The effects of acute aerobic exercise on executive functions

Bachelor thesis, 15 credits

Gothenburg, 2019-01-20

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Abstract
The aim of the study was to examine the acute effects of exercise on three executive functions: attention, inhibition and working memory, in regularly exercising women \((n = 10)\) and men \((n = 10)\). Furthermore, the purpose was to investigate if different intensity levels of aerobic exercise had an effect on executive functioning. Twenty adults, aged 21-54 years, participated in the study. The participants were randomly assigned to one of two different exercise intensity levels, moderate or vigorous. Every participant was assigned two conditions, inactive and active. In both conditions, the participants were exposed to twenty minutes on a stationary bicycle, followed by a 10 minute delay before testing cognitive functions. To evaluate executive performance, three cognitive tests were used: the Stroop test, Trail Making Test and Digit span. No significant results were found. Results from previous studies, combined with the present study, indicate that the relationship between exercise and executive functioning is very complex and needs further research.

Keywords: attention, cognition, executive functions, exercise, inhibition, working memory
Cognition, which refers to the complex system that includes all mental abilities, is crucial for all aspects in everyday life and health (Eysenck & Keane, 1990; Glass, Holyoak, & Santa, 1979). Several studies have indicated that exercise has positive effects on cognition, both long-term effects and more immediate effects after acute bouts of exercise (Chaddock-Heyman, Hillman, Cohen, & Kramer, 2014; Colcombe et al., 2006; Hillman, Erickson, & Kramer, 2008; Hötting & Röder, 2013). In both cases, researchers have postulated physiological and biochemical explanations for the increases in cognition. Exercise over a long period of time may have more beneficial effects on cognition simply because the physiological effects of exercise are prolonged (Etnier, Salazar, Landers, Petruzzello, Han, & Nowell, 1997). Acute effects have primarily been found on the more complex cognitive abilities, such as executive functions (Chang, Labban, Gapin, & Etnier, 2012; Hung, Tsai, Chen, Wang, & Chang, 2013) and memory (Lambourne & Tomporowski, 2010). It is clear that there is a correlation between exercise and cognitive functioning, but researchers are still debating the cause-and-effect relationship, as well as the characteristics of the exercise required for an effect (Chang et al., 2012; Davranche & McMorris, 2009; Wang, Chu, Chu, Chan, & Chang, 2013; Yanagisawa, Dan, Tsuzuki, Kato, Okamoto, Kyutoku, & Soya, 2010). Therefore, if exercise can improve cognition, it is important to establish the intensity, amount, and type of exercise that is required (Colcombe & Kramer, 2003; Soga, Shishido, & Nagatomi, 2015).

Cognition and Exercise

Cognition has been researched for over a hundred years. A famous early case study about Phineas Gage, a railroad worker who survived an iron bar through his frontal lobes, was conducted as early as 1848. The injuries from the accident changed Gage’s personality and resulted in an impairment of his complex cognitive functions (Harlow, 1868/1993). Ever since this case study, researchers have continued to find more evidence for the relationship between complex cognitive functions and the frontal lobes (Alvarez & Emory, 2006; Baddeley, 1996; Fuster, 1997, 2001). Cognitive functions encompass the abilities needed for information processing, e.g. perception, memory, learning, thinking, and plans of action (Lezak, Howieson, & Loring, 2004). Some of these information-processing abilities can be improved by exercise (Chang et al., 2012; Etnier et al., 1997; Lambourne & Tomporowski 2010).

Exercise refers to a type of planned and structured physical activity that differs from occupational or household activities. The purpose of exercise is to achieve, improve or maintain a certain objective regarding physical fitness, stress reduction or enjoyment (World Health Organization, 2011). Exercise has proven to be beneficial for cognitive functioning in all stages of life. During childhood and adolescence, exercise seems to have long lasting effects on brain structure and function (Chaddock et al., 2010). Longitudinal research on older adults have suggested that exercise contributes to an increase in brain volume and has the ability to improve some memory functions, reduce cognitive decline and slow down age-related deterioration (Colcombe et al., 2006; Erickson et al., 2011; Hillman et al., 2008). The positive effects are believed to have biochemical and physiological explanations. Exercise induces the release of neurochemicals, such as brain-derived neurotrophic factor (BDNF), that improve neuroplasticity (Colcombe, Kramer, McAuley, Erickson, & Scalf, 2004; Piepmeier & Etnier, 2015; Szuhany, Bugatti, & Otto, 2014). Neuroplasticity is the brain’s ability to adapt to and compensate for disease-, injury-, and age-related changes (Hötting & Röder, 2013; Smith, 2013). High concentrations of the protein BDNF in hippocampus and cerebral cortex have been associated with increased hippocampal volume and improved memory functions. In addition, because of BDNF’s involvement in plasticity,
the protein may have the ability to act as a protector against age-related structural and functional decay (Erickson et al., 2011; Murer, Yan, & Raisman-Vozari, 2001). Although many results indicate that long term exercise has positive chronic effects, existing studies are somewhat limited due to the complications in conducting longitudinal research (Etnier et al., 1997).

Positive effects on cognitive functioning have also been found after acute bouts of exercise. These effects can be attributed to physiological and biochemical responses to exercise, such as increased arousal, heart rate, BDNF, and cerebral blood flow (Chang et al., 2012; Hung et al., 2013). The effects have primarily been found on higher-level cognitive abilities (Brown & Bray, 2018; Chang et al., 2012; Hung et al., 2013). Higher-level abilities are often referred to as executive functions, they are more complex and control the simpler lower-level mental abilities (Alvarez & Emory, 2006; Eslinger, 1996; Lezak et al., 2004). To obtain an effect from exercise on the higher cognitive functions, at least 20 minutes of aerobic, also known as cardiovascular, exercise is desirable (Chang et al., 2012). However, scientists have not yet agreed on the exercise intensity that is most beneficial for an effect. Some researchers have suggested that a high exercise intensity is beneficial when there is a delay between exercise and performance, where the best effect would be received between 11 and 20 minutes post exercise (Chang et al., 2012; McMorris & Hale, 2015). Other researchers have suggested that positive effects are received after exercise at a moderate intensity (Brown & Bray, 2018; Chang et al., 2012). Moderate intensity is often set between 55% and 76% of an individual’s maximum heart rate (HRmax; Brown & Bray, 2018; Chang et al., 2012; Norton, Norton, & Sadgrove, 2010; Soga et al., 2015).

It has been hypothesized that the relationship between training intensity and cognitive functioning is nonlinear. The relationship between dose and effect has been thought of as an inverted-U shape, where moderate intensity exercise would have the greatest benefits on cognitive functions and other intensity levels would be less beneficial (Hung et al., 2013; Lambourne & Tomporowski, 2010; McMorris & Hale, 2012). The inverted-U hypothesis might also be connected to the stress response and release of the catecholamine neurotransmitters, involved in cognitive control. Catecholamine release is affected by stress levels and the main catecholamines are: epinephrine (adrenaline), norepinephrine (noradrenaline), and dopamine. Low levels of stress fail to activate neurons and do not increase arousal. Failure to activate neurons, and subsequently increase arousal, leads to poor performance, because arousal is needed for stimulus processing and alertness. Moderate stress facilitates cognitive performance as it increases arousal, leading to optimal performance and neural activation in the prefrontal cortex. Excessive stress is a consequence of perceived danger where the brain prepares to quickly respond to threatening stimuli. This process reduces neural activity and function in the prefrontal cortex while other brain areas take over (Arnsten, 2000; McMorris & Hale, 2015).

**Executive Functions and Exercise**

Executive function, also referred to as executive control, is an umbrella term for higher level cognitive functions involved in goal-directed behavior. Attention, impulse control, decision making, problem solving and working memory are some of the executive processes (Alvarez & Emory, 2006; Anderson, 2008; Fuster, 1997). The frontal lobes, more specifically the frontal cortex, plays an important role in these processes, but other brain regions are also necessary (Alvarez & Emory, 2006; Fuster 1997). An acute bout of moderate intensity exercise can lead to an increased activation in the prefrontal cortex, which is related to improved executive performance (Yanagisawa et al., 2010). Studies have indicated that aerobic exercise is particularly beneficial during developmental changes of executive
functions and the areas of the brain responsible for those functions (Hötting & Röder, 2013; Ludyga, Gerber, Brand, Holsboer-Trachsler, & Pühse, 2016). During developmental changes, exercise contributes to maintenance of executive functioning and neuroplasticity. Exercise might encourage optimal structural and functional development in children and can reduce structural and functional decline in older adults (Hillman et al., 2008; Hötting & Röder, 2013; Murer et al., 2001).

The duration of the effects from acute bouts of exercise is under debate. A meta-analysis by Chang et al. (2012) concluded that very light to moderate exercise intensity facilitated executive performance immediately following exercise. However, when there was a delay after exercise, a high intensity was more beneficial. Although higher exercise intensity may lead to physical fatigue, it releases a greater amount of catecholamines, which facilitates cognition. Brown and Bray (2018) argued that a delay after high intensity exercise would provide time to recover from the physical stress of the strenuous exercise, while keeping the benefits from catecholamines, which then would improve executive performance (Brown & Bray, 2018). When executive functions were measured after a delay, intensities from light to very hard were beneficial, but higher intensities lead to more benefits. The physiological mechanisms that occur after higher intensity exercise provide a longer lasting effect on the executive functions, compared to lower intensity. Lower intensity seems to be more beneficial immediately following exercise (Chang et al., 2012). Brown and Bray (2018) discovered that exercise improved executive performance, both immediately post exercise and after a 10 minute delay, they also discovered that moderate intensity exercise had the most positive effects on executive performance. Chang et al. (2012) observed that a delay of 11-20 minutes post exercise was optimal for executive functioning and that the positive effects started to diminish after 20 minutes. Hung et al. (2013) found that some aspects of executive functioning were facilitated for up to 80 minutes post exercise.

Despite mixed results regarding intensity and duration of the effects, most researchers have agreed that exercise has the ability to enhance executive functioning. It is important to note that executive functions are multiple abilities combined and therefore exercise may not have an effect on all of them and the effects may vary between them (Davranche & McMorris, 2009). According to Bunge and Crone (2009) executive functions include five different abilities: to selectively attend to specific stimuli while ignoring interfering stimuli, to process material in working memory, to switch between tasks, to inhibit prepotent responses and to decide whether a thought or an action is relevant/appropriate. The abilities commonly seen affected by exercise are functions associated with frontal brain regions (Hötting & Röder, 2013), for example selective attention, inhibition (McMorris, Sproule, Turner, & Hale, 2011) and working memory (Baddeley, 1996).

**Attention, Inhibition and Exercise**

Attention is a limited capacity system, therefore one must select which stimuli to process. This is known as selective attention, which includes the ability to focus on specific stimuli as well as the ability to exclude other distracting stimuli (Barkley, 1997; Lezak et al., 2004; Halperin, 1996). Information processing can be either controlled or automatic. Controlled processes are conscious and flexible but require a substantial amount of time, effort and attention, affecting the limited capacity system. Automatic processes do not require attention or conscious awareness, they are fast but can easily be disrupted by an automated response to a specific stimulus (Eysenck & Keane, 1990; Schneider & Shiffrin, 1977). Automaticity needs to be practiced, however, once an activity is automated, it is more difficult to control or inhibit (Lezak et al., 2004; Schneider & Shiffrin, 1977). Behavioral inhibition is an important part of attentional focus and aims to suppress external and internal
interfering factors, to inhibit prepotent responses and stop ongoing responses (Barkley, 1997; Fuster, 1997).

Exercise leads to increased arousal, which benefits attention and speed of processing. Central in the arousal process are the catecholamine neurotransmitters, in particular norepinephrine, released during exercise (McMorris, 2016; McMorris, Collard, Corbet, Dicks, & Swain, 2008; McMorris et al., 2011). There is also strong evidence that exercise has a positive effect on inhibitory control (Davranche, Brisswalter, & Radel, 2015; Ludyga, Gerber, Brand, Pühse, & Colledge, 2018; Soga et al., 2015; Tomporowski, 2003), this could be due to a combination of catecholamine release and elevated levels of BDNF (Ludyga et al., 2018). Additionally, exercise has shown to increase the brain volume in older adults, primarily in the prefrontal and temporal cortices (Colcombe et al., 2006). The prefrontal cortex is activated during inhibition of prepotent responses as well as during shifting of attention (McMorris et al., 2011). Improved attentional shifting has shown a positive correlation with increased volume of the prefrontal cortex (Tamura et al., 2014).

Higher fitness level has often been associated with more positive effects from exercise (Chaddock-Heyman et al., 2014; Chang et al., 2012; Davranche et al., 2015; Tomporowski, 2003). Several explanations have been provided for this. Chang et al. (2012) and Tomporowski (2003) have suggested that fit individuals have turned exercise into an automated process that requires fewer attentional resources, leaving more resources available for other processes, such as executive functions. Tomporowski (2003) further proposed that individuals with higher fitness levels are better at tolerating the physical stress from exercise and therefore recover faster. Chang et al. (2012) provided an explanation as to why less fit individuals experience negative effects primarily during exercise. The explanation was based on the transient hypofrontality hypothesis, which states that during exercise, neural activation is required for motor control and coordination. Because of limited processing capacity, a conflict between resources arises which results in a temporary decrease of neural activation in other areas of the brain, such as the prefrontal cortex. This shift in neural resources leads to a transient impairment of the functions in the frontal cortex, such as attention and inhibition (Chang et al., 2012; Davranche & McMorris, 2009; Dietrich, 2006).

**Working Memory and Exercise**

Working memory is essential for executive functioning (Eslinger, 1996), it is comprised by several components primarily responsible for two different tasks. The first task is to provide a short term storage, which can retain auditory and visual information temporarily. The second task is to work with or process new information and integrate it with already existing knowledge or other sources of information (Baddeley, 2000). According to Baddeley (1996), there is a supervisory component of the working memory, the central executive. It is located in the frontal lobes and is responsible for integrative processes. Baddeley proposed that the central executive is crucial for cognitive functioning and has four major functions: to selectively attend to stimuli, to carry out multiple tasks simultaneously, to switch and control an innate response and to activate long-term memory (Baddeley, 1986, 1996, 2000).

Exercise seems to have some positive effects on memory, the effects could be a result of both increased hippocampal volume (Erickson et al., 2011) and increased activation in the prefrontal cortex (Yanagisawa et al., 2010). Both of these brain structures are important for working memory functions and they often work together to encode, retrieve and integrate information into existing memory networks (Preston & Eichenbaum, 2013).

Long-term effects of exercise have been associated with an increase of BDNF (Erickson et al., 2011; Piepmeier & Etnier, 2015; Szuhany et al., 2014) and have shown to
Acute moderate intensity exercise has shown to have a positive effect on speed of cognition in working memory tasks and the positive effects are mainly on functions of the frontal brain regions. Frontal regions are activated during monitoring of working memory processes, performed by the central executive. The central executive requires elevated arousal levels and catecholamine release to perform tasks. The improvements from exercise are a result of increased arousal and a simultaneous catecholamine release which, at an optimal level, enhances processing (McMorris et al., 2011).

However, a couple of studies have shown that exercise does not always influence working memory in a positive way. For example, an experiment by Coles and Tomporowski (2008) revealed that exercise had no effect on working memory and an experiment by Soga et al. (2015) demonstrated a decline in working memory functions during exercise. The decline was attributed to the transient hypofrontality hypothesis, which concerns the conflict in neural processes during exercise that leads to a temporary decrease in prefrontal cortex activation.

Present study

Results from previous research are inconsistent and suggest that exercise has different effects on the executive functions. The executive functions thought to be affected by exercise are attention (McMorris et al., 2011), inhibition (Davranche et al., 2015; Ludyga et al., 2018; Soga et al., 2015; Tomporowski, 2003), and working memory (Erickson et al., 2011; McMorris et al., 2011; Piepmeier & Etnier, 2015; Szuhany et al., 2014), all which are connected to the frontal brain region (Baddeley, 1996; McMorris et al., 2011). The effects of exercise have mainly been attributed to physiological and biochemical mechanisms (Chang et al., 2012; Etnier et al., 1997; McMorris & Hale, 2015).

Research on the long-term effects of exercise has primarily been done on children and older adults. The results of these studies are coherent, showing positive effects from exercise on cognition. Both children and older adults go through developmental changes in structures and functions of the brain. Exercise seems to play an important role in optimal development (Chaddock et al., 2010; Erickson et al., 2011; Hillman et al., 2008; Hötting & Röder, 2013).

The acute effects can be obtained after 20 minutes of cardiovascular exercise (Chang et al., 2012). The effects seem to be connected to an exercise induced increase of arousal level and a simultaneous release of BDNF and catecholamines (Hung et al., 2013; Ludyga et al., 2018; McMorris & Hale, 2012). Moderate exercise intensity is believed to be most beneficial for executive functioning and seems to have positive effects both immediately after exercise as well as after a delay, this is somewhat supported by the inverted-U hypothesis (Chang et al., 2012; Hung et al., 2013; Lambourne & Tomporowski, 2010; McMorris & Hale, 2012). It is also believed that higher intensity can lead to longer lasting positive effects, however, this would require a resting period after cessation of exercise (Chang et al., 2012; McMorris & Hale, 2015).

During exercise, executive functioning is impaired, which can be explained by the transient hypofrontality hypothesis (Soga et al., 2015). The impairments seem to affect individuals with lower fitness levels to a greater extent. However, the impairments are transient and should therefore disappear for all individuals, regardless of fitness level, after the cessation of exercise (Davranche & McMorris, 2009; Dietrich, 2006).
Purpose and Research Questions

The aim of the current study is to examine the acute effects of exercise on three executive functions: attention, inhibition, and working memory, in regularly exercising women and men. Furthermore, the purpose is to investigate if different intensity levels of aerobic exercise have different effects on executive functions.

1. Does aerobic exercise have effects on executive functions in regularly exercising women and men?
2. Are the effects of exercise moderated by level of intensity (i.e. moderate or vigorous)?

Method

Participants

A total of 20 volunteer participants, 10 men and 10 women, whose ages ranged from 21 to 54 (M = 29.9, SD = 1.6), were recruited for the current study. The participants were regularly involved in different exercise activities: CrossFit, horseback riding, cheerleading, running, dancing, gymnastics, climbing, powerlifting, gym and martial arts. Out of 20 participants, 19 estimated that they were involved in a combination of cardiovascular and resistance training, whereas one participant was only involved in resistance training. The participants’ estimated amount of training hours per week varied from four hours to 13.5 hours (M = 7.76, SD = 2.98). They had been regularly exercising for six months up to 22 years (M = 10.47, SD = 7.53).

Non-probability sampling was used, more specifically convenience sampling to make sure there were enough participants. The participants were recruited through announcements on social media and the information about the study was shared on Instagram as well as in Facebook groups with relevant participants. The study reached more participants as individuals further shared the information on social media, resulting in a snowball effect.

Participants were eligible if they were regularly exercising and if they were able to attend on two occasions within a two week period. Considering ethical guidelines the participants also had to be at least 18 years of age and had to sign an informed consent (see Appendix A) where they agreed to participating and that they had been provided with information about the purpose of the study and ethical principles (see Appendix B). The participants were instructed to refrain from exercise on the same day as the test and those who met the inclusion criteria were then randomly assigned to different conditions and intensity levels in the experiment.

Materials and Apparatus

A questionnaire was used to assess the exercise habits of the participants. The questionnaire included questions about age and sex, type of exercise or sports activity, amount of training hours per week, for how long the participant had been exercising regularly and the type of exercise. The four alternatives for type of exercise were: cardiovascular training, strength training, a combination of cardiovascular and strength training or other type of exercise.

The exercise variable was manipulated using a Star Trac V-bike stationary bicycle and the level of exertion was assessed by heart rate and a rating scale for perceived exertion. Heart rate was monitored with a heart rate belt and a Suunto Spartan Sport wrist band displaying heart rate. To make sure the participants were not overexerted, their own perception of exertion was measured by the Borg’s Rating of Perceived Exertion Scale. To measure the cognitive functions three tests were used: The Stroop test, Trail Making Test and Digit span. The cognitive tests were translated to Swedish. To record the duration of the
cognitive tests, two instruments were used. A handheld stopwatch was used to measure the elapsed time from start to finish of every test and was reset after each one. A camera recorded the whole session and the footage was used to verify the duration recorded by the stopwatch. The camera was directed at the cognitive test and did not include the participant in the frame.

**Borg Rating of Perceived Exertion Scale.** Borg’s RPE scale is a 15-grade scale for rating perceived exertion during physical work (Borg, 1982). The scale ranges from 6 to 20, where every odd number has a description for the perceived exertion level; e.g. 7 is described as “very very light”, 13 as “somewhat hard” and 19 as “very, very hard”. When using this RPE scale the participant is able to report any number between 6 and 20 according to their own perception.

**The Stroop test.** The Stroop test (Stroop, 1935/1992) is a well used neuropsychological test used to measure a variety of cognitive and personality functions, including executive functions such as inhibition and selective attention (Jensen, 1965; Lezak et al., 2004; Pachana, Thompson, Marcopulos, & Yoash-Gantz, 2004; Stroop 1935/1992). The Stroop test is a non-standardized test and there are many versions available. In this study, a printed version was used, consisting of two parts.

Part one consisted of 100 words printed on a paper in five columns and 20 rows, read from left to right from the top row to the bottom row. The words were nine different names of colors: red, blue, green, black, yellow, orange, pink, brown and grey, printed in the same color as the word (e.g. RED printed in red ink, BLUE printed in blue ink etc). The participant’s task was to say the word that was written. When part one was finished, the participant continued to part two.

Part two was designed in the same way as part one, the 100 names of colors were also the same as in part one, but printed in a conflicting color. The name of the color and the color of the ink the word was printed in were never congruent (e.g. GREEN was never printed in green ink but could be printed in blue, red, yellow, black, orange, pink or grey ink). The task in part two was to say the color the word was printed in and not the written word. For example, if the word GREEN was printed in red ink, the correct response would be to say “red”.

For both parts a timer was used, resetting the time for each test. The timer was started when the participant turned the paper over and stopped after the participant read the last word. Performance was measured by the time it took to complete the test, where less time meant better performance. Before both parts, the participant was given written instructions and five-item practice sample. In the sample for part one, the color of the word matched the name of the color written, and in part two the color of the word conflicted with the word written.

**Trail Making Test.** The Trail Making Test is another popular neuropsychological test measuring executive functions, visual search, speed of processing and mental flexibility (Tombaugh, 2003). The test is standardized and consists of two parts, A and B. Part A consists of a sheet of paper with 25 numbers in circles. The participant has to draw a line, without lifting the pencil from the paper, from one to two, two to three etc until the participant reaches 25. Part B is constructed in a similar way but instead of 25 numbers, there are circles with numbers ranging from one to 12 as well as letters from A to L. The participant is once again supposed to draw a line without lifting the pencil but this time alternating between numbers and letters, a number is always followed by a letter and vice versa (1-A-2-B-3-C etc; Lezak et al., 2004).

In both parts, the participant received both written and standardized verbal instructions followed by a sample for each part. In part A, the sample consisted of eight
circles with numbers and in part B, the sample consisted of four numbers, 1-4, and four letters, A-D, in circles. The time was measured by a timer that started when the participant put the pencil on the first circle and stopped when the participant reached the last circle. Performance on part A and B were measured separately, where less time to finish the test meant better performance. If the participant made an error, additional standardized instructions for possible errors were given.

**Digit span forward and Digit span backward.** Digit span forward and backward measures span of immediate verbal recall and can also be used to measure attention and working memory capacity (Lezak et al., 2004). There are two different Digit span tests, forward and backward. Both tests consist of a series of digit sequences with random digits read by the examiner and repeated back by the participant. The instructions are given verbally by the examiner and the participant is given a sample before the test starts.

In the Digit span forward test the examiner reads a sequence out loud and the participant repeats the digits back in the same order (Lezak et al., 2004). In the forward part there are eight different levels, ranging from a sequence of two digits to a sequence of nine digits. Each level has two sequences, for example level three consists of 3A: 6-4-3-9 and 3B: 7-2-8-6. For every level both A and B are always presented, whether the participant succeeds or not.

Digit span backward is executed in a similar way, except when the participant repeats the sequence back, it is repeated backwards, starting with the last digit read by the examiner (Lezak et al., 2004). In the backward part there are seven levels, similar to Digit span forward every level consists of both A and B, and both sequences are always presented. The seven levels range from a sequence of two digits to a sequence of eight digits. For example, in 3A the examiner reads 3-2-7-9 and the participant should repeat the digits as 9-7-2-3.

Digit span forward and backward are scored in the same way. Every time the participant repeats the sequence back correctly, they receive one point. If the sequence is incorrect the participant does not receive any points. The test stops when the participant fails to repeat both A and B of the same level correctly or when the last level is accomplished.

**Procedure**

The individuals interested in participating in the study received further information about how and where the study would be conducted and two test sessions were booked on separate occasions. The participants received an ID number, ranging from FP001 to FP020, based on order of confirmation to participate in the study.

To randomly assign the participants to different conditions a coin was tossed. First a coin was tossed to decide whether the first session was going to be active or inactive, then the coin was tossed again to decide if the active condition intensity was going to be moderate or vigorous. All the sessions were booked within two weeks and every participant had to have at least one day in between the sessions. Due to the participants’ availability, the number of days between the two sessions differed, ranging from two days to nine days ($M = 3.75$) and the time of the day varied from 6 a.m. to 10 p.m.

The experiment was conducted at a CrossFit gym in Southwestern Sweden, one participant at a time. Before the experiment began the participants had to sign an informed consent, where they agreed to participating and that they had been provided with information about the purpose of the study and ethical principles. The participants then filled out a questionnaire with background information (see “Materials and apparatus”). Based on the common formula, HRmax = 220 - age, the maximum heart rate was estimated by subtracting the participant’s age from 220 (Robergs & Landwehr, 2002). For instance, a 30 year old individual’s maximum heart rate would be 190. The different heart rate zones for the inactive
and active (moderate or vigorous) conditions were calculated. The participants put on a heart rate belt and the receiver of the heart rate monitor was attached to the handle of the stationary bike. The Borg scale was then explained and the stationary bike was adjusted to fit the participant. Before the cycling started, the participants were provided with instructions for the activity. To make the inactive and active conditions as similar as possible, except for the level of exertion, the participants had to sit on the stationary bike for 20 minutes in both conditions. For the inactive condition, the participants were instructed to pedal very slowly, keeping the heart rate under 55% HRmax. For the active condition the participants were divided into different intensities, moderate or vigorous, based on exercise intensity categories by Norton et al. (2010). The participants assigned to the moderate intensity level had to stay between 55% and 70% HRmax, the ones assigned to the vigorous intensity level between 70% and 90% HRmax.

Both heart rate and perceived exertion were assessed every other minute during the active condition and every fifth minute during the inactive condition to assure the participant stayed within the right heart rate zone and to be able to call off the session if the participant seemed too exerted or negatively affected by the activity.

After 20 minutes on the stationary bicycle the participants were given a cool-down period before the cognitive part of the session. General instructions for the tests were given after the cool-down period, these instructions were manuscripted and standardized for all participants. When 10 minutes had passed after the cessation of exercise, the Stroop test started, followed by Trail Making Test and lastly Digit span. Before every test, standardized instructions were given to make sure everyone had the exact same information.

**Design and Analysis**

A 2 x 2 mixed factorial design was used, where the first independent variable, the exercise condition (inactive/active), was a within-subject factor, and the second independent variable, intensity (moderate/vigorous) was a between-subject factor.

To analyze the data, a two-way analysis of variance (ANOVA) was conducted using IBM SPSS Statistics 24. The effect sizes were computed using an online effect size calculator (Effect Size Calculator, 2018).

**Results**

In this section results and effect sizes are reported. For mean values and standard deviations, see Table 1. For descriptive data regarding the participants, see previous section about participants under “Method”.

<table>
<thead>
<tr>
<th>Cognitive test</th>
<th>Total (N = 20)</th>
<th>Moderate (n = 10)</th>
<th>Vigorous (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inactive M (SD)</td>
<td>Active M (SD)</td>
<td>Inactive M (SD)</td>
</tr>
<tr>
<td>Stroop 1a</td>
<td>65.50 (17.79)</td>
<td>63.95 (17.50)</td>
<td>68.92 (18.09)</td>
</tr>
<tr>
<td>Stroop 2a</td>
<td>122.27 (25.18)</td>
<td>117.57 (25.47)</td>
<td>121.53 (22.92)</td>
</tr>
<tr>
<td>TMT Aa</td>
<td>22.68 (6.01)</td>
<td>22.32 (4.63)</td>
<td>22.07 (6.11)</td>
</tr>
<tr>
<td>TMT Ba</td>
<td>50.55 (17.82)</td>
<td>55.03 (24.14)</td>
<td>57.21 (21.09)</td>
</tr>
<tr>
<td>DSBb</td>
<td>9.85 (2.18)</td>
<td>9.30 (1.81)</td>
<td>10.00 (2.40)</td>
</tr>
<tr>
<td>DSBb</td>
<td>7.05 (2.11)</td>
<td>7.20 (1.99)</td>
<td>7.30 (2.54)</td>
</tr>
</tbody>
</table>

Note: Stroop 1 = Stroop part 1; Stroop 2 = Stroop part 2; TMT A = Trail Making Test part A; TMT B = Trail Making Test part B; DSB = Digit Span Forward; DSBb = Digit Span Backward.

*Dependent measure: time (in seconds) for completion of the test. *Dependent measure: points on the test (participants receive one point per correct response).
Stroop Test

No significant effect was found for Stroop test part 1. The participants did not significantly differ in the amount of time it took to finish Stroop test part 1 depending on inactive or active condition ($d = 0.06$). The effect size was trivial.

No significant difference was exhibited between the two intensity levels; there was no difference in performance on Stroop test part 1 between moderate ($M = 66.46$, $SD = 17.35$) or vigorous exercise intensity ($M = 63.00$, $SD = 18.50$, $d = 0.19$). The size of the effect was weak. Furthermore, no significant interaction effect was found between exercise condition and intensity level.

Stroop test part 2 revealed no significant difference between the inactive and active condition, the effect size was trivial ($d = 0.13$).

There was no significant difference between moderate ($M = 118.88$, $SD = 21.28$) and vigorous exercise intensity ($M = 120.96$, $SD = 29.90$, $d = 0.08$). The effect size reveals that the difference was trivial. No significant interaction effect was found.

Trail Making Test

Trail Making Test part A did not exhibit a significant difference between the inactive and active condition, indicating that there was no significant difference in the time it took to finish TMT A depending on if the participant was inactive or active. The effect size was trivial ($d = 0.05$).

There was no significant between-subject effect, indicating that neither moderate ($M = 22.08$, $SD = 5.20$) nor vigorous exercise intensity ($M = 22.93$, $SD = 5.68$, $d = 0.16$) significantly improved performance. The size of the effect was weak. No interaction effect was found.

Trail Making Test part B showed no significant difference between the inactive and active condition, and the effect size was weak ($d = 0.15$).

There was no significant difference between moderate ($M = 58.69$, $SD = 25.55$) and vigorous intensity ($M = 46.89$, $SD = 13.86$, $d = 0.57$) but there was a medium sized effect. No interaction was exhibited.

Digit Span

Digit span forward did not reveal a significant effect. The participants did not score differently depending on if they were in the inactive or active condition. The effect size was weak ($d = 0.19$).

No significant difference occurred between moderate ($M = 9.7$, $SD = 2.29$) and vigorous intensity ($M = 9.45$, $SD = 1.77$, $d = 0.12$). The effect size was trivial. There was no significant interaction.

Digit span backward showed no significant difference between the inactive and active condition. The effect size ($d = 0.05$) was trivial. There was no significant difference between moderate ($M = 7.2$, $SD = 2.46$) and vigorous exercise intensity ($M = 7.05$, $SD = 1.67$, $d = 0.07$). The effect size was trivial. No interaction effect was exhibited.

Discussion

The purpose of this study was to investigate if an acute bout of exercise had an effect on executive functions. No significant results were found. The results indicated that there was no difference on the performance on the cognitive tests between the inactive and active condition. Moreover, there was no significant difference between moderate and vigorous exercise intensity. No significant interaction between condition and intensity was found.

Previous studies have been inconsistent in their findings. In an attempt to unravel the inconsistency, the current study used similar experimental methods and combinations of
details, such as duration of the active condition, intensity level, and time of delay between activity and cognitive tests, as those used in previous studies where significant positive effects were found. In spite of this, the results of this study do not support that these specific exercise conditions significantly improve cognitive functioning.

For instance, the exercise duration in the current study was set to 20 minutes, which according to Chang et al. (2012) would be the minimum duration required for a positive effect. Exercise for less than 20 minutes would not affect biochemical and physiological mechanisms enough to influence executive functioning in a positive way (Chang et al., 2012). The participants in the current study were used to regular exercise and had, on average, been training for 10 years. Individuals with higher fitness levels are able to tolerate more physical and psychological stress from exercise, which might affect biochemical responses (McMorris & Hale, 2012; Tomporowski, 2003). Therefore, highly fit individuals may need more than 20 minutes to raise their arousal levels enough to affect the biochemical response leading to positive effects on executive functions.

Long-term exercise has been associated with higher levels of BDNF (Erickson et al., 2011; Piepmeier & Etnier, 2015; Szuhany et al., 2014). An acute bout of exercise elevates the BDNF levels temporarily, but they start to return to baseline after about 10 minutes (Piepmeier & Etnier, 2015). It is possible that the participants already had some long-term benefits from exercise, such as elevated baseline BDNF levels, which would benefit executive functioning during both inactive and active conditions. This would explain the nonsignificant difference between the two conditions. In addition, the acute bout of exercise may have further elevated the BDNF levels temporarily, but without additional positive effects on executive functions. An explanation for the lack of additional effects could be that the elevated BDNF from the acute bout had returned to baseline after the 10 minute delay.

Brown and Bray (2018) conducted an experiment where the participants were exposed to 20 minutes of exercise followed by a 10 minute delay before the cognitive tests, which was an almost identical setup as the one used in the current study. However, Brown and Bray (2018) found a positive effect, whereas no effect was found in the current study.

The difference could be due to the fitness level of the participants. In the study by Brown and Bray (2018), the participants’ fitness levels were not specified but described as recreationally active. This implies that participants were involved in some recreational physical activity but they were not required to be regularly exercising. In the current study, in addition to 10 years exercise experience, the participants were training for almost eight hours per week, which indicates high fitness levels. Furthermore, Chang et al. (2012) concluded that fitness level significantly moderated the effects on the cognitive tests during and immediately after exercise, but not after a delay. During and immediately after exercise, a high fitness level showed the most positive effects. This could, on one hand, be attributed to the transient hypofrontality hypothesis, indicating that highly fit individuals need less resources for exercise and can instead use the resources for cognitive functioning. On the other hand, it could be attributed to the participants’ ability to recover faster after exercise (Chang et al., 2012; Tomporowski, 2003).

Whether a delay between the cessation of exercise and cognitive tests would be beneficial or not could depend on the intensity level of the exercise. Two different intensity levels were used in the present study, moderate and vigorous. According to a meta-analysis by Chang et al. (2012), moderate intensity had beneficial effects immediately after cessation of exercise and after a delay. Higher intensity lead to longer lasting positive effects on cognition but would be beneficial only after a delay. These results were based on 79 studies with multiple intensity levels, where very hard intensity had a distinctively larger effect, after
a delay, than any other intensity. Very hard intensity was set above 93% HRmax (Chang et al., 2012). In the current study, moderate intensity was between 55% and 70% HRmax and vigorous intensity was between 70% and 90% HRmax, which means that none of the participants went above 90% HRmax. This could explain why there were no significant results and no differences between the intensity levels. To get an effect from exercise after a delay, the participants would have had to exercise at a higher intensity level. In addition, the higher intensity level should have differed more from the moderate level for a visible difference between the two intensity levels.

The two intensity levels would also test the inverted-U hypothesis supported by previous research. The hypothesis suggests that there is a non-linear relationship between exercise and cognition where moderate intensity is believed to have the most beneficial effects on cognitive functioning (McMorris & Hale, 2012). Because of the lack of significant results in the present study, it is impossible to support or reject the inverted-U hypothesis. However, based on the results from the present study and possible explanations from previous studies, it seems plausible that the inverted-U hypothesis is only applicable when there is no delay between exercise and the cognitive tests. When there is a delay, as mentioned earlier, a higher intensity or longer duration of exercise might be more beneficial.

Exercise induces an increase of arousal and the release of catecholamines (Hung et al., 2013; Ludyga et al., 2018; McMorris & Hale, 2012). For a positive effect to be obtained, the catecholamine levels need to rise high enough to affect cognitive functions (McMorris et al., 2011; McMorris & Hale, 2012, 2015). The duration and intensity it takes to increase catecholamines is individual (McMorris, et al., 2000). However, it has been discovered that higher intensity exercise leads to a faster significant increase in catecholamines (Chmura, 1998). While intensity has been identified as the most important factor in the catecholamine response to exercise, duration also plays an important role (Zouhal, Jacob, Delamarche, & Gratas-Delamarche, 2008). If a high intensity is not reached, a longer duration is required. After 20 minutes of vigorous exercise, the plasma noradrenaline levels were at the same level as they were after 60 minutes of moderate exercise (Kjaer, Secher, & Galbo, 1987). An animal study by Pagliari and Peyrin (1995) revealed that 20 minutes of aerobic exercise increased only the plasma catecholamine concentrations. To increase the catecholamine concentrations in the brain, another 20 minutes of exercise was required. Furthermore, the study revealed that a longer duration of exercise caused longer lasting elevated catecholamine levels (Pagliari & Peyrin, 1995). Therefore, the short duration and the intensity levels used in the study might not be enough to affect cognitive functioning. To get the positive effects from catecholamine release, the exercise duration should be at least 40 minutes to sufficiently increase the concentrations of catecholamines in the brain.

In the brain, the catecholamines dopamine and norepinephrine aid executive functioning, in the blood however, norepinephrine is involved in regulation of the cardiovascular system (McMorris & Hale 2015). Catecholamine concentrations can increase both in the blood and the brain during arousal, but the catecholamines do not cross the blood-brain barrier (McMorris & Hale, 2015). This implies that it is possible to increase the catecholamine concentrations in the blood by increasing the exercise intensity but to be able to increase the catecholamine levels in the brain significantly, the individual must interpret the situation as threatening or stressful. It is the perception of stress and psychological arousal that triggers the release of catecholamines in the brain, not the exercise-induced physiological arousal (McMorris & Hale, 2015). Considering the fact that the participants in the present study were used to regular exercise, a stationary bicycle may not be enough to increase their perception of stress and raise their catecholamine concentrations in the brain enough to
improve cognitive functioning.

In conclusion, previous studies combined with the present study imply that the relationship between exercise and cognitive functioning is very complex. Catecholamines may play an important role in this relationship. It is possible that the combination of the duration of the exercise, the intensity, and the duration of the delay is very individual. Therefore, if the active condition is set to 20 minutes, to avoid a loss of effect due to a decrease in important neurochemicals during the recovery time, highly fit individuals should be tested immediately after cessation of exercise. Alternatively, if there is a delay before the cognitive tests, highly fit individuals may require more than 20 minutes of activity or a higher intensity level, to be able to benefit from the exercise.

**Limitations**

Before drawing conclusions from this study, there are a number of limitations that should be taken into account. Some of the limitations of the study are factors that can lead to unsystematic random errors of measurement and affect internal validity negatively. As much as random errors affect the score of individuals, it tends to balance out and not affect the total score. Other limitations, such as the pursuit of external validity, can affect the study’s power negatively (Mitchell & Jolley, 2013).

To minimize errors, the experiment was standardized as much as possible. It was conducted in the same location, used the same materials for all participants and everyone received the same verbal and written instructions. For example, when time was measured during the experiment, two instruments were always used simultaneously. This was done to make sure the time durations recorded on different devices were congruent and to ensure time would be recorded even if one device stopped working. In spite of attempts to reduce errors, environmental conditions were not identical for all participants. Time of day and noise level were factors that varied between sessions and could account for some random errors. Chang et al. (2012) discovered that the time of day significantly influenced the effects. Their findings suggested that sessions administered in the morning had larger positive effects whereas negative effects were found when the sessions were conducted during different times of the day. The data collection in the present study was performed during a two-week period and the sessions were conducted any time between 6 a.m. and 10 p.m. Some participants were tested in the morning, but many were tested in the afternoon and evening. The first and second session were sometimes administered during different times of the day. This variety could help explain the nonsignificant results.

In the current study, all cognitive tests were pilot tested before the experiment was conducted. There were no complications during pilot testing, however, two limitations were discovered during the experiment. It was not possible to use a computerized version of the Stroop test in the current study, instead a printed version was used. A computerized version would have been able to register reaction time more accurately, and therefore give more reliable results. The second limitation was the Trail Making Test. Because the test is standardized with only one version, the participants seemed to have somewhat memorized the pattern, resulting in faster completion during the second session. In order to compensate for the practice effects on the cognitive tests, the participants were randomly assigned to the different conditions.

The design of the present study was time consuming and limited to a specific location. As a result, interested individuals were unable to participate, leading to only 20 participants in the study. A low number of participants could make it harder to detect significant results and could lead to low power. However, the majority of the effect sizes were weak or trivial, which indicates that a higher number of participants would not lead to significant results.
Therefore, it is likely that the lack of significant results is due to something other than a low number of participants, such as a complex relationship between the variables.

**Conclusions**

No statistically significant results were found in the present study, it is therefore difficult to draw any conclusions about the cause and effect relationship between exercise and executive performance. Based on previous studies, exercise may enhance executive functioning but this is dependent on a number of factors and could also be very individual. One moderating factor that seems especially important is the participants’ fitness levels, which is a possible explanation for the lack of significant results in the current study. To accommodate participants’ fitness levels, a change of design might be needed. For higher fitness level, a design including higher intensity, longer duration of exercise or no delay between the cessation of exercise and cognitive tests may be necessary.

**Implications**

The results from the current study can contribute to research on the effects of exercise on executive functioning. While the present study did not find any significant results, it adds to the large body of research and may encourage researchers to further try to understand the complex cause-and-effect relationship between exercise and executive performance.

**Future Research**

It is important to continue to research the combinations of exercise duration, intensity and delay to gain a better insight in the circumstances required to receive a positive effect from exercise. To investigate the cause-and-effect relationship, larger samples sizes are needed as well as larger doses of the exercise variables, such as higher intensity and longer duration. It would also be of value to test the participants during, immediately after exercise, and after a delay to test the duration of possible effects. The combinations of duration, intensity and delay may be very individual, which would require experimental designs with specific conditions depending on each individual. Future research must also investigate the influence of possible moderators, such as fitness level, by comparing active individuals of different fitness levels to inactive individuals. A large amount of studies focus on children and older adults, but few examine the effects on adults, it would therefore be of interest to further examine this group.
References


McMorris, T., & Hale, B. J. (2012). Differential effects of differing intensities of acute


Appendix A

Informerat samtycke för deltagande i studie

Jag har fått ta del av informationen om studien “Motions effekt på kognitiva funktioner”. Genom att signera detta dokument ger jag mitt samtycke till att delta i studien. Jag är medveten om att deltagandet är frivilligt och att jag når som helst kan välja att avsluta min medverkan utan att ange orsak.


Namn:
___________________________________________________________________________

Ort och datum:
___________________________________________________________________________

Signatur:
___________________________________________________________________________
Informationsbrev

Studie om motions effekt på kognitiva funktioner

Förfrågan om deltagande i studien om motions effekt på kognitiva funktioner
Vi är två studenter på Högskolan i Halmstad som går tredje året på programmet Psykologi inriktning idrott och motion. Vi skriver just nu vår C-uppsats där vi vill studera om det finns någon effekt på kognitiva funktioner efter utövande av motion.

Syfte med studien
Syftet med studien är att undersöka om motion har effekt på hjärnans kognitiva funktioner. Syftet är inte att på något sätt se och jämföra prestationerna på individnivå, utan endast att undersöka skillnad på gruppnivå.

Vad betyder deltagandet i studien?

De två testtillfällena kommer att utföras olika dagar och det är viktigt att du inte har utfört någon typ av motion samma dag som du ska delta. Motionsaktiviteten som ska utföras kan upplevas fysiskt ansträngande, det är därför viktigt att du anser dig själv i god form för att kunna utföra detta. Deltagandet är helt frivilligt och du har rätt att när som helst under studiens gång dra dig ur utan att ange orsak.

Väljer du att delta i studien kommer vi att kontakta dig för att boka in de båda testtillfällena. Vid första testtillfället kommer du få signera ett informerat samtycke för deltagandet. Detta ger oss ditt medgivande att delta i studien, samt att du är införstådd i studiens syfte, vad deltagandet innebär, samt att du har möjlighet att avsluta ditt deltagande när som helst.

Vad händer med informationen?
För att data från de olika mättillfällena ska kunna kopplas samman och för att behålla alla deltagare anonyma kommer du att tilldelas ett personligt ID-nummer. Datan som samlas in kommer att analyseras i statistikprogrammet SPSS och inga analyser kommer att ske på individnivå. Under studiens gång kommer inga obehöriga ha tillgång till datan som samlas in och analyseras och all insamling kommer att förvaras under säkra förhållanden fram till studien är avslutad. Därefter kommer all insamlad data att förstöras.

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Tack på förhand!