.g. epilepsy, traumatic brain injury, schizophrenia, bipolar disorder), food allergies, sleep disorders and standard MRI contraindications (e.g., metallic implants, pregnancy, claustrophobia).

Individuals were also excluded if they were deemed aerobically “trained”, which was operationally defined as engaging in moderate to vigorous physical activity more than 3 hours per week. Participants were compensated up to \$50 (\$25 per exercise/imaging session) via Amazon gift card after they completed the study.

### **Procedure**

This study was a within-subjects, two-phase crossover experimental design (participants came in twice to the lab to participate in each condition.) Written consent/assent was obtained for the participants. Then, participants were randomly assigned to order of experimental condition at their first exercise/imaging session. The two experimental conditions were identical except for the exercise bout duration (30 vs. 60 minutes). Randomization was completed using a computer-based random number generator. Measures were identical between the two exercise sessions.

After a 4-week washout period, participants completed the second phase of the study, alternating to the opposite exercise protocol (i.e., those completing the 30-minute exercise duration condition on their first visit completed the 60-minute exercise duration condition on their second visit). The four-week interval between assessments was to ensure the female participants were in the same menstrual cycle phase during both assessments. Participants were asked to fast (though water consumption was not restricted) for 6 hours before their exercise sessions. They were also instructed to avoid caffeine consumption within a 24-hour period before their appointment time. Participants were asked for verbal confirmation of compliance with these procedures prior to the assessment.

At an initial visit before the exercise visits, parental consent and adolescent assent were obtained and participants were randomized to experimental order (with either the 30-minute or 60-minute exercise duration occurring first). Participants' parents were asked to complete three questionnaires at the initial appointment (Facts About You, Health History Questionnaire, and Physical Activity Readiness Questionnaire) to assess participant eligibility for the study. Participants also completed the BRIEF2-SR at this appointment.

At the exercise visits, participants were then equipped with a Polar H7 heart rate monitor to allow for continuous monitoring of heart rate, with continuous heart rate displayed on a synced device (Plews et al., 2017). The participant's resting heart rate was obtained while having the participant sit. From this, the participant's target heart rate range was calculated using the following equation:  $(220 - [\text{participant age}] * 0.50)$  to  $(220 - [\text{participant age}] * 0.70)$  (Center for Disease Control and Prevention, 2020). This formula was used to confirm that exercise intensity was consistent across participants. In a private room at the Brigham Young University MRI research facility, participants were instructed to jog/run on a treadmill at a moderate intensity while keeping their heart rate within 50-70 percent of their maximum heart rate. Participants were told their target heart rate range and how to adjust the intensity of the treadmill to stay within it (i.e., based on whether they were above or below this range to adjust the speed or incline of the treadmill). The participant engaged in either 30 or 60 minutes of physical activity, depending on their initial exercise duration condition. Researchers were present for the duration of the exercise to ensure the participant stayed within their target heart rate range. The participants heart rate was monitored for the duration of their exercise, and any deviations from the target heart rate range of 30 seconds or more were noted. A water bottle was provided for the participants and weighed before and after their bout of exercise.

Participants completed a Go/No-Go task developed by Batterink and colleagues (2010) examining inhibition-related neural activation while viewing food images. Two functional runs consisting of 48 trials per run were conducted. For each trial, an image of a food (vegetable or dessert) was presented for 500 milliseconds. Trials were separated by a fixation cross, which was presented for intervals between 7 and 9 seconds between trials (in order to allow for hemodynamic recovery). Participants were instructed to respond with a button press to healthy foods (vegetables) and withhold a button press when viewing unhealthy foods (desserts). Participants were instructed to respond as quickly and accurately as possible. Reaction times were measured using a fiber-optic response system. Trials were presented in a semi-random order with unhealthy foods appearing with equal frequency after 1, 2 and 3 healthy food presentations. Stimuli for these procedures was displayed using E-prime software with images displayed on an MRI-compatible screen located at the end of the scanner. Participants viewed the monitor using a mirror attached to the head coil.

After the Food Go/No-Go task (approximately 1-hour post-exercise) participants were instructed to complete the Trails A portion of the Trails A & B. They were then told that there needed to be a 20-minute delay before the Trails B portion of the test was given. A large pizza buffet was prepared for the participant, with the total weight of each box of pizza weighed to the nearest gram. Participants were then taken to a room and left alone with the pizza buffet. They were instructed to eat as much as they would like and that the researchers would check in on them after 20 minutes, at which time they could have more time to eat the pizza if they wished. Participants were seated in front of the buffet and allowed to eat for at least 20 minutes, with participants indicating that they were finished after this time. Participants were seated facing away from cameras and all trash cans were removed from the room. After participants left the

room, the pizza was reweighed to the nearest gram and pre-post weight difference was used to determine caloric consumption. Participants were then instructed to complete the Trails B portion of the Trails A & B.

## **Measures**

### ***Executive Function***

Participants completed the Behavior Rating Inventory of Executive Functioning, Second Edition Self-Report Form (BRIEF2-SR) at the baseline assessment to measure their executive functioning (purposeful, goal-oriented, problem-solving behavior; Gioia et al., 2000a). The BRIEF2-SR is a 55-item inventory used to assess impairment in EF for 11-18-year olds.

Participants were instructed to complete all items on the form indicating whether the item applied to them “Never”, “Sometimes” or “Often”. Higher scores on this measure indicate greater EF dysfunction. The BRIEF2-SR provides a Global Executive Composite (GEC), which indicates the overall executive functioning of the adolescent. It also provides seven clinical scales: Inhibit (i.e., “I don’t think of consequences before acting”, “I am impulsive (I don’t think before doing)”), Self-Monitor (i.e., “I don’t notice when my behavior causes negative reactions until it’s too late”, “I have a poor understanding of my own strengths and weaknesses (I try things that are too difficult or too easy for me)”), Shift (i.e., “I have trouble accepting a different way to solve a problem with things such as schoolwork, friends or tasks”, “I get stuck on one topic or activity”), Emotional Control (i.e., “I have outbursts for little reason”, “I am easily overwhelmed”), Task Completion (i.e., “I have difficulty finishing a task on my own”, “I have good ideas but do not get the job done (I lack follow-through)”), Working Memory (i.e., “I forget to hand in my homework, even when it’s completed”, “I have a short attention span”), and Plan/Organize (i.e., “I have difficulty finding things (such as clothes, glasses, shoes, books or pencils)”, “I don’t plan

ahead for future activities”). It also includes three BRIEF2-SR index scores: the Behavioral Regulation Index (BRI) which is made up of the Inhibit and Self-Monitor scales, the Emotional Regulation Index (ERI) which is comprised of the Shift and Emotional Control scales, and the Cognitive Regulation Index (CRI) which is comprised of the Task Completion, Working Memory and Plan/Organize scales. These scale scores and index scores are meant to provide a more detailed look at specific aspects of EF and can be used for clinical purposes. Additionally, the BRIEF2-SR uses three validity scales: Infrequency, which made up of 3 items (i.e., “I cannot find the front door of my home”, “I forget my name”), Negativity, which is made up of 8 items (i.e., “I am unaware of my behavior when I am in a group”, “I have problems waiting my turn”) and Inconsistency, which compares eight pairs of responses (i.e., “I get upset over small events” and “I overreact”). The BRIEF2 has reliability coefficients above .90 for Parent and Teacher Forms and above .80 for the Self-Report Form (Gioia et al., 2000b). For the sample used in this study, the reliability coefficients (Cronbach’s alphas) were as follows: for the BRIEF2-SR index scores  $\alpha = .76$  and for the BRIEF2-SR scale scores  $\alpha = .809$ , both of which are acceptable. Additionally, construct and criterion validity have been established for this measure in clinical pediatric and adolescent populations (Donders et al., 2010; Toplak et al., 2009). Findings support the idea that the BRIEF uses a fractioned, multi-component view of of EF when examining the different subscales (Gioia et al., 2002).

### ***Food-specific Inhibition (Accuracy and Reaction Time)***

Adolescents completed a food-specific Go/No-Go task developed by Batterink and colleagues (2010) to assess food-specific inhibition. An image of a vegetable (go trial) or a dessert (no-go trial) were presented and the adolescent was instructed to respond with a button

press and to avoid pressing the button when shown desserts. Both accuracy and reaction time were derived from this task and used in primary study analyses. Participants' accuracy in withholding a response to unhealthy food stimuli (i.e., a higher percentage represents better inhibition) and their reaction time (faster reaction time on their correct go responses indicates better inhibition) were used to determine their food-specific inhibition. I calculated accuracy by determining the percentage of correct no/go responses for each participant during each session. In order to determine reaction time, I calculated the average reaction time for each participant during each session for the correct go responses.

This novel task has previously been shown to be valid (Batterink et al., 2010). Specifically, Nakata et al. (2008) found that the food-specific Go/No-Go task successfully engaged the response inhibition system, recruiting the neural areas implicated in inhibitory control. This task has been shown to elicit greater activation in the superior frontal gyrus and inferior frontal gyrus (regions implicated in response inhibition) during no-go trials relative to go trials (Nakata et al., 2008). Food-specific Go/No-Go tasks have been shown to reflect self-control in the context of food cues and to evaluate possible deficits in an individual's ability to self-regulate since participants showed similar performance (i.e., overall accuracy and reaction times) when compared to other Go/No-Go tasks (Teslovich et al., 2014). To further support this paradigm as a way to assess response to food images, Batterink and colleagues (2010) showed that areas associated with reward value of food (the insula and frontal operculum) were activated more in the dessert (no-go) condition relative to the vegetable (go) condition, showing that desserts were indeed viewed as more appetizing and rewarding than vegetables. In order to avoid ambiguity, images were omitted that did not fit into the vegetable or dessert categories. Further, participants pre-scan palatability ratings of the food were consistent with these findings such that desserts

were rated as significantly more appetizing than vegetables (Batterink et al., 2010). Taken together, these findings support the validity of this new paradigm. In terms of reliability, one study showed a stop-signal reaction time test-retest reliability of 0.65 in two sessions that were 8.6 days apart (Weafer et al., 2013). Although there has not been extensive reliability and validity testing of this newer food-specific Go/No-Go paradigm, other similar Go/No-Go tasks have shown good support for test-retest reliability, ranging from  $r=.57$  ( $p < .0001$ ) to  $r=.83$  ( $p < .0001$ ; Langenecker et al., 2007). Also, modest convergent validity with other tests of EF has been established (up to a correlation of  $.51$  ( $p < .01$ ) with a digit span task, a simple measure of EF), though the complexity of these tests may vary, perhaps making them difficult to compare (Langenecker et al., 2007).

### ***Post-exercise Food Consumption***

Post-exercise food consumption was operationalized as the number of calories eaten during a single *ad libitum* buffet session after each exercise bout. Specifically, caloric intake was measured using a pizza buffet, where the participants were given 20 minutes to consume as much pizza as they desired, after which they could elect to spend more time eating if they wished. The pizza boxes were weighed to the nearest gram before and after the participant ate in order to calculate caloric consumption. This buffet-type measure is commonly used for measuring spontaneous energy and macronutrient intake and has been shown to be a reliable method for assessing macronutrient preferences in a laboratory setting (Arvaniti et al., 2000). In order to establish validity, a few studies have investigated the intra-individual variation in intake between sessions of *ad libitum* buffet-style meals (Arvaniti et al., 2000). Specifically, between two identical *ad libitum* buffet-type meals, results showed significant intraclass correlations (ICC) for energy (ICC = .97,  $p = .0001$ ), lipid (.97,  $p = .0001$ ), carbohydrate (ICC = .92,  $p = .0003$ ), and

protein (ICC = .82,  $p = .0072$ ) intake (Arvaniti et al., 2000). As further support, between three ad libitum buffet sessions, another study showed no significant difference between total energy intake (ICC = .99), percent of intake related to fat (ICC = .96), carbohydrates (ICC = .81), and protein (ICC = .38) between the three sessions. Thus, this type of buffet showed excellent reliability for total energy intake and fat intake and good reliability for carbohydrate intake. These findings support the idea that an ad libitum buffet to assess energy intake, such as in a lunch setting, has shown high reproducibility (Gregersen et al., 2008). It is important to note that there may have been an effect of measurement occasion order on calorie consumption. A one-sample t-test indicated that for their first visit, participants ate an average of around 500 calories, while for their second visit they consumed around 475 calories on average. There was a significant difference ( $p = .000$ ) between the initial visit ( $M = 502.868$ ,  $SD = 180.595$ ) and the second visit ( $M = 475.350$ ;  $SD = 180.032$ ).

### **Data Analytic Plan**

Since measurements were clustered within each participant with predictors at both within-subjects and between-subjects levels, I used a generalized linear mixed models (GLMM) package in SPSS to estimate linear mixed models in order to analyze study hypotheses. I used a normal error distribution and an identity link. I used this analysis because it allows us to tell if there were differences in the outcome variables based on the independent variable\*condition interactions. It also allows us to look at different levels (i.e., within and between subjects) while assuming a shared error term, which is able to account for the within-participant design of this study. This allows us to look at participants in comparison to themselves, rather than to other individuals in a different group. There were two main research questions: (1) the impact of EF and exercise duration on calorie consumption and (2) the impact of EF and exercise duration on



food-specific inhibition (accuracy and reaction time on a Food Go/No-Go task). The independent variables were exercise duration, EF, age, BMI percentile and gender. The dependent variables were food consumption and accuracy and reaction time (the two aspects of food-specific inhibition). Coefficients for all statistical analyses will be presented as unstandardized beta coefficients ( $B$ ) and standardized beta coefficients ( $b$ ; See Tables 5 and 7). Age, sex, and BMI percentile were included as covariates in all analyses, controlling for potential effects of these variables. For a full explanation of the 9 models that were used (with IVs, DVs and covariates used in each model), refer to Table 1. When there was a significant interaction of exercise duration and a level 2 predictor (a dependent variable or a control variable), I ran a simple slopes analysis to determine which exercise duration determined the condition-specific effect. Since the default for the output when running a linear mixed model is when the condition equals 0 (which was the 30-minute exercise duration), I first needed to recode the exercise duration variable into a new variable, exchanging the 0 and 1. Then, I replaced my exercise duration variable with the newly recoded variable in my syntax and ran the analysis. I then compared this to the original analysis which will allow me to determine which condition caused the effect. In order to reduce the risk of Type 1 error, I used Bonferroni corrections when considering pair-wise comparisons.

### ***Data Cleaning***

In order to clean the data, I first checked for normality and accounted for it as described below. Then I accounted for missingness and outliers as described below.

### ***Normality***

In order to test for normality, I used a Shapiro-Wilk Test (although it is important to note this test can have limitations when used with a small sample size) and graphically represented the data. If needed, I used a transformation to make the data normal. Emotional Control and

reaction time were both non-normally distributed. I used a Log10 transformation on both Emotional Control and reaction time to reduce skewness. After the transformations, all data were deemed sufficiently normal to run the planned analyses.

### ***Validity***

Additionally, to ensure validity I used the three validity scales included in the BRIEF2-SR to ensure that the scores are valid for EF. The Inconsistency scale measured if the respondent answered in a consistent manner. The Negativity Scale measured the extent to which the respondent answered the items in an unusually negative manner. The Infrequency Scale measured the extent to which the participant endorsed unlikely events. Per the BRIEF2-SR manual, if the participant's answers on the BRIEF2-SR indicated that their data should not be included because of validity issues, I did not include it in the analyses. However, no answers were excluded since they all met the criteria for being included by the standards of this measure.

### ***Power Analysis***

Since the analyses I performed were post-hoc, a power analysis does not provide additional information not already represented in the statistical tests I used. Also, power analyses usually focus on a single or few tests, not the dozens of parameters and complex relationships across models such as found in this study. Although power analyses often give useful information when planning a study (such as sample sizes needed to detect statistical significance and cost-benefit ratios), in a post-hoc study such analyses are conceptually flawed (Zhang et al., 2019). This is because most research studies are conducted from a random sample, but once data are collected, the random component of the study disappears (Zhang et al., 2019). Essentially, performing a post hoc power analysis would be “attempting to identify population-level parameters with sample-specific statistics”, which makes no conceptual sense as well as yielding

“quite different power estimates that are difficult and can be misleading” (Zhang et al., 2019, p.3). Such tests do not show true power for detecting statistical significance since post hoc power estimates are “generally variable in the range of practical interest and can be very different from the true power” (Zhang et al., 2019, p.4). Thus, power analyses were not included for this study, since doing such would be both conceptually flawed and analytically misleading. However, standardized beta coefficients were included.

### ***Missing Data***

In GLMM, missing data is dealt with in the following way: all available data is used on the dependent variable and listwise deletion is used on any independent variables. I had four instances of missing data for the dependent variables. I did not have any missing data for the independent variables.

### ***Outliers***

If any outliers were present, I fenced them by using the 2-interquartile range method. Within the independent variables, there were six moderately high outliers that were fenced. Within the dependent variables, there were two moderately low outliers and two extremely low outliers (for accuracy) and six moderately high outliers (for reaction time) that were fenced.

## **Results**

### **Sample Characteristics**

The final sample of this study consisted of 34 adolescents (53% female) recruited from local high schools in Utah County, Utah and from flyers distributed to faculty of Brigham Young University (See Table 2 for full demographic information; see Table 3 for full descriptive statistics for primary measures). The mean age was age = 14.76 years (SD = 1.60). The mean height was 65.5 inches (SD = 3.97) and mean weight was 124.46 pounds (SD = 25.05). The

mean BMI was 20.19 (SD = 2.48). Mean BMI percentile was 51.85 (SD = 24.21). Average family monthly income was \$7,997 (SD = \$9,247). The sample was 84.84% White (Not Hispanic), 11.77% Hispanic and 5.88% Other.

## **Hypothesis 1**

### ***Main Effects of BRIEF2-SR GEC on Calories***

I hypothesized that there would be a positive association between BRIEF2-SR GEC and calorie consumption. When accounting for covariates (gender, age, BMI percentile), GEC was not significantly associated with calories. Only gender was significantly related to calories, with males consuming more calories than females ( $B = -204.66$ , 95% CI  $[-308.05, -101.260]$ ,  $p = .000$ ,  $SE = 51.63$ ; see Table 6 for full results of main effects significance testing with unstandardized betas and Table 7 for standardized betas). There was no change in this analysis when outliers were included.

### ***Main Effects of BRIEF2-SR Index Scores on Calories***

I hypothesized that there would be a positive association between the BRIEF2-SR index scores and calorie consumption. None of the BRIEF2-SR index scores (BRI, CRI, ERI) were significantly related to calories. There was no change in this analysis when outliers were included.

### ***Main Effects of BRIEF2-SR Scale Scores on Calories***

I hypothesized that there would be a positive association between the BRIEF2-SR scale scores (Emotional Control, Inhibit, Plan Organize, Working Memory, Task Completion, Self-Monitor, Shift) and calorie consumption. When accounting for covariates (gender, age, BMI percentile), only Shift was significantly associated with calorie consumption ( $B = -8.422$ , 95%

CI [-14.122, -2.722],  $p = .005$ ,  $SE = 2.841$ ). There was no change in this analysis when outliers were included.

## **Hypothesis 2**

### ***Interaction between BRIEF2-SR GEC and Exercise Duration on Calories***

I predicted that exercise duration would affect the association between GEC and calorie consumption, such that this association would be significant for the 30-minute exercise duration but not for the 60-minute condition. The interaction between exercise duration and GEC predicting calorie consumption (controlling for gender, age, and BMI percentile) was not significant ( $p > .05$ ; see Table 4 for full results of interaction effects significance testing with unstandardized betas and Table 5 for standardized betas.) There was no change in this analysis when outliers were included.

### ***Interaction between BRIEF2-SR Index Scores and Exercise Duration on Calories***

I predicted that exercise duration would affect the association between the BRIEF2-SR index scores and calorie consumption, such that this association would be significant for the 30-minute exercise duration but not the 60-minute condition. The interactions between BRIEF2-SR index scores and exercise duration predicting calorie consumption (controlling for gender, age, and BMI percentile) were non-significant ( $p > .05$ ). There was no change in this analysis when outliers were included.

### ***Interaction between BRIEF2-SR Scale Scores and Exercise Duration on Calories***

I predicted that exercise duration would affect the association between the BRIEF2-SR scale scores and calorie consumption, such that this association would be significant for the 30-minute exercise duration but not the 60-minute condition. The interactions between BRIEF2-SR scale scores and exercise duration predicting calorie consumption (controlling for gender, age,

and BMI percentile) were non-significant. There was no change in this analysis when outliers were included.

### **Hypothesis 3**

#### ***Main Effects of BRIEF2-SR GEC on Accuracy***

I hypothesized an inverse association between GEC and accuracy. When accounting for covariates (gender, age, BMI percentile), GEC was significantly related to accuracy ( $B = -.003$ , 95% CI  $[-.007, .000]$ ,  $p = .033$ ,  $SE = .0016$ ). However, since the confidence interval includes 0, this statistic should be interpreted with caution. There was no change in this analysis when outliers were included.

#### ***Main Effects of BRIEF2-SR Index Scores on Accuracy***

I hypothesized an inverse association between the BRIEF2-SR index scores and accuracy. ERI (Emotional Regulation Index) was significantly related to accuracy when accounting for covariates ( $B = -.003$ , 95% CI  $[-.005, -.001]$ ,  $p = .002$ ,  $SE = .0009$ ). When outliers were included in this analysis, ERI was still significant ( $B = -.004$ , 95% CI  $[-.006, -.001]$ ,  $p = .014$ ,  $SE = .0014$ ), but BRI was also significant, although the confidence interval included 0 ( $B = -.003$ , 95% CI  $[-.007, .000]$ ,  $p = .033$ ,  $SE = .0016$ ).

#### ***Main Effects of BRIEF2-SR Scale Scores on Accuracy***

I hypothesized an inverse association between the BRIEF2-SR scale scores and accuracy. When accounting for covariates, four of the scale scores were significantly related to accuracy: Emotional Control ( $B = -.002$ , 95% CI  $[-.004, .000]$ ,  $p = .014$ ,  $SE = .0009$ ), Inhibit ( $B = -.002$ , 95% CI  $[-.004, -.2.618E-5]$ ,  $p = .047$ ,  $SE = .0011$ ), Plan Organize ( $B = .004$ , 95% CI  $[.002, .007]$ ,  $p = .001$ ,  $SE = .0012$ ) and Task Completion ( $B = -.002$ , 95% CI  $[-.004, .000]$ ,  $p = .015$ ,  $SE = .0007$ ). When outliers were included in this analysis, Inhibit ( $B = -.003$ , 95% CI  $[-.004, -.001]$ ,

$p = .005$ ,  $SE = .0009$ ) and Plan Organize ( $B = .004$ , 95% CI [.002, .006],  $p = .001$ ,  $SE = .0011$ ) were still significant, but Emotional Control ( $B = -.002$ , 95% CI [-.005, 0],  $p = .104$ ,  $SE = .0012$ ) and Task Completion ( $B = -.001$ , 95% CI [-.003, .001],  $p = .325$ ,  $SE = .0009$ ) were no longer significant.

#### ***Main Effects of BRIEF2-SR GEC on Reaction Time***

I hypothesized a positive association between GEC and RT. GEC was not significantly associated with RT. Only gender was significantly related to reaction time ( $B = -133.66$ , 95% CI [-224.42, -42.89],  $p = .005$ ,  $SE = 45.31$ ). There was no change in this analysis when outliers were included.

#### ***Main Effects of BRIEF2-SR Index Scores on Reaction Time***

I hypothesized a positive association between the BRIEF2-SR index scores and RT. When accounting for level 2 predictors (BRI, CRI, ERI, gender, age, BMI percentile), only BRI was significantly related to reaction time ( $B = -.9.786$ , 95% CI [-16.780, -2.792],  $p = .007$ ,  $SE=3.486$ ). There was no change in this analysis when outliers were included.

#### ***Main Effects of BRIEF2-SR Scale Scores on Reaction Time***

I hypothesized a positive association between the BRIEF2-SR scale scores and RT. Only Inhibit was significantly related to reaction time ( $B = -.6.184$ , 95% CI [-12.304, -.063],  $p = .048$ ,  $SE = 3.037$ ). When outliers were included in this analysis, Inhibit was no longer significant ( $B = -3.382$ , 95% CI [-10.533, 3.769],  $p = .347$ ,  $SE = 3.5621$ ) and Self Monitor became significant ( $B = -.6.889$ , 95% CI [-13.616, -.161],  $p = .045$ ,  $SE = 3.3511$ ).

### **Hypothesis 4**

#### ***Interaction between BRIEF2-SR GEC and Exercise Duration on Accuracy***

I predicted that exercise duration would affect the association between GEC and accuracy, such that this association would be significant for the 30-minute exercise duration. The interaction between exercise duration and GEC on accuracy (controlling for gender, age, BMI percentile) was non-significant ( $p > .05$ ). There was no change in this analysis when outliers were included.

***Interaction between BRIEF2-SR Index Scores and Exercise Duration on Accuracy***

I predicted that exercise duration would affect the association between the BRIEF2-SR index scores and accuracy, such that this association would be significant for the 30-minute exercise duration.

There was a significant interaction between Behavior Regulation Index and exercise duration on accuracy such that when individuals exercise for 60 minutes, there is a significant effect of BRI on accuracy ( $B = -.004$ , 95% CI  $[-.006, -.001]$ ,  $p = .002$ ,  $SE = .0011$ ) but when individuals exercise for 30 minutes, there is no significant effect of BRI on accuracy ( $p > .05$ ). Similarly, there was a significant interaction between Cognitive Regulation Index (CRI) and exercise duration on accuracy ( $B = .004$ , 95% CI  $[.001, .007]$ ,  $p = .023$ ,  $SE = .0016$ ).

For BRI, this means that when accounting for the interaction of BRI and exercise duration on accuracy, there is a significant difference between 30 versus 60 minutes of exercise. When individuals exercise for 60 minutes, there is a significant effect of BRI on accuracy ( $B = -.005$ , 95% [CI =  $-.008, -.002$ ],  $p = .000$ ,  $SE = .0014$ ) but when individuals exercise for 30 minutes, there is no significant effect of BRI on accuracy ( $p > .05$ ). When outliers were included in this analysis, BRI was no longer significant ( $B = -.002$ , 95% [CI =  $-.006, .001$ ],  $p = .223$ ,  $SE = .0017$ ).

For CRI, this means that when accounting for the interaction of CRI and exercise duration on accuracy, there is a significant difference between 30 versus 60 minutes of exercise.



When individuals exercise for 60 minutes, there is a significant effect of CRI on accuracy ( $B = -.004$ , 95% CI  $[-.007, -.001]$ ,  $p=.023$ ,  $SE = .0016$ ) but when individuals exercise for 30 minutes, there is no significant effect of CRI on accuracy ( $p>.05$ ).

#### ***Interaction between BRIEF2-SR Scale Scores and Exercise Duration on Accuracy***

I predicted that exercise duration would affect the association between the BRIEF2-SR scale scores and accuracy, such that this association would be significant for the 30-minute exercise duration. The results of the cumulative effects of exercise duration and level 2 predictors (Emotional Control, Inhibit, Plan Organize, Working Memory, Task Completion, Self Monitor, Shift, gender, age, BMI percentile) showed there was a significant difference in accuracy between the 30 and 60 minute durations for Task Completion ( $B = .004$ , 95% CI  $[.001, .006]$ ,  $p=.001$ ,  $SE = .0010$ ).

For Task Completion, this means that when accounting for the interaction of Task Completion and exercise duration on accuracy, there is a significant difference between 30 versus 60 minutes of exercise such that, when individuals exercise for 30 minutes, there is a significant effect of Task Completion on accuracy, but when individuals exercise for 60 minutes, there is no significant effect of Task Completion on accuracy ( $p>.05$ ). There was no change in this analysis when outliers were included.

#### ***Interaction between BRIEF2-SR GEC and Exercise Duration on RT***

I predicted that exercise duration would affect the association between GEC and RT, such that this association would be significant for the 30-minute exercise duration. The results of the cumulative effects of exercise duration and level 2 predictors (GEC, gender, age, BMI percentile) showed there was no significant difference in reaction time between the 30 and 60-minute durations ( $p>.05$ ). There was no change in this analysis when outliers were included.

***Interaction between BRIEF2-SR Index Scores and Exercise Duration on RT***

I predicted that exercise duration would affect the association between the BRIEF2-SR index scores and RT, such that this association would be significant for the 30-minute exercise duration. The results of the cumulative effects of exercise duration and level 2 predictors (BRI, ERI, CRI, gender, age, BMI percentile) showed there was no significant difference in reaction time between the 30 and 60-minute durations ( $p > .05$ ). There was no change in this analysis when outliers were included.

***Interaction between BRIEF2-SR Scale Scores and Exercise Duration on RT***

I predicted that exercise duration would affect the association between the BRIEF2-SR scale scores and RT, such that this association would be significant for the 30-minute exercise duration. There was a significant interaction between the Inhibit scale score and exercise duration in predicting RT while controlling for covariates ( $B = 5.017$ , 95% CI [.897, 9.138],  $p = .018$ ,  $SE = 2.045$ ).

For Inhibit, this means that when accounting for the interaction of Inhibit and exercise duration on accuracy, there is a significant difference between 30 versus 60 minutes of exercise such that, when individuals exercise for 30 minutes, there is a significant effect of Inhibit on reaction time, but when individuals exercise for 60 minutes, there is no significant effect of Inhibit on reaction time ( $p > .05$ ). There was no change in this analysis when outliers were included.

**Discussion**

The aim of this study was to determine whether exercise bout duration had an impact on the relationship between executive functioning and food consumption outcomes in order to establish whether modifying exercise duration may be beneficial for eating behavior. I aimed to

test the relationship between EF and calorie consumption under two exercise duration conditions.

I also tested the impact of exercise duration on the relationship between EF and food-specific inhibition.

### **EF and Calorie Consumption**

I hypothesized that the relationship between EF and calorie consumption would be positive. However, I did not find this to be the case in a meaningful way. Of the 11 EF variables I tested, only Shift was significantly associated with calorie consumption, and this had a very small effect size. The data shows that those with higher shifting abilities may consume slightly more calories when presented with high calorie foods. However, my findings suggest that these individuals with higher shifting abilities may only consume a few more calories (~8), which may not be clinically significant. For instance, a reasonable calorie deficit for those attempting to lose weight may vary between 500 and 1,000 calories a day, causing them to lose about one pound a week, since 3,500 calories equals one pound (Guth, 2014). To put this in perspective, a change of 8 calories a day would result in one pound of weight gain in 62.5 weeks, or well over a year. Thus, in context, 8 calories may be essentially negligible in this instance, though it was significant statistically.

For the most part, we did not find that EF affected calorie consumption. However, in a very small way, this finding contributes to the literature that has shown that EF is associated with eating behaviors, such as regulating food intake in emerging adults (Allom & Mollam, 2014; Calvo et al., 2014). It also provides reason to continue to research this topic, since most of our findings do not coincide with much of the existing literature. The effect size was very small and only in regard to inhibition (and not other types of EF) and our finding also adds to this literature by providing possible contrary evidence to the notion that individuals with higher EF show more

control of eating behavior in the presence of food, though much more research is needed. Hall (2016) showed that EF can modulate food cravings for high calorie foods, which may be an interesting area of future research related to the current study. Additionally, current literature shows that through inhibitory control training, individuals may be able to reduce desire for, and consumption of, high calorie foods in laboratory and real-world settings (Lawrence et al., 2015). Our findings are mixed relative to the current research and show that EF can modulate food consumption of high calorie foods in adolescents since the effect size was very small and only for inhibition, and not other types of EF. Our research shows that adolescents with higher shifting abilities may not inhibit their consumption of high calorie, well-liked foods in a very small way. However, it is important to note that this finding is not supported in the literature since better EF has been associated with healthier eating, like consuming more fruits and vegetables (Allom & Mullan, 2014). This could be an interesting area for future research, specifically, to expand the ad libitum food buffet to include a wider variety of foods and see if adolescents with higher EF choose more fruits and vegetables. More research is needed to elucidate these findings.

Although previous research has shown that decreased EF is associated with unhealthy eating behaviors and obesity, it is unlikely that the change in such a small number of calories, such as what we saw, would have any important outcomes (Pieper & Laugero, 2013). It is also important to note that these findings only reflect two instances of the individual's eating behavior. It could be the case that were we to include more observations of the adolescents' diet, or a longer diet recall, that the small effect we observed would be compounded and could potentially lead to substantial weight gain. In this case, our finding may contribute to the existing research that shows the relationship between EF and calorie consumption.

**EF, Calorie Consumption and Exercise**

I also hypothesized that exercise duration would have a significant impact on the relationship between EF and calorie consumption in the shorter exercise duration condition but not for the longer exercise duration. However, I did not find this to be the case, but instead found that there was no significant effect of exercise duration on calorie consumption.

Thus, the data shows that those with higher shifting abilities may consume slightly more calories when presented with high calorie foods after exercise and this does not differ whether they exercise for 30 or 60 minutes. Taken together, exercise duration does not appear to have an effect on caloric consumption in a laboratory meal, regardless of baseline EF. In terms of recommendations for adolescents, adjusting exercise duration is unlikely to produce substantial benefits in terms of post-exercise caloric consumption.

**EF and Accuracy**

I hypothesized that the relationship between EF and accuracy would be negative (since higher scores on the BRIEF2-SR indicate higher EF dysfunction). I did not find that EF and accuracy were related in a meaningful way, though some of the associations were significant (i.e., ERI index scores, emotional control, inhibit, plan organize and task completion scale scores with accuracy). It is important to be cautious with interpreting the statistics that could suggest those with higher planning and organizing abilities being negatively associated with accuracy (Tan & Hulob, 2011), since the confidence intervals of these statistics included 0. Importantly, these findings are not supported widely in the current literature, although the populations most commonly studied are adult, clinical populations which differ from our adolescent, non-clinical population (Groppe & Elsner, 2014; Manasse et al., 2015a, Manasse et al., 2015b; Svaldi et al., 2014).

Even when interpreting the results that are generally supported by other studies, such as those with higher emotional control, inhibition and task completion having higher accuracy abilities being more accurate, it is important to note that the confidence intervals are close to 0, and that more information is needed from further studies (especially those with larger sample sizes and higher power) to support these findings.

### **EF and RT**

I hypothesized that the relationship between EF and mean RT would be positive. The data showed that there may be a small association between EF (specifically behavioral regulation and inhibition) and RT, though the effect size was very small. The data showed that individuals with higher BRI scores and higher inhibition scores had slightly slower RT.

As shown previously, the effect sizes in this study are very small and further research is needed to clarify these findings. An explanation for these findings having such small effect sizes or being close to or non-significant is that our research did not include individuals who had issues with either EF or overweight/obesity, which are related to one another (Fitzpatrick et al, 2013). Since obese individuals show deficits in a number of aspects of EF compared to healthy-weight controls, it could have been that we did not include individuals who had a wide enough range of EF or weight status (Fitzpatrick et al., 2013). Although research in this domain has not been well-studied in adolescents, it is possible that the lack of EF and weight diversity in our sample could explain our findings. However, our research did shed light on a specific population that may have otherwise been overlooked, that of normal-weight adolescents who do not have EF deficits.

### **EF, Accuracy, and Exercise**

I also hypothesized that exercise duration would have a significant impact on the relationship between EF and accuracy, with shorter exercise duration having a significant impact

on the relationship between these two variables. I found that exercise bout may have a very small effect on the association between EF and accuracy, but that these effects are not meaningful even though some were significant. The associations between GEC (as well as most of the scale scores and ERI) and accuracy were not affected by exercise duration. However, after 60 minutes of exercise, those with higher BRI and CRI index scores (meaning they had higher dysfunction in these areas) were less accurate. Those with higher task completion scores were slightly less accurate after 30 minutes of exercise compared to 60 minutes. However, these effects were very small and may not be meaningful. More information is needed in further studies to support this finding. In terms of application, accuracy on a Go/No-Go task is a commonly used measure of response inhibition, which is a core deficit in many mental illnesses (Wright et al., 2014) and thus our research may have implications for clinicians.

The data suggests that exercise duration may have an impact on the relationship between EF and food-specific inhibition, but it is not clear whether this consistently is after 30 or 60 minutes of exercise. Since the findings are not clear across all EF variables that were tested and although a number of the statistics are significant at the level of  $p < .05$ , many of the confidence intervals are very close to, or include, 0, and thus should be interpreted with caution. For instance, we see that after 60 minutes of exercise, the relationship between the behavioral regulation index (BRI) and accuracy is impacted such that for every one unit increase on the behavioral regulation index, there is a .005% decrease in accuracy. These findings suggest that after a longer bout of exercise, individuals with higher behavioral regulation abilities may be slightly more accurate on a Food Go/No-Go task. However, this effect size is so small that it could very well be negligible. The data about the impact of cognitive regulation is almost identical to this but showed a decrease of .004% accuracy. Again, these effect sizes are very

modest. To put this in perspective, the variability in Go/No-Go accuracy have been shown in previous research to be significant when they vary by about 4% - 10%, which is much larger than the effects we found (Redick et al., 2011).

### **EF, RT and Exercise**

I hypothesized that exercise duration would have a significant impact on the relationship between EF and RT, with shorter exercise duration having a significant impact on the relationship between these two variables. For most of the EF variables I studied, I did not see an effect of exercise condition as anticipated. However, after 30 minutes of exercise, compared to 60 minutes, we did see a significant effect of inhibition on reaction time, although it was only by 5 milliseconds. This finding suggests that after 30 minutes of exercise, as inhibition abilities increase, reaction time decreases, but only by a miniscule amount, one we may even deem negligible. However, if this finding does indicate a true difference, it would be a meaningful contribution to the current literature by showing that a shorter bout of exercise may lead a more inhibited person to react more quickly. The current literature shows that EF is associated with inhibition and that exercise can improve EF in children (Best, 2010; Guiney & Machado, 2013; Tan & Hulob, 2011) and the current research contributes by showing this relationship may be more complex than previously imagined, especially when exercise bout duration is considered.

However, it is likely that this small difference in RT would not manifest any meaningful differences outside of a lab setting. Our research has the added benefit of showing how these variables act when combined, for instance that we only see this association after 30 minutes but not 60 minutes of exercise. However, once again the effect size is very small (about 5 milliseconds) and the confidence interval for this finding was almost 0. Comparatively, one research paper showed a standard deviation of 66 milliseconds on the low end for their Go/No-



Go task, meaning that their standard deviation was 13 times larger than our effect size (Rubia et al., 2001). Overall, these findings suggest that exercise bout duration may affect adolescents' food-specific inhibition in very small ways but more research is needed to corroborate these findings. Additionally, more research needs to be done to show how exercise duration can affect food-specific inhibition for adolescents who have low EF, such as those with ADHD.

### **Effect of Gender**

It is also interesting to note that in a number of the models I used, there was a significant effect of gender. Compared to females, males consumed about 200 more calories during the ad libitum buffet. This is not surprising since it is well supported that males consume more calories than females (Jensen & Holme, 1999). However, it is interesting to note that there may be more than just larger BMI (which was controlled for in our study) that contributes to males consuming more calories than females (Jensen & Holme, 1999; Minas et al., 2016; Rozin et al., 2003). For instance, from a young age, societal expectations for boys' and girls' consumption for food quantities are different, with boys expected to have voracious appetites and eat everything in front of them while girls are expected to be choosier and expected to eat less (Jensen & Holme, 1999). Substantially more women than men have major concerns about eating and food in regard to weight and health and how their choices are perceived by others (Rozin et al., 2003). Further, research has shown that women report feeling judged for how much they eat and for their weight, whereas there may be more of a tolerance for overweight among men (Charles & Kerr, 1986; Counihan, 1992; Sobal et al., 1995; Zylan, 1996). For instance, young women living at home reported their fathers monitoring how much they eat and regulating what they view as overeating by their daughters (Counihan, 1992). Women may also be more susceptible to being primed when it comes to regulating food intake (by consuming less calories) after discussing

fitness or health, whereas men do not show this effect (Minas et al., 2016). Since our study focused on both fitness (i.e., treadmill running) and health (i.e., the food Go/No-Go task), the girls in our study may have been primed to consume less calories. These findings together show a multifaceted explanation of why calorie consumption may vary by gender, which may begin at an early age and be subject to priming effects.

In terms of the results of the Go/No-Go task, the current research provides evidence to suggest that males may have faster reaction times than females by about 134 milliseconds, although we did not observe an effect of gender on accuracy. It is important to point out that age was accounted for in these models, since inhibitory neural networks change with age (Rubia et al., 2013). The current literature is mixed in terms of the effect of gender on response inhibition and reaction time, with some research showing no effect of gender on an inhibitory control task (Kertzman et al., 2018; Yuan et al., 2008), others showing no reaction time difference but finding that females achieved better accuracy scores (Sjoberg & Cole, 2018) and yet others finding that males were more accurate on the task (Melynnyte et al., 2017). The research at hand supports the literature that shows there is no difference in accuracy but also deviated from the current research that shows there is no difference in reaction time. These differences may be due to the task being a Food Go/No-Go task rather than the original Go/No-Go Task, and thus that there has not been ample research on the gender effects associated with this specific task as of yet. Our results may also be a consequence of our research studying an adolescent population, or that our sample size was small. Future research should aim at investigating gender differences on a Food Go/No-Go task to elucidate the current findings.

### **Limitations**

Some of the output from the models changed once the outliers were excluded. Some of the analyses became significant with the exclusion of outliers, while others became non-significant. In order to be consistent, the output referred to in the discussion consists of the variables with outliers excluded.

A number of factors should be considered when assessing the limitations of this study. There may be sample effects that emerged since our sample was a mostly white, high socioeconomic status and healthy weight (i.e., non-overweight/obese) population. Future researchers may want to study individuals with different weight statuses or levels of EF (including those with Attention Deficit Hyperactivity Disorder) in order to form a clearer picture of the adolescent population as a whole. A greater degree of racial/ethnic and socioeconomic diversity would allow us to generalize these findings more broadly.

Our study also had a small sample size, which is a drawback. A larger sample size would have allowed us to have more confidence in the results of the statistical analyses. Since we may have had low statistical power for testing the interaction effects, this means what we have a high probability of having a Type II error, which means we may not be able to detect any effects should they be present. Sample sizes for linear mixed models are a complicated and widely discussed topic and there are many theories as to how to calculate power for linear mixed and what sample size is sufficient. The sample size for this study was 34 participants since it was part of a larger MRI study, which is comparable to other research in the field of MRI research. However, within the field of Go/No-Go testing this sample size is quite small. This should be noted as a weakness of the research and a greater sample size would be suggested for future research. These factors should be considered when interpreting the results.

Although we did not find support that exercise duration impacts calorie consumption and food inhibition across the board, this may be due to the fact that the type of exercise we employed (i.e., treadmill running) may not have been cognitively demanding enough to have an impact on our outcomes. There are widely reported effects of cognitively engaging exercising versus non-cognitively engaging having a stronger effect on children's EF (Best, 2010; Diamond, 2015) and we can speculate that this may also be true for our outcome variables (i.e., types of inhibition related to food choices). Perhaps if the type of exercise type in our study had been one that improved bimanual and hand-eye coordination or involved rhythmic movement (such as martial arts) we may have seen more of a consistent effect on the outcome variables (Diamond; 2015; Lakes & Hoyt, 2004). Future studies could employ the use of more cognitively demanding exercise, such as dance or martial arts in order to measure the impact on food-related health outcomes in teens.

Another potential limitation in this study was that there was variation in the time of day that data was collected. Data was collected during after school hours, but start times varied between 2:00 PM and 6:00 PM. Starting at the exact same time for each participant would ameliorate any time of day effects. Even having a smaller window of start times may be able to help address this potential issue.

Additionally, it is important to note that the Go/No-Go task we used may have been too simplistic or easy, thus creating a floor effect for reaction time and a ceiling effect for accuracy. Indeed, our results showed that the mean accuracy scores were above 90%, meaning that participants were highly adept at the task. A more difficult task would perhaps draw out more variation in results and help us to better understand the interaction of EF and exercise duration on our outcomes. It is also important to note that the Food Go/No-Go task is fairly novel and needs

to be continued to be assessed for validity. A naturalistic approach to assessing inhibition in addition to this task could prove useful.

It is also important to note that using the BRIEF2-SR for our measure of baseline EF has its drawbacks. Using a self-report measure relies on the accuracy and self-reflective abilities of the participant. Teens may have varying abilities to reflect accurately on their own EF, which could impact their scores. Using additional measures of EF, such as a teacher or parent reporting in addition to the self-report questionnaire could provide additional information and more accurately portray the adolescent's EF.

Another potential drawback of our study is that we did not perform naturalistic observations. Although lab studies such as ours are able to control for more variables (such as time of day, amount of exercise, hours of fasting and kind of foods available), and although we did leave the participants alone with the ad libitum buffet and placed them facing away from any cameras to avoid changing their behavior due to being monitored, participants may still have felt they were being observed during the study and not eaten as they would have outside of an experimental setting. Additionally, a number of EF constructs may be different inside versus outside the lab. For instance, inhibition in a lab setting may differ and individuals may find it easier to inhibit in a lab setting, but environmental cues (such as social influence) could play a much greater role in determining their decisions in a naturalistic setting. In the future, research should expand these findings to include more diverse food buffets, track calorie consumption over longer periods of time and include naturalistic observations of adolescents, such as meals at home, restaurants or in school cafeterias if possible to account for these factors.

## **Implications**

The results of this study showed how EF is related to food-specific inhibition and calorie consumption in adolescents under two exercise conditions. Three aspects of the study are novel. First, this study showed the impact of exercise bout duration on the associations between EF and food specific inhibition and EF and calorie consumption. Second, this study explored these concepts in a community adolescent population, a group that has previously been understudied, but whose EF may be especially sensitive to the impact of exercise. Third, this study used a variety of both cognitive and behavioral outcome measures, allowing for multimethod assessment of several study constructs. Fourth, this study used a within-participant design, which adds a unique element that allows us to compare participants to themselves, rather than a different group. Additionally, the associations between adolescent EF, eating habits and exercise have yet to receive adequate research, especially in terms of aerobic exercise bout duration.

At this time there is not overwhelming evidence that exercising for either 30 or 60 minutes produces superior benefits for adolescents in terms of managing post-exercise food consumption. Thus, combined with existing research that supports the idea that many benefits of exercise are available with just 30 minutes of exercise, either 30 minutes or 60 minutes of exercise may be good recommendations for adolescents (Schubert et al., 2013.) Individuals who exercise for 30 minutes may avoid compensatory eating behaviors, but there may also be many benefits to longer exercise that need to be explored (Rosenkilde et al., 2012). Further research looking at a wider range of health outcomes for teens is recommended to offer these guidelines with a higher degree of confidence. Specifically, research examining the cardiovascular benefits and possible prevention of cardiovascular disease, other diseases, mental health outcomes, possible impact on weight loss, and long-term benefits should be taken into account. Additional

research that establishes the benefits of longer or shorter research needs to be considered when considering adapting exercise duration bout guidelines.

Further, there is the issue of time and the practicality of fitting exercise in a teen's busy schedule, which may be imperative to consider when giving adolescents exercise guidelines. Because of the demands on teenagers' time, exercising for 30 minutes per day may be a more reasonable guideline since it has the potential for higher adherence (Tergerson & King, 2002). Indeed, since teens said that their top barriers to exercising were time and their schedules, 30 minutes of exercise per day could be a better recommendation since teens may find these guidelines more reasonable and may be more likely to consistently adhere to a shorter exercise bout (Tergerson & King, 2002).

This study is useful for adolescents, families, educators, clinicians and policy-makers. It provides valuable information about the current recommended amount of exercise: that there is not sufficient meaningful evidence based on the current study to encourage 60 minutes of exercise over 30 minutes (or vice versa) or that exercise consistently impacts the relationship between EF and food-related outcomes. Teens may find it easier to consistently adhere to guidelines encouraging fewer minutes of exercise, so based on the current study, individuals should be encouraged to exercise, and the duration can be up to their discretion.

It should be noted that some aspects of EF, like inhibition, may slightly influence calorie consumption, and thus, continued research could look into improving specific aspects of EF in order to restrict consumption of high calorie foods (such as is currently being done in inhibitory control training). This may be useful for clinicians who are advising overweight or obese patients and for these individuals to choose research-based interventions.

This study also shows the need for further exercise, EF and food-related outcome research in non-clinical, adolescent populations. This population is establishing habits they will carry through with them into adulthood. For instance, further research is needed to clarify how exercise and EF are related to food-related inhibition (such as on a Food Go/No-Go task) in order to provide research that is useful to informing guidelines for adolescents. This information could prove useful to aiding adolescents in improving their diet and exercise choices. Although the consequences of their habits may not be apparent during their teen years, poor habits relating to exercise and food consumption impact future obesity, which in turn puts individuals at risk for numerous negative health outcomes later in life. This research may be able to assist those concerned with the lifelong health of adolescents in optimizing their chances for good health throughout their lifetimes.

In conclusion, the current research shows that, in a laboratory setting, there may be a very small impact of EF on dietary behaviors for teens. Additionally, when comparing 30 versus 60 minutes of non-cognitively demanding exercise (i.e., treadmill running), the association between EF and dietary outcomes does not vary in a meaningful way for adolescents. The current recommendation informed by this research is that there are not calorie consumption differences depending on exercise bout duration but that the practical advantages of 30-minute exercise bouts may make this option preferable for some teens. However, additional research exploring health outcomes and long-term benefits of longer vs. shorter exercise duration are needed to continue to inform these findings.



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**Table 1***Models*

	Independent Variable(s)	Dependent Variable	Interaction(s)
Model 1	GEC	Calories	GEC*Exercise Duration
Model 2	BRI, CRI, ERI	Calories	BRI*Exercise Duration, CRI*Exercise Duration, ERI*Exercise Duration
Model 3	Emotional Control, Inhibit, Plan Organize, Working Memory, Task Completion, Self Monitor, Shift	Calories	Emotional Control*Exercise Duration, Inhibit*Exercise Duration, Plan Organize*Exercise Duration, Working Memory*Exercise Duration, Task Completion*Exercise Duration, Self Monitor*Exercise Duration, Shift*Exercise Duration
Model 4	GEC	Food Go/No-Go Accuracy	GEC*Exercise Duration
Model 5	BRI, CRI, ERI	Food Go/No-Go Accuracy	BRI*Exercise Duration, CRI*Exercise Duration, ERI*Exercise Duration
Model 6	Emotional Control, Inhibit, Plan Organize, Working Memory, Task Completion, Self Monitor, Shift	Food Go/No-Go Accuracy	Emotional Control*Exercise Duration, Inhibit*Exercise Duration, Plan Organize*Exercise Duration, Working Memory*Exercise Duration, Task Completion*Exercise Duration, Self Monitor*Exercise Duration, Shift*Exercise Duration
Model 7	GEC	Food Go/No-Go Reaction Time	GEC*Exercise Duration
Model 8	BRI, CRI, ERI	Food Go/No-Go Reaction Time	BRI*Exercise Duration, CRI*Exercise Duration, ERI*Exercise Duration



Model 9	Emotional Control, Inhibit, Plan Organize, Working Memory, Task Completion, Self Monitor, Shift	Food Go/No-Go Reaction Time	Emotional Control*Exercise Duration, Inhibit*Exercise Duration, Plan Organize*Exercise Duration, Working Memory*Exercise Duration, Task Completion*Exercise Duration, Self Monitor*Exercise Duration, Shift*Exercise Duration
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*Note.* GEC = General Executive Composite. BRI = Behavioral Regulation Index. CRI = Cognitive Regulation Index. ERI = Emotional Regulation Index.

**Table 2***Participant Demographics*

	Total <i>n</i> = 34
Age: Mean (SD)	14.76 (1.60)
Sex: Number of females (%)	18 (52.94%)
Ethnicity: Number of Caucasian (%)	28 (82.35%)
Ethnicity: Number of Hispanic (%)	4 (11.76%)
Ethnicity: Number of Other (%)	2 (5.88%)
Family monthly income: Mean (SD)	\$7,997 (\$9,247)
BMI (kg/m <sup>2</sup> ): Mean (SD)	20.19 (2.48)
BMI percentile: Mean (SD)	51.85 (24.21)

*Note.* SD = standard deviation

**Table 3***Means and Standard Deviations for Primary Measures*

	Mean	Standard Deviation
GEC	55.23*	5.51
BRI	54.54*	7.88
CRI	55.21*	7.86
ERI	55.47*	9.06
Emotional Control	55.29*	10.44
Inhibit	56.85*	8.21
Plan Organize	52.62*	8.06
Working Memory	54.74*	9.02
Task Completion	58.18*	10.69
Self Monitor	50.62*	8.84
Shift	54.18*	8.74
Calories	489.85	179.29
Go/No-Go Accuracy	.93	.06
Go/No-Go Reaction Time	634.95	141.11

*Note.* \*Means for these scores are expressed as T-scores. GEC = General Executive Composite. BRI = Behavioral Regulation Index. CRI = Cognitive Regulation Index. ERI = Emotional Regulation Index.

**Table 4***Unstandardized Main Effects of Generalized Linear Mixed Model Analysis*

	Calories	Accuracy	Reaction Time
GEC	-1.410 (p=.732)	<b>-.003 (p=.033*)</b>	-.152 (p=.418)
BRI	2.524 (p=.575)	-.001 (p=.299)	<b>-9.786 (p=.007*)</b>
CRI	-2.279 (p=.533)	.000 (p=.891)	4.849 (p=.118)
ERI	-.493 (p=.898)	<b>-.003 (p=.001*)</b>	-.975 (p=.735)
Emotional Control	4.904 (p=.142)	<b>-.002 (p=.014*)</b>	.457 (p=.860)
Inhibit	-.467 (p=.906)	<b>-.002 (p=.047*)</b>	<b>-6.184 (p=.048*)</b>
Plan Organize	5.071 (p=.182)	<b>.004 (p=.001*)</b>	5.517 (p=.109)
Working Memory	-3.384 (p=.134)	.001 (p=.305)	-.914 (p=.709)
Task Completion	-2.902 (p=.168)	<b>-.002 (p=.015*)</b>	2.120 (p=.472)
Self Monitor	2.990 (p=.497)	-2.509 (p=.985)	-4.432 (p=.109)
Shift	-7.184 (p=.073)	-.002 (p=.073)	-1.904 (p=.562)

*Note.* \* =  $p < .05$ . GEC = General Executive Composite. BRI = Behavioral Regulation Index. CRI = Cognitive Regulation Index. ERI = Emotional Regulation Index.

**Table 5***Standardized Main Effects of Generalized Linear Mixed Model Analysis*

	Calories	Accuracy	Reaction Time
GEC	-.059 (p=.732)	<b>-.003 (p=.033*)</b>	-2.852 (p=.418)
BRI	.111 (p=.575)	-.1.050 (p=.299)	<b>-.547 (p=.007*)</b>
CRI	-.100 (p=.533)	.137 (p=.891)	.270 (p=.118)
ERI	-.025 (p=.898)	<b>-.518 (p=.001*)</b>	-.063 (p=.735)
Emotional Control	.286 (p=.142)	<b>-.374 (p=.014*)</b>	.034 (p=.860)
Inhibit	-.021 (p=.906)	<b>-.316 (p=.047*)</b>	<b>-.360 (p=.048*)</b>
Plan Organize	.228 (p=.182)	<b>.581 (p=.001*)</b>	.315 (p=.109)
Working Memory	-.170 (p=.134)	-.181 (p=.305)	-.058 (p=.709)
Task Completion	-.173 (p=.168)	<b>-.382 (p=.015*)</b>	.161 (p=.472)
Self Monitor	.147 (p=.497)	-.004 (p=.985)	.278 (p=.109)
Shift	-.350 (p=.073)	-.243 (p=.073)	-.118 (p=.562)

*Note.* \* =  $p < .05$ . GEC = General Executive Composite. BRI = Behavioral Regulation Index. CRI = Cognitive Regulation Index. ERI = Emotional Regulation Index.

**Table 6**

*Unstandardized Interaction Effects of Executive Function \* Exercise Duration on Calories, Accuracy and Reaction Time*

	Calories	Accuracy	Reaction Time
GEC*Exercise Duration	.881 (p=.773)	.002 (p=.308)	1.274 (p=.592)
BRI*Exercise Duration	-.610 (p=.806)	<b>-.004 (p=.002*)</b>	3.396 (p=.247)
CRI*Exercise Duration	1.456 (p=.665)	<b>.004 (p=.023*)</b>	-.839 (p=.766)
ERI*Exercise Duration	.305 (p=.919)	.001 (p=.497)	-.540 (p=.717)
Emotional Control*Exercise Duration	.374 (p=.850)	.002 (p=.058)	1.065 (p=.430)
Inhibit*Exercise Duration	-.389 (p=.910)	-.001 (p=.401)	<b>5.017 (p=.018*)</b>
Plan Organize*Exercise Duration	.540 (p=.908)	-.001 (p=.355)	-1.894 (p=.364)
Working Memory*Exercise Duration	2.592 (p=.228)	.001 (p=.422)	1.279 (p=.584)
Task Completion*Exercise Duration	-.380 (p=.846)	<b>.004 (p=.001*)</b>	-.684 (p=.670)
Self Monitor*Exercise Duration	1.812 (p=.697)	-.003 (p=.079)	-.972 (p=.614)
Shift*Exercise Duration	-2.740 (p=.590)	.000 (p=.922)	-1.543 (p=.476)

*Note.* \* =  $p < .05$ . GEC = General Executive Composite. BRI = Behavioral Regulation Index. CRI = Cognitive Regulation Index. ERI = Emotional Regulation Index.

**Table 7***Standardized Interaction Effects of Executive Function \* Exercise Duration on Calories,**Accuracy and Reaction Time*

	Calories	Accuracy	Reaction Time
GEC*Exercise Duration	.037 (p=.773)	.002 (p=.308)	.068 (p=.592)
BRI*Exercise Duration	-.027 (p=.806)	<b>-.513 (p=.002*)</b>	.190 (p=.247)
CRI*Exercise Duration	.064 (p=.665)	<b>.522 (p=.023*)</b>	-.407 (p=.766)
ERI*Exercise Duration	.015 (p=.919)	.131 (p=.497)	-.035 (p=.717)
Emotional Control*Exercise Duration	.022 (p=.850)	.305 (p=.058)	.079 (p=.430)
Inhibit*Exercise Duration	-.018 (p=.910)	-.142 (p=.401)	<b>.292 (p=.018*)</b>
Plan Organize*Exercise Duration	.024 (p=.908)	-.196 (p=.355)	-.108 (p=.364)
Working Memory*Exercise Duration	.130 (p=.228)	.173 (p=.422)	.082 (p=.584)
Task Completion*Exercise Duration	-.023 (p=.846)	<b>.657 (p=.001*)</b>	-.052 (p=.670)
Self Monitor*Exercise Duration	.089 (p=.697)	-.390 (p=.079)	-.061 (p=.614)
Shift*Exercise Duration	-.134 (p=.590)	-.018 (p=.922)	-.096 (p=.476)

*Note.* \* =  $p < .05$ . GEC = General Executive Composite. BRI = Behavioral Regulation Index. CRI = Cognitive Regulation Index. ERI = Emotional Regulation Index.