Acute effects of physical exercise of different intensities on working memory

- Master thesis

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Abstract

**Aim:** The purpose of this study was to investigate acute effects of physical exercise of different intensities on working memory.

**Method:** Twelve young adults, 20-40 years, 8 males and 4 females passed the screening and participated in a randomized experimental crossover within-subject design study with three experimental conditions. Working memory was measured with n-back consisting of three difficulty levels.

**Results:** No significant interaction effect within subjects between the three different exercise intensity conditions for accuracy or response time was found. A significant main effect of time was detected for n-back response time, $F(1,11)=40.2, p<=.001$, reflecting an overall shorter response time after exercise compared to before, independent of exercise intensity condition. A two-way interaction effect on accuracy was found between n-back session 1 and 2 in the low fitness group.

**Conclusions:** The exercise intensity does not seem to matter for the improvement of working memory performance. However, participants response time was shown to be faster following any given exercise intensity.
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1. Introduction

Positive effects of acute exercise on cognition are now well-established (Chang et al., 2012). Burstein et al. (2021) reported that a single bout of aerobic exercise had positive impact on selective cognitive functions, such as cognitive flexibility and attention. As a matter of fact, a single bout of physical exercise has also been coupled to greater performance in working memory, which is the ability to maintain and update information in short-term memory (McMorris et al., 2011; Moreau & Chou, 2019). Greater manageability of working memory is desired and important and since it is reconciled with learning over time it could be coupled with success in academic achievements and work life where learning is a fundamental aspect. Despite the central role of working memory, evidence on how physical exercise intensity matters in acute effects on working memory is insufficient (Alloway & Alloway, 2010). Further, some correlational results suggest that working memory could be predictive of fluid intelligence (Fukuda et al., 2010) and Cochrane et al. (2019) shows that capacity limitations in attention and memory tasks are related to fluid intelligence.

The investigation of how physical exercise intensity matters is important for the understanding of how to apply the most adequate intensity, in the dose-response relationship between a single bout of physical exercise and positive effects on working memory. The meta-analysis by Chang et al. (2012) suggested that the intensity by the exercise with most beneficial effects were dependent upon the timing of cognitive measurement, with higher intensities being beneficial only after a delay. In contrast to young adults, current support of acute effects on executive functions and working memory by physical exercise is often assigned to older adults (Chang et al., 2012; Ludyga et al., 2016), children or adolescents, perhaps due to individual undergoing development changes or declines at those respective stages in life (Lebeau et al., 2022). Current study differentiates from this previous work by addressing healthy young adults. In addition, since evidence on how intensity play a role is insufficient, this study aimed to investigate acute effects on working memory by physical exercise of different intensities. An improved understanding of the influence of exercise intensity could contribute with new knowledge on how acute exercise can be optimized for maximal effects on working memory and in extension on academic and work-related success in healthy young adults.
2. Background

2.1 Working memory

Cognition is a term that covers different processes in the brain, including for example attention, memory and executive functions (Tomporowski et al., 2011). Cognitive functions play a significant central role in people's everyday life and gives the opportunity to cope with our daily activities. Further, cognition is a set of mental processes for acquiring and managing information and knowledge (Friedman, 2022). Breukelaar et al. (2018) and Diamond (2013) describing those executive functions are basic mental processes required when concentrating and for the need to pay attention. Working memory is often conceptualised as being one of the three executive functions and refers partly to the ability to keep information in mind and manipulate it. Other executive functions are inhibition or inhibitory control such as control attention, thoughts and shut out external factors to focus on what is necessary at the time, and cognitive flexibility as refers to the ability to view things from another perspective, and it can also include being able to admit being wrong or adapt to altered demands (Diamond, 2013; Martinez-Diaz et al., 2020). In daily life, our working memory is utilized during demanding bursts of concentration, for example when participating in sports requiring concentration or reading, mental arithmetic, playing chess etc. Research in understanding executive functions often address working memory (Chang et al., 2012; Slutsky-Ganesh et al., 2020).

To investigate working memory in humans, the n-back test is a valid and commonly used instrument (Soga et al., 2015; Sun et al., 2019). The n-back test requires respondents to identify items that has been shown in n-steps prior, which rests on the ability to hold and manipulate information in memory. Common is 1, 2 or 3 steps prior to when the items are shown again (Owen et al., 2005). The test challenges a subject to update, maintain and manipulate information that is kept in mind. Hence, it is demanding for processes within the working memory (Owen et al., 2005). Among many areas of the brain identified as activated when performing the n-back test, the prefrontal cortex is most prominent. The prefrontal cortex is an important area in the brain when utilizing working memory (Owen et al., 2005; Sun et al., 2019). Activation in prefrontal cortex has for example been captured via functional near-infrared spectroscopy (fNIRS) following tasks that put demands on working memory (Sun et al., 2019).
2.2 Physical activity and physical exercise, anaerobic threshold and exercise intensity

Caspersen et al. (1985) defined physical activity as “any bodily movement produced by skeletal muscles that results in energy expenditure”. By this definition, physical activity has become an umbrella-term that covers a variety of bodily movements representing different modalities, durations, and intensities of physical activity. This means that physical activity can be categorized into different activities for example unplanned daily walks, bodily movement at home or at work. Physical activity can also be categorized as sports or planned training with an objective in mind (Caspersen et al., 1985). Herold et al. (2019) further elaborate that when physical activity become planned, structured, and specific it is referred to be physical exercise. Physical exercise is in many instances done with the aim to maintain or improve physical fitness and can be considered as a subcategory within physical activity (Caspersen et al., 1985). Physical activity can be carried out as regular or as a single bout of physical exercise, often referred to as acute physical exercise in research. Since present study involves planned physical activity of a fixed duration and intensity, physical exercise will be the term used.

Physical exercise can be performed in different intensities. Depending upon research aim, studies often determine exercise intensity by putting it in relation to subjects' percentage of VO2max or percentage of maximal heart rate. While FYSS (2017) defines low intensity as 20-39%, moderate intensity as 40-59% and high intensity as 60-89% of VO2max, others have defined 50%-75% of a subjects VO2max as intermediate (McMorris et al., 2011). Various intensities of the exercise and one's fitness level will likely drive the body's demand of energy production, referred to as aerobic- and anaerobic thresholds. Aerobic threshold is the point where the body starts to depend on anaerobic metabolism to produce energy, often reflecting an increase in exercise intensity. Anaerobic threshold is the point when the body starts to produce more lactate than the body can handle. Once intensity rise beyond this threshold, levels of blood lactate begin to rise, and the body cannot keep up with the oxygenation demands from muscles to produce energy. At this point, fatigue sets in and the body cannot sustain exercise for a much longer period (Wasserman, 1986; Jakobsson & Malm, 2019).
2.3 Acute effects of physical exercise on cognition

A great deal of research has been conducted on how exercise affects cognitive functions (Chang et al., 2012; de Greeff et al., 2017; Ludyga et al., 2016; Park et al., 2021; Roig et al., 2013; Warren & Voss, 2015). For example, Roig et al. (2013) concluded in a meta-analysis that acute and long-term cardiovascular exercise improving cognitive functions as long- and short-term memory. The authors proposed a combination of acute and long-term exercise for the most beneficial effects on human memory. Today it is growing evidence about effects of acute and long-term physical exercise on cognitive functions and cognitive performance in preadolescent children as well as in adults (de Greeff et al., 2017; Chang et al. 2012; Olivo et al., 2021; Lambourne and Tomporowski, 2010). The authors also suggest that cognitive performance may be depending on measurement timing, selected cognitive task, the type of exercise performed and different development phases in children (Ellemberg & St-Louis-Deschenes, 2010). The improvements in children may be attributed to a reduction in reaction time in the cognitive performance task (Ellemberg & St-Louis-Deschenes, 2010). Thus, it appears that the beneficial effects on cognitive performance apply to study populations of different ages.

2.4 Acute physical exercise and working memory

Evident in research is that acute physical exercise can have positive effects on executive functions, which often includes working memory function (Chang et al., 2012; Verburgh et al., 2014). In a meta-analysis containing 24 articles, McMorris et al. (2011) reports that acute intermediate intensity exercise has strong beneficial effect on response time but a low to moderate effect on accuracy, in working memory tasks. Another meta-analysis reported small significant positive acute effects on executive functions by exercise. The subcomponents of executive functions were examined and small significant positive acute effects on working memory were shown (Moreau & Chou, 2019). Besides, acute aerobic exercise promotes improvements in cognitive functions within the prefrontal cortex (Mandolesi et al., 2018). The prefrontal cortex is a brain region prominent to be activated when performing working memory tasks (Owen et al., 2005).
Different modes of physical exercise appear to play a role in affecting executive functions and working memory and should thus be mentioned specifically. In an experimental and controlled study that investigated effects on executive functions by different modes of physical exercises, Pontifex et al. (2009) presented faster reaction time in subjects with task conditions requiring working memory capacity immediately and 30 min post a single bout of aerobic physical exercise. Findings from another experimental study shows young adults improved performance of working memory during acute aerobic exercise, pointed to faster reaction time in the subjects' answers (Zheng et al., 2022). In addition, Kao et al. (2020) reported that a single bout of aerobic exercise of 20 minutes temporarily improved working memory. Thus, it appears that acute exercise can improve working memory in young healthy adults, perhaps most prominently in terms of reaction time.

2.5 The role of intensity, Inverted U-shaped theory and anaerobic threshold

Some research suggests that the relationship between physical exercise intensity and cognitive functions follows the Inverted U-shaped theory (Chang et al., 2012; Olivo et al., 2021). The Inverted U-shaped theory originates from Yerkes and Dodson (1908). The implication of the theory is that optimal benefits of exercise to promote cognition are achieved at intermediate levels of arousal, while low or high arousal that deviates from intermediate levels may instead result in cognitive performance impairments. This theory makes physical exercise a double-edged sword, meaning that when physical exercise intensity is too low, no performance improvement is shown. If exercise intensity is too high, the performance improvement is rather impaired than improved. When physical exercise is of moderate intensity though, it has shown to be most beneficial for cognition in both short- and long term (Chang et al., 2012).

Cira et al. (2021) proposes endurance physical exercise to be functioning in an experimental setting of arousal changeover towards higher arousal. This changeover has been affiliated with cognitive processing, especially higher order processes requiring cognitive performance, such as executive functions. Chang et al. (2012) reported that higher intensity of physical exercise appears to be beneficial. However, the authors argue that when intensity overrides the anaerobic threshold the effects inhibit cognitive performance rather than benefits. Another line of reasoning that has been advanced is that the anaerobic threshold is individual; thus, one suggestion is that individuals with higher fitness could see better effects when the
intensity of physical exercise is higher and if the physical exercise is prolonged for 20 minutes or longer (Chang et al., 2012). That being said, one possibility is that improved cognitive performance is demonstrated at higher intensity if the exercise remains aerobic, according to the perspective of Yerkes and Dodson (1908) and reports from Chang et al. (2012).

However, Chang et al. (2012) adds that very light (<50% HRmax), light (50-63% HRmax) and moderate (64-76% HRmax) intensity had positive acute effects on cognitive tasks immediately after exercise. When intensity becomes hard (77-93% HRmax) and very hard (>93% HRmax), effects were shown to decrease when the cognitive test is performed immediately after exercise. If timing of cognitive test however were performed with a delay following the exercise, largest effects was shown higher intensity, whereas very light intensity showed no positive effects. The different outcomes may perhaps be driven by the timing of cognitive test following exercise and intensity of the given exercise.

Similar effects of physical exercise on working memory have been reported in both males and females (Shah et al., 2022; Wilke, 2020).

2.6 Moderating factors

Studies in the exercise and cognitive functions area often apply different exercise duration interventions (Knaepen et al., 2010). In a meta-analysis Chang et al. (2012) suggests the acute exercise session to be at least 20 minutes to show positive effects on cognitive functions. Moreover, Burstein et al. (2021) concluded that 20 minutes of acute exercise had positive impacts on cognitive functions in a cross-over RCT study. Different modalities of physical exercise are also prominent in literature. Common physical exercise utilized in studies is aerobic, often in the case of treadmill running or cycle ergometer. Another physical exercise modality to encounter in studies is resistance exercise. However, larger evidence in effects on cognitive functions have been shown by aerobic physical exercise compared to resistance exercise and are therefore the current preference of exercise mode across intervention protocols in research (Chang et al., 2012). Additionally, acute aerobic exercise appears to have a generally beneficial effect across tasks requiring demands of executive control (Pontifex et al., 2009).
2.7 Brain-derived neurotrophic factor and exercise intensity

One physiological response of acute exercise that may play a role in its cognitive effects is brain-derived neurotrophic factor (BDNF). BDNF is a neurotrophin that is important for memory function, neurogenesis and triggers the process of plasticity in the brain (Tsai et al., 2021). BDNF has been reported to increase acutely following exercise (Chang et al., 2012; Dinoff et al., 2017; Knaepen et al., 2010). Exercise increases energy metabolism and promotes a cascade of molecular processes which in turn support neuroplasticity and cognitive function. It is believed that higher intensity of exercise is likely to induce greater BDNF increases. In a meta-analysis, Dinoff et al. (2017) describes a positive association between increasing exercise intensity and larger peripheral BDNF concentrations. In previous research on cognitive functions and working memory by exercise and physiological response by exercise, an understanding has emerged that there exist varying results (Chang et al., 2012). Unlike some studies that show positive results on working memory by moderate intensity exercise, others also show positive results by high intensity exercise. Previous studies report a linear relationship between high intensity exercise and peripheral BDNF concentrations in healthy young adults (Dinoff et al., 2017; Knaepen et al., 2010; Ross et al., 2019). If BDNF were to influence the acute effects on working memory by acute aerobic exercise, the higher intensity of the exercise could benefit the outcome.

2.8 Summary

This study intends to investigate acute effects on working memory with a 10-minute delay following each exercise intensity condition. By reason of previous reported research concerning measurement timing, exercise intensity (Chang et al., 2012) and increases of peripheral BDNF concentration following high exercise intensity (Dinoff et al., 2017; Knaepen et al., 2010), following hypothesis is formulated in line with the linear relationship. Since the working memory task will be performed with a delay, the hypothesis of this study is in line with the linear relationship of intensity and physiological responses following the acute physical exercise. This means that the effects are expected to be prolonged due to higher intensity of the exercise, given that the delay before the working memory task begins is set to be 10 minutes. If the working memory were to be performed immediately following exercise, moderate intensity of the physical exercise could rather be the optimal intensity in line with the Inverted U-shape theory.
3. Hypothesis
- Higher intensity will result in greater benefit to working memory compared to moderate intensity, and moderate intensity will result in greater benefit than low intensity according to the linear relationship.
- Additional exploratory analyses were carried out to investigate possible moderating effects by n-back difficulties and fitness level for greater working memory performance.

4. Method

4.1 Design
The study had a randomized experimental cross-over within-subject design in which participants become their own control. The study presented here investigated acute effects of a single bout of aerobic exercise at three different intensities on working memory. Participants performed physical exercise at three different intensities in randomized order at three different experimental occasions. Participants performed a working memory task before and after every physical exercise occasion within the intervention sessions. In between every occasion for each exercise condition, a weekly wash-out period took place to equalize participants prerequisites ahead of every experimental occasion. This study was part of a more comprehensive pilot study that was considering wider interests than present study.

4.2 Participants
This study aimed to recruit fifteen participants. At a significance level of 0.05 and statistical power of 0.8, this sample size meant that the study was powered to detect large effects (Cohen’s d = 0.8) (Faul et al., 2009). It should be noted that the pilot study was not designed to be powered for working memory as the outcome but for fNIRS signal, which was a measure not considered in the present study.

Twenty-one young adults (20–40 years) were invited to the first session of screening, whereof twelve participants passed the screening session and completed the study (See figure 1 for overview). The recruitment was carried out at Stockholm universities i.e., GIH and Karolinska Institute, through advertising on science study recruitment platforms as Accindi, GIH and Karolinska Institute websites, as well as GIH Instagram. Recruitment was also done
by physical promotion of the study in university classes at GIH and physical advertising on paper forms at GIH facilities.

Interested participants were welcome to contact responsible researcher and a return email was consisting of a minor questionnaire was sent out to the respondents via Sunet drive solution. The questionnaire was an initial check that the participants met the inclusion criteria for participation and the questions referred to participants health, physical activity behaviour and availability to take part in the study. Respondents who corresponded to inclusion criteria by the online-questionnaire check were welcome to GIH for a first physical meeting. Ahead of the first visit, each participant was given a written description of the study information, aim, procedure and risks of participation. The first visit began with the researcher to confirm that the participant had taken part of the written study information, followed by a verbal description of the study information and further questions. Thereafter, a written informed consent was obtained ahead of screening and data collection.

Criteria for inclusion in terms of participants at an age within 20-40 years, not participating in any other study simultaneously and was assessed appropriate to participate in a study that included physical activity. Initially, participants were required to score 2.75 or below on the self-rating scale Shirom-Melamed Burnout Questionnaire (Melamed et al., 1992). This was later altered to the global SMBQ-limit, 3.75 or below. Since this study aimed to recruit healthy participants, some exclusion criteria were put up and screened for during visit 1. Participants that demonstrated a lower score than 25 out of 30 on Mini Mental State Examination, was excluded (Folstein et al. 1975). Females with a score lower than 6 and males with a score lower than 8 on Alcohol Use Disorders Identification Test, was excluded (Bergman et al., 1994). If participants scored lower than 8 on Hospital Anxiety and Depression scale, further participation was discontinued (Zigmond & Snaith, 1983). This was later altered to a limit of 10. Other exclusion criteria were screened for by a health declaration. In consideration of medical obstacles for participation, smoking, post-Covid, chronical medication assessed to affect the question at issue, chronical disease or syndrome and other somatic diseases or injuries affecting the ability to perform physical exercise. Once participants passed the inclusion and exclusion criteria, they received a study participant ID and were scheduled to four forthcoming interventions-visits.
Figure 1. Overview of recruitment process.

4.3 Procedure

4.3.1 Baseline measures

By the reason that present study was a part of a larger pilot study, other baseline measures were collected during the first visit which was not of interest in terms of screening or analyses in this study. Nevertheless, the other baseline measures are mentioned here for completeness. Baseline measures like Patient Health Questionnaire 9 (PHQ-9), Generalized Anxiety Disorder 7-item scale (GAD-7) and Karolinska Sleep Questionnaire (KSQ) was conducted. By interest from the larger pilot study, visit 2, 3 and 4 collected data of participants daily health and weekly physical activity status, sleep quality of recent night and sleepiness last 10 minutes. Mentioned data was collected with State of Health and Physical Activity Questionnaire, Sleep Quality Scale (SQS) and Karolinska Sleepiness Scale (KSS). Further, data of participants mood by Positive and Negative Affect Schedule (PANAS-SF) questionnaire, estimation of mental fatigue by Visual Analog Scale (VAS) and physical exertion by the BORG/RPE-scale was collected for purposes of the pilot study. Participants answered the questionnaires in a total of four times during each visit, twice prior the intervention and twice after. Finally, participants wore fNIRS cap and heart rate variability (HRV) data was collected during intervention visits for purposes of the pilot study.
4.3.2 Submaximal test

If participants passed the criteria for inclusion and exclusion, visit 1 continued by Ekblom-Bak submaximal VO2max-test (EB-test). EB-test estimates VO2max based on age, sex and heart rate differences between a low standard work rate and an individually high work rate (Ekblom-Bak et al., 2014; Björkman et al., 2016). The test procedure follows that participant cycles in four minutes at a low standard load at a pedalling frequency of 60 revolutions per minute. This load is the same for everyone. Average heart rate during the last minute is then noted. Thereafter, the load is increased to a higher individually load that makes the participant attain a steady state heart rate above 120 beats per minute. The participant also reports a general perceived physical exertion around 12-15 at the Borg RPE scale (see figure 2 for Borg RPE scale) (Borg, 1998). Further, the average heart rate during the last minute of the four minutes work at the higher load is noted. Finally, VO2max is calculated by participants gender, based on differences in heart rate between the lower and higher load, a factor which corresponds to the higher load and at last age (Björkman et al., 2016).

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
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<tr>
<td>6</td>
<td>No exertion at all</td>
</tr>
<tr>
<td>7</td>
<td>Extremely light</td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Very light</td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Light</td>
</tr>
<tr>
<td>12</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Somewhat hard</td>
</tr>
<tr>
<td>14</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Hard</td>
</tr>
<tr>
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<td>17</td>
<td>Very hard</td>
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<tr>
<td>18</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Extremely hard</td>
</tr>
<tr>
<td>20</td>
<td>Maximal exertion</td>
</tr>
</tbody>
</table>

Figure 2. Borg RPE scale.
4.3.3 Individualised exercise load

During visit 1, participants performed Ekblom-Bak submaximal test in order to estimate participants VO2max. Estimated VO2max was used to individualize the load for the different intensities for intervention visits. The loads were calculated by the ASCM leg ergometer equation, expressed as VO2 (ml/kg/min) = 1.8 (work rate (kg x m/min) / body mass (kg) +7) (Glass & Byron Dwyer, 2006). The original plan was to determine intensities as 40, 60 and 80% of participants VO2max. However, during the initial recruitment it was discovered that the Ekblom-Bak VO2max-test appeared to overestimate participants score in VO2max, which made it impossible to individualize intensities to 40, 60 and 80% of the participants maximal oxygen consumption. Therefore, procedure was changed, and definitions of intensities were adjusted and defined as low, moderate and high intensity.

Participants familiarized themselves with the loads calculated by the ACSM ergometer equation (Glass & Byron Dwyer, 2006). At first, participants exercised 5 minutes each on selected load at 40, 60 and 80% of estimated VO2max. Participants were told to cycle with a cadence of 70 at 40%, 80 at 60% and 90 at 80%. The test leader noted participants heart rate and perceived physical exertion during the 5 minutes at each intensity, to determine that accurate load was given in accordance with respective intensity. But, since the EB-test overestimated VO2max scores, the procedure was changed during recruitment. Revised procedure during this familiarization part focused on determining 80% of participants VO2max, where participants perceived physical exertion at 15-17 on Borg RPE scale was pursued. The load for 40 and 60% was determined based on that and more time was given to determine 80% of participants VO2max more accurately. Since EB-test was known to overestimate, participants began to exercise at 70% of individual VO2max for 5 minutes. If participants experienced and pointed to 15-17 at the Borg RPE scale, current load was determined to be 80% and corresponded to the load given at high intensity. If participants perceived physical exertion reflected lower than 15 on Borg RPE scale at a load corresponding to 70% after 5 minutes, the load was increased to 80% and the participant cycled further 5 minutes. If participants perceived physical exertion was within 15-17, the load was determined. If the perceived physical exertion was higher than 17, the load for 70% was determined. If the perceived physical exertion was higher than 17 at the load of 70%, the load was decreased to 60%, and was determined to be the load at 80% if the physical exertion
reflected Borg RPE scale within 15-17. Also, a maximal ceiling of 250 watts for males and 180 watts for females at 80% was applied.

4.3.4 N-back

Participants performed the working memory task 10 minutes prior to each exercise intensity condition and 10 minutes following each exercise intensity condition. Both working memory task occasions carried on for approximately 15 minutes each. Computerized numerical n-back was the working memory task which proceeded at approximately 15 minutes. The n-back test started with 40 seconds of rest. After the initial 40 second rest, participants performed 3 blocks of 1-back, 2-back and 3-back with 40 seconds of rest between each block. Each block consisted of 20 numerical digits and each digit was presented on the screen for 1.5 second and a 0.5 second space until next presented digit. The task required participants to identify if current digit on the screen was the digit that was presented 1, 2 or 3 steps prior to the current or not. Participants pressed left arrow key on the keyboard if they believed that the digit was present and the right arrow key on the keyboard if they believed the digit was absent. Participants performance in the n-back test was measured as accuracy and response time. Accuracy was measured in hit ratio. Hit ratio was calculated by dividing the number of correct responses (hits) with the total number of trials. Average response time was calculated based on correct trials only.

N-back task was verbally introduced and explained by the test leader, followed by participants to practise 1-back, 2-back and 3-back with feedback of results according to instructions given on the computer screen, for approximately 5 minutes. Thereafter, participants practised 1-back, 2-back and 3-back again without feedback of results on the computer screen, also for approximately 5 minutes. This practice of the n-back task without feedback was also given to the participants once at each intervention visit, before the pre-test measurement.

4.3.5 Exercise intervention

The exercise intervention consisted of leg cycling with a standardized duration of 20 minutes in accordance with recommendations from previous research (Chang et al., 2012; Burstein et al., 2021) (See figure 3 for overview). The intervention began with 1 minute warmup at optional warmup-load followed by 19 minutes of exercise at individual watt load
corresponding to either low, moderate or high intensity. Four times at every fifth minute during the exercise intervention, the test leader noted participants heart rate via heart rate monitor that was placed on the participants chest. In addition, participants were asked to point at perceived physical exertion on the Borg RPE scale, also four times in total at every fifth minute. Participants were instructed not to talk or drink any water during the 20 minutes of physical exercise, because of the possibility to interfere with the heart rate. In visit 2 (first intervention), participants were randomly assigned any of the low, moderate or high intensity workloads. At visit 3, participants were given either of the two remaining intensity workloads and during visit 4, the participants were given the last remaining intensity workload. Participants was informed of specific intensity during current visits, just ahead of when each of the exercise interventions was performed.

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<tr>
<td>Informed consent - screening CB&amp;As</td>
<td>10min Pre-exercise 15min 10min</td>
</tr>
<tr>
<td>Ebbom-Bak Submaximal VO2 max-test</td>
<td>Exercise 20min 10min Post-exercise 15min 10min</td>
</tr>
<tr>
<td>Familiarization</td>
<td>N-back pre</td>
</tr>
<tr>
<td>Baseline measures, Q&amp;As</td>
<td>Q&amp;As - HRV - Rest</td>
</tr>
<tr>
<td>N-back practice</td>
<td>N-back post</td>
</tr>
<tr>
<td>NHRS calibration - heart rate monitor</td>
<td>C2 Moderate</td>
</tr>
<tr>
<td>N-back pre</td>
<td>C3 High</td>
</tr>
<tr>
<td>N-back pre</td>
<td>N-back post</td>
</tr>
<tr>
<td>N-back post</td>
<td>N-back post</td>
</tr>
</tbody>
</table>

Figure 3. Overview of screening and intervention protocol.

### 4.4 Statistical analysis

Jamovi was used for analysing the collected data (The jamovi project, 2021). The aim was to investigate whether the acute effects of aerobic exercise on working memory differs depending on exercise intensity. To test the hypothesis, a repeated measure ANOVA with two within subject-factors, condition (low, moderate and high intensity) and time (before exercise, after exercise) was conducted, one for accuracy and one for response time. If the hypothesis would turn out to be supported, n-back performance improvement should increase as exercise intensity increases.
In addition to the hypothesis testing analyses, descriptive statistics were also produced. Descriptive statistics for the study participants are presented, including demographic characteristics and baseline data for physical and sedentary behaviour, as well as average n-back performance at each timepoint and condition. The descriptive section also included average physical- and perceived physical exhaustion during exercise in the three intensity conditions. In order to confirm that the different physical intensity exercise conditions resulted in different levels of physical exhaustion and perceived physical exhaustion two repeated measures ANOVA with one within-subject factor (condition) was performed.

Explorative analyses were performed to investigate whether n-back difficulty may act as a moderating factor for the acute effects of exercise intensity on n-back performance. To this end, three-way repeated measures ANOVAs, including n-back difficulty level as an additional within-subject factor (1-back, 2-back, 3-back) were conducted for accuracy and response time. The analyses were also completed to investigate VO2max as a moderating factor. A median split based on VO2max was carried out to divide the sample into two groups, and group membership was added as an additional between-subject factor within the repeated measures ANOVA (0, low fitness and 1, high fitness).

Figure 4. QQ-plot of VO2max for low fitness group (0) and high fitness group (1).
5. Ethical considerations

The content of the study means that it falls under the Ethics Review Act. Since the study is carried out according to a method that affects the participants physically, the project is tested by an ethics review board. Further, this means that the person in charge of the study has the obligation to obtain written informed consent from the participants (ALLEA, 2017; Vetenskapsrådet, 2017). In this study, the medical risks could appear from given physical exercise, like soreness or discomfort from exertion if the participants are not used to exercising at given duration or intensity. Since these are the known risks, the benefit of physical exercise rather may compensate for the known risks. However, interested attendants will answer questionnaires regarding their health status, concerning anxiety, depression, mental fatigue and alcohol consumption habits. Because of this, a possibility arises if answers by interested attendant are outside of the range of acceptable score, the researcher have the obligation to make sure that the interested attendant properly get in contact with the help that is requested by their answers.

5.1 Personal data management

Collected data will be stored on Sunet Drives S3 solution. Sunet Drives fulfils the legal requirements for IT security, is structured and configured to guarantee technical compliance in terms of information security and GDPR. This management solution is built to protect the research data against possible decisions by other actors that could endanger its integrity because the storage is based within Sweden’s borders and has the obligation to observe silence regarding the data that is stored. Vetenskapsrådet is the head-director of Sunet and led by a board appointed by Vetenskapsrådet.

6. Results

Following sections reports the study results from the analyses described in section 5.5. Results presented are divided in descriptive analyses, primary analyses and explorative analyses.

6.1 Descriptive analyses

Descriptive statistics for demographic characteristics, education level, physical activity and sedentary behaviour is given in Table 2. For further frequencies see appendix 1.
6.1.1 Demographics and physical activity

Table 1.

Demographic data, sedentary, physical exercise and physical activity baseline data.

Sedentary behaviour scale (0 – large sedentary behaviour, 7 – nonexistent sedentary behaviour). Physical exercise behaviour scale (0 – no time for physical exercise during a week, 6 – two hours of physical exercise during a week). Physical activity scale (0 – no time for physical activity during a week, 7 – More than five hours of physical activity during a week).

**Descriptives**

<table>
<thead>
<tr>
<th></th>
<th>Number</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Count</th>
<th>Percent of Total</th>
</tr>
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<td>12</td>
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<tr>
<td>Physical exercise behaviour (0-6)</td>
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<td>1.9</td>
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<td></td>
</tr>
<tr>
<td>Physical activity behaviour (0-7)</td>
<td>12</td>
<td>6.0</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.1.2 Measured and perceived physical exhaustion during exercise

6.1.2.1 Measured physical exhaustion (pulse)

The repeated measures ANOVA showed significant effect of exercise conditions on heart rate, \( F(2,20)=240, p<.001 \) (see appendix 2 for complete ANOVA table). Pairwise tests done post hoc showed that pulse in the low-intensity condition was significantly lower than in the moderate-intensity condition, \( t(10)=-11.7, p<.001 \), and the high-intensity condition, \( t(10)=-20.9, p<.001 \). The test also revealed that pulse in the moderate-intensity condition was significantly lower than in the high-intensity condition, \( t(10)=-10.7, p<.001 \). Figure 5 illustrates means of participants pulse at the different exercise intensity conditions.

Figure 5. Estimated marginal means of heart rate by exercise condition.

6.1.2.2 Perceived physical exhaustion (Borg rating)
The repeated measures ANOVA showed a significant effect of intensity condition on perceived physical exhaustion $F(2,20)=79.5$, $p<.001$ (see appendix 3 for complete ANOVA table). Test done post hoc showed that perceived physical exhaustion in low-intensity condition was significantly lower than moderate-intensity condition, $t(10)=-6.65$, $p<.001$, and high-intensity condition, $t(10)=-11.53$, $p<.001$. The test also showed that perceived physical exhaustion in moderate-intensity condition is significantly lower than high-intensity condition, $t(10)=-6.62$, $p<.001$. Figure 6 illustrates means of subjects perceived physical exhaustion at the different exercise conditions.

![Figure 6](image.png)

Figure 6. Estimated marginal means of Borg in the three different exercise conditions.

6.1.3 N-back performance

Descriptive statistics of means and standard deviations for all exercise conditions and times for n-back is presented in Table 2.
Table 2. Means, standard deviations, minimum and maximum for participants accuracy and response time for all experimental conditions and n-back sessions.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Accuracy (hit ratio)</th>
<th>Response time (correct trials)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Session</td>
<td>Mean</td>
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<tr>
<td>Low intensity</td>
<td>S1</td>
<td>0.94</td>
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<tr>
<td></td>
<td>S2</td>
<td>0.95</td>
</tr>
<tr>
<td>Moderate intensity</td>
<td>S1</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>0.95</td>
</tr>
<tr>
<td>High intensity</td>
<td>S1</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>0.95</td>
</tr>
</tbody>
</table>

6.2 Primary analyses

6.2.1 N-back accuracy

The repeated measures ANOVA with exercise condition (low, moderate and high intensity) and time (before exercise and after exercise) as repeated measures factors showed no interaction effect on n-back accuracy $F(2, 22)=0.35, p=0.71$ (see figure 7 for interaction plot). There was no main effect of condition for n-back accuracy, $F(2,22)=0.50, p=0.61$. There was also no main effect of n-back session, $F(1,11)=0.00, p=0.96$. (See appendix 4 for analysis).
6.2.2 N-back response time

The repeated measures ANOVA with exercise condition (low, moderate and high intensity) and time (before exercise and after exercise) as repeated measures factors showed no significant interaction effect on n-back response time, $F(2,22)=0.15, p=0.86$ (see figure 8A for interaction plot). Neither did the repeated measures ANOVA model show main effects of condition on n-back response time $F(2,22)=0.41, p=0.67$. However, a significant main effect of time was found for n-back response time $F(1,11)=40.2, p=0.001$, reflecting an overall shorter response time after exercise compared to before exercise, independent of condition (see figure 8B for incidental finding). (See appendix 5 for analysis).
Figure 8A. Interaction plot of estimated marginal means.

Figure 8B. Estimated marginal means of participants response time in n-back session 1 (before exercise) and session 2 (after exercise).
6.3 Explorative analyses

6.3.1 N-back difficulty level

The primary analyses did not show the hypothesized interaction effect between condition and time on n-back performance. However, n-back accuracy indicated evidence of ceiling effects for 1-back and 2-back, meaning that the capacity to show improvements in performance at 1-back and 2-back difficulty levels was likely very limited (see figure 9A & 9B). This indicates that support for the hypothesis could have been hidden due to the ceiling effects of 1-back and 2-back. To explore this possibility, additional exploratory analyses were performed.

6.3.1.1 Accuracy n-back performance

Histograms of mean n-back accuracy revealed that 1-back and 2-back difficulty showed high accuracy in both session 1 and session 2. Figure 9A and 9B revealed histograms of largely skewed data by mean accuracy close to maximum. The 3-back difficulty on the other hand, showed a more normally distributed data of mean accuracy in figure 9C. The mean performance of accuracy across all difficulties is shown in Figure 9D, evidencing somewhat normal distribution.
Figure 9D.

Figure 9A, 9B, 9C and 9D. Histograms of subjects mean n-back accuracy at different n-back level and mean performance of accuracy across all difficulties.

6.1.3.2 Response time n-back performance

Histograms of mean n-back response time showed no such skewed data as n-back accuracy. Figure 10A, 10B and 10C revealed more normally distributed data, therefore no indications of ceiling effect were detected. The mean performance of response time across all difficulties is shown in Figure 10D.
Figure 10D.

Figure 10A, 10B, 10C and 10D. Histograms of subjects mean n-back response time at different n-back level and mean performance of response time across all difficulties.

6.3.1.1 Accuracy and difficulty

The ANOVA showed no significant three-way interaction effect between condition, time and n-back difficulty, $F(4,44)=0.50$, $p=0.7$. As such, there was no indication of differential support for the hypothesized two-way interaction at the different n-back difficulty levels.

The ANOVA did also not show any significant two-way interaction effect between condition and n-back difficulty on accuracy $F(4,44)=0.90$, $p=0.48$, nor significant two-way interaction effect between session and n-back difficulty on accuracy $F(2,22)=0.48$, $p=0.62$, and no significant two-way interaction effect between condition and session on accuracy $F(2,22)=0.35$, $p=0.70$. The ANOVA model showed no significant main effects of session, $F(1,11)=0.00$, $p=0.96$, or condition on accuracy, $F(2,22)=0.50$, $p=0.61$. The ANOVA did however show significant main effects n-back difficulty levels on accuracy, $F(2,22)=39.4$, $p=<.001$. Figure 11 displays how accuracy performance is higher in 1-back and 2-back compared to 3-back difficulty level (See appendix 6 for complete ANOVA model).
6.3.1.2 Response time and difficulty

Additionally, the repeated measures ANOVA was conducted to explore the possibility of three-way interaction on response time. The ANOVA model showed no three-way interaction effect on response time \( F(4,44)=0.15, p=0.96 \), and no two-way interaction effect on response time between condition and n-back difficulty \( F(2,22)=2.50, p=0.10 \), between session and n-back difficulty \( F(4,44)=1.38, p=0.25 \), and between condition and session \( F(2,22)=0.17, p=0.84 \). The ANOVA model showed no significant main effects on response time between condition \( F(2,22)=0.43, p=0.66 \). However, the ANOVA model did show significant main effects on response time between difficulty \( F(2,22)=19.1, p=<.001 \), and between session \( F(1,11)=38.4, p=<.001 \). Figure 12A illustrates overall longer response time when n-back difficulty becomes more severe. Figure 12B illustrates overall faster response time in second n-back session compared to the first session (See appendix 7 for complete ANOVA model).

Figure 11. Estimated marginal means of participants n-back accuracy at different n-back difficulty levels. Level n1 represents the least difficult level and n3 the most difficult level.
Figure 12A. Estimated marginal means of response time at the different n-back difficulty levels.

Figure 12B. Estimated marginal means of response time between n-back sessions.
6.3.2 VO2max and n-back performance

6.3.2.1 Accuracy and VO2max

The three-way ANOVA with condition and time as within-subject factors and VO2max as between subject factor for n-back accuracy performance, revealed no significant interaction effect, $F(2,18)=0.92, p=0.42$. The ANOVA neither showed any two-way effect between condition and VO2max $F(2,18)=0.14, p=0.86$. The ANOVA did however reveal a two-way interaction effect between n-back session 1 and 2 and VO2max group on accuracy, $F(1,9)=13.5, p=0.005$. Figure 13 illustrates the significant two-way interaction effect. For complete ANOVA see appendix 8, including tests that were performed post hoc with tukey-correction for multiple comparisons. Tests performed post hoc revealed that the low fitness group performed less accurate in session 2 compared to session 1 of the n-back, $t(9)=3.36, p=0.03$. Conversely, the high fitness groups showed no significant difference between session 1 and 2, meaning no improvement nor impairment of n-back performance.

![Figure 13. Estimated marginal means of n-back accuracy between sessions by low fitness group (0) and high fitness group (1).](image)
### 6.3.2.2 Response time and VO2max

The ANOVA was also conducted for response time and showed no significant three-way interaction effect, $F(2,18)=0.39$, $p=0.68$. There was not a significant two-way interaction effect between condition and VO2max on response time, $F(2,18)=1.20$, $p=0.32$. No significant two-way interaction effect was either observed between session and VO2max on response time, $F(1,9)=0.10$, $p=0.74$ (see appendix 9 for complete ANOVA table).

### 7. Discussion

#### 7.1 Summary of main results

The objective of this study was to investigate whether the acute effects of aerobic exercise on working memory differs depending on exercise intensity. Working memory was evaluated with the N-back task, before and after exercise in the three exercise conditions (low, moderate and high intensity), both in terms of accuracy and response time. Results from the confirmatory analyses showed no significant interaction effect between session and time on accuracy nor response time, meaning that change in n-back performance following exercise did not differ depending on the intensity of the exercise. The hypothesis was therefore not supported by the data in this study.

#### 7.2 Result discussion

Since previous research has supported a role of exercise intensity for acute effects on cognition (Chang et al. 2012; Kao et al. 2020), it brings the question of why the outcome of this study was different. One possibility could be that the physical exercise intervention did not correspond to low, moderate and high exercise intensity. However, the loads for the different intensity conditions were investigated, and the intervention applied during the different physical exercise conditions did work properly according to subjects’ physical exhaustion (pulse) and perceived physical exhaustion (Borg RPE scale). Mean rating regarding participants perceived physical exertion on the Borg RPE scale was 11 for the low intensity condition, 14 for moderate intensity condition and 16 for high intensity condition. In translation, low intensity corresponded to a light experience, moderate intensity to somewhat hard experience and high intensity to between a hard and very hard experience. This conclude that the intervention of physical exercises worked properly and did bring the subjects to low, moderate and high intensity exercise in relation to each other. Chang et al. (2012) reports that the effect appears to be driven in an interactive way by intensity of the exercise and the time...
between acute exercise and when the cognitive task is performed. Chang elaborates that when the cognitive task is performed immediately following exercise, very light (<50% HRmax), light (50-63% HRmax) and moderate (64-76% HRmax) intensity of the exercise seems to generate better positive effect. If the cognitive task is performed with a delay at least 1-minute after the exercise, exercise by very light intensity no longer shows positive effects. However, larger intensity of the exercise seems to drive the positive effects, were hard (77-93%) and very hard (>93%) intensity benefit the outcome (Chang et al., 2012). Very hard intensity is translated as 93% or higher of ones HRmax and is further reported to be most beneficial for positive effects on cognitive outcomes when the cognitive task is performed with at least 1-minute delay following exercise. So, the interpretation of results from Chang et al. (2012) could be that the present study did not rise to the necessary intensity needed to make the effects visible, since this study included a 10-minute delay. According to the results of Chang et al. (2012), perhaps effects for light and moderate intensity would have been visible if the cognitive task in this study was performed immediately following the exercise.

Moreover, other studies often compare one given intensity to a resting condition (Moreau & Chou, 2019; Zheng et al., 2022). Since this study included no condition of passive rest, it is possible that a difference between high intensity and passive rest would be larger and perhaps possible to detect than to current conditions included. Presumably a control group consisting of sedentary construction with a different design or adding one intervention condition of sedentary behaviour could have generated clearer divergence based on the results of this study. Chang et al. (2012) explains that discrepant results could be attributed to different study designs, thus a crossover design with relatively small sample size could have been a factor to why this study showed a different outcome compared to others (Kao et al., 2020; McMorris et al., 2011; Shah et al., 2022; Wilke, 2020). Imaginable is that the effect is not possible to detect because of the small sample size. It may not necessarily reflect reality and the effect could be hidden, meaning a type 1 error. Because the present study was powered for other outcome measures (fNIRS) and not n-back, it only had sufficient power to detect large effect sizes. Since sample size could impact effects sizes, a larger sample could be required to detect effect sizes reported by meta-analyses (Chang et al., 2012). Nonetheless, the study did detect a main effect for response time, just not the interaction effects. Therefore, the main effect of response time was large enough to be detected with the present sample.
Furthermore, ceiling effects for accuracy in 1-back and 2-back difficulty levels may have meant that the subjects' capacity to improve the accuracy score from before exercise session to after exercise session was limited. The ceiling effects was believed to block the predicted interaction effects, thus, exploratory analyses were conducted to investigate if the interaction effect were hidden, by including n-back difficulty to the original analysis. However, the outcome revealed no significant interaction between session and condition and contradicts any major influence of the apparent ceiling effects.

An incidental finding was discovered as part of the confirmatory analyses, showing a significant main effect on response time between sessions in the n-back task. This effect reflected that response time was shorter in the n-back session following the physical exercise interventions compared to before. This finding was independent of physical exercise condition which could be interpreted as if physical exercise is done regardless of intensity, meaning that people make faster decisions after physical exercise. Similar to this incidental finding, a recent study directed to young adults as well, also demonstrated that subjects exhibited faster response time on a working memory task following acute aerobic exercise (Zheng et al., 2022). By the findings of Zheng et al. (2022) and this study, it appears a possibility that physical exercise may impact the speed at which people solve working memory tasks. Moreover, similar findings regarding shorter response time at tasks with demands on the working memory following an acute aerobic physical exercise session, are also reported by Ponifex et al. (2009). However, the design of current study did not consist of any sedentary control group or incorporated any condition of sedentary behaviour. Since this incidental finding was independent of physical exercise condition and because of the design, it is not possible to determine whether it was the exercise per se that caused the improved response time in the n-back task. In addition, the same main effect did not appear in the ANOVA regarding accuracy on the n-back task. To summarize, the main effect in this study indicate that participants performed better at the n-back task after a single bout of exercise, than before the exercise. This corresponds to faster answers, however not more accurate and independent of exercise condition. This means that accuracy performance neither increased or decreased in comparison between before and following exercise and that intensity of the acute exercise did not affect any of the main effects.
Chang et al. (2012) reported that fitness level could moderate the effects when the cognitive test is performed immediately following exercise. To investigate if this could be the case when a delay is included between exercise and cognitive test, a median split of subjects VO2max was done, separating the group of subjects into two groups (low- and high fitness group). The results showed that the low fitness group performed more accurate on the n-back task before exercise, compared to after exercise. Meanwhile, the high fitness group showed no significant difference between first and second session on n-back. So, while the low fitness group displayed a clear impairment between the first and second n-back session, the high fitness group did not. Compared, the high fitness group showed no signs of being affected in a negative way from the physical exercise ahead of the n-back session, whilst the low fitness group was. At first sight, the results could be interpreted as that people with lower fitness do not benefit in tasks that put demands on the working memory following exercise. This differs from previous research, where Chang et al. (2012) reported that fitness level did not moderate the effects when the timing of measurement for the cognitive task is performed following a delay. One possibility is that the interaction effect in this study could be driven by baseline differences, were participants within the low-fitness group overperformed in the first n-back session and then scored as expected in the second session. Simultaneously, the high-fitness group did not display any significant difference between baseline and the post-measurement. Perhaps this coincidence created the interaction effect.

The data of current study did not support the inverted U-shape theory or the linear relationship theory. Chang et al. (2012) elaborates that the effects could be driven in an interactive way, where higher intensity of the exercise benefits the outcome if a delay is included between exercise and when the cognitive task is performed. This speaks for the linear relationship theory, were exercise intensity and BDNF concentrations follows a linear relationship. Anyway, Chang et al. (2012) also states that when the cognitive task is performed immediately following exercise, very light, light and moderate intensity is most beneficial for the cognitive outcome. This speaks against the linear relationship theory and inverted U-shape theory, were either higher intensity or moderate (optimal) intensity is to promote the positive outcome. Dinoff et al. (2017) and Knaepen et al. (2010) reported a positive association between increasing intensity of the exercise and larger peripheral BDNF concentrations. If higher BDNF concentrations were to affect the working memory, possibly even higher intensity of the exercise is needed. Since this study cannot confirm that exercise intensity was executed at 80%, perhaps the intensity was too low.
7.3 Discussion of method

The study's method had both strengths and limitations. First, the interest from a valid population to participate was to a high degree positive. The meticulous screening of participants via questionnaires was a great way of including the sought after population and excluding participants that did not fit the criteria for inclusion. However, since the data collection period for this study was in progress for approximately three months, some changes in the screening criteria was inevitable to collect data at appointed time. If the data collection was prolonged for further months, this would probably not have been an issue. This screening was therefore a strength as well as a limitation. A strength because of a rigorous screening of appropriate participants and a limitation due to forcing a change during ongoing data collection.

Another limitation of the study concerns the estimation of participants VO2max. This study utilized Ekblom-Bak submaximal test for estimation of VO2max and the test seemed to overestimate VO2max scores. Therefore, in the beginning, the estimation of participants load at each intensity condition was not exactly reflecting 40, 60 and 80% of their actual VO2max. For that reason, the intensities carried out was re-termed low, moderate and high intensity. The intensities were also confirmed and differentiated by measured physical exertion (pulse) and perceived physical exertion (Borg RPE scale). To estimate 40, 60 and 80% of participants VO2max, it is likely more accurate to use a maximal oxygen consumption test/ramp test for more valid calculations, and which in addition brings the possibility of extracting participants aerobic- and anaerobic threshold. Current workloads were differentiated by pulse and Borg RPE scale and clearly separates loads for respective intensity. However, it is impossible to make clear that participants workload was corresponding to 40, 60 and 80% of their own VO2max. It corresponds to participants pulse and perceived physical exertion, however that does not clarify which load that was sufficient. Since EB-test do not present participants maximal pulse, it is not possible to calculate either. If the loads were insufficient, it could also have influenced the results.

An issue of debate is whether the aerobic physical exercise should had been carried out on a cycle ergometer or a treadmill. When performing aerobic exercise, especially on higher intensities for 20 minutes on a cycle ergometer, it could incorporate other demands such as more local muscle strength in the legs than running on a treadmill would. The ones familiar
to physical exercise on a cycle or ergometer could experience this type of physical exercise more comfortable than others that are not. Perhaps treadmill running could have eliminated this and produced more sincerely outcomes than a cycle ergometer.

Reflecting on the working memory task, n-back, it appears that 1-back and 2-back difficulty of the n-back task is inappropriate to utilize because of the ceiling effects concerning accuracy when investigating working memory performance. In this study, it seems to have become too easy for the participants already at session 1 to evaluate any significant improvement at session 2. However, all n-back difficulty levels were needed in this study because of interests from the larger pilot study. But this was not the case regarding 3-back difficulty which could be considered as a valid n-back difficulty. A positive aspect is that 3-back went well and could be used when investigating working memory.

Finally, this study included a 10-minute delay from where the physical exercise was finished until that the working memory task began. Perhaps the 10-minute delay may have something with the non-interaction effects to do. One possibility is that a 10-minute delay could be too much and therefore contributing to the disappearance of physiological effects before or during the n-back task was performed. Another possibility is that the high intensity did not rise to the necessary intensity needed when performing the n-back task following a 10-minute delay. Chang et al. (2012) reported that the positive effects are driven in an interactive way by higher exercise intensity when the cognitive task is performed following a delay consisting of at least 1-minute. In parallel, lower intensity seems do drive the positive effects when the cognitive task is performed immediately following exercise. Based on that report, one possibility is that the positive effects would have been prominent in this study if the n-back task was performed immediately after exercise.

7.4 Conclusions

Summarizing the findings from the study results starts with concluding that there was no significant interaction between exercise intensity and session on working memory performance, either for accuracy or response time. This means that low, moderate or high intensity of the physical exercise did not seem to matter for the improvement of working memory performance following acute exercise, when the working memory task is performed with a delay of 10 minutes following the 20-minute durative aerobic physical exercise. The hypothesis was therefore not supported by the data. A significant main effect of response
time was however prominent, reflecting an overall shorter response time in the n-back session following the physical exercise compared to the n-back session prior to the physical exercise. For the population in respect of young adults whose everyday life consist of work and studies that puts demands on working memory, these results mean that a single bout of 20 minutes aerobic physical exercise may have a positive effect on the time it takes to fulfil such demands. The results also imply that the acute exercise that is performed, does not seem to be dependent upon if the exercise is done at low, moderate or high intensity. A limiting factor of this study was the lack of passive rest control. To draw conclusions that exercise at any intensity is positive for response time in working memory demanding tasks, a somewhat similar study needs to be conducted but with including a passive control.

7.5 Forthcoming research

Future research is necessary to provide empirical evidence with regard to if different intensities of acute physical exercise matter for the improvement of working memory performance. In this study, no such interaction effect was found. Also, since the understanding originates that intensity did not reinforce the effect of the overall shorter response time at the n-back session following physical exercise, it would be interesting to investigate whether this effect could differ between the exercise conditions and a sedentary condition. Future studies should also increase the sample size since current sample size may have been insufficient to detect effects. Furthermore, only including higher n-back difficulty trials can be important because of the ceiling effects that was seen in 1- and 2-back. Research consisting physical exercise interventions may also consider using maximal oxygen-/ramp test when conducting VO2max tests, for a valid and reliable score. Finally, it would be interesting to investigate the influence of delay between pre-working memory task, physical exercise and post-working memory task. Perhaps studies in the future explores the influence of changing the delay to both shorter and longer than present study.
REFERENCES

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Appendix - Descriptives

Appendix 1

Frequencies of sex

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Frequencies of age

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Frequencies of education

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Frequencies of physical exercise behaviour - baseline

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Frequencies of physical activity everyday behaviour - baseline

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Appendix – Result part

Appendix 2.

Within Subjects Effects
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*Note. Type 3 Sums of Squares*

**Appendix 3.**

**Within Subjects Effects**

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*Note. Type 3 Sums of Squares*

**Appendix 4.**

Two-way ANOVA for n-back accuracy condition*session

**Within Subjects Effects**

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*Note. Type 3 Sums of Squares*

**Between Subjects Effects**
### Within Subjects Effects

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*Note. Type 3 Sums of Squares*

### Between Subjects Effects

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*Note. Type 3 Sums of Squares*
Appendix 6.

Repeated Measures ANOVA

Three-way ANOVA for accuracy condition*session*difficulty

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*Note. Type 3 Sums of Squares*
### Between Subjects Effects

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*Note. Type 3 Sums of Squares*

### Appendix 7

### Repeated Measures ANOVA

Three-way ANOVA for response time condition*session*difficulty

### Within Subjects Effects

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**Note.** Type 3 Sums of Squares

### Between Subjects Effects

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**Note.** Type 3 Sums of Squares

**Appendix 8.**

**Repeated Measures ANOVA**

Three-way ANOVA for accuracy condition*session and VO2max group as between subject factor

### Within Subjects Effects

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Note. Type 3 Sums of Squares

Between Subjects Effects

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Note. Type 3 Sums of Squares

Post Hoc Tests

Post Hoc Comparisons – Session*VO2max median split

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<th>VO2 max split</th>
<th>Session</th>
<th>VO2 max split</th>
<th>Mean difference</th>
<th>SE</th>
<th>Df</th>
<th>Ptukey</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>0</td>
<td>S1</td>
<td>1</td>
<td>0.01688</td>
<td>0.02112</td>
<td>9.00</td>
<td>0.853</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>0</td>
<td></td>
<td>0.01536</td>
<td>0.00456</td>
<td>9.00</td>
<td>0.035</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>1</td>
<td></td>
<td>0.00953</td>
<td>0.02107</td>
<td>9.00</td>
<td>0.968</td>
</tr>
<tr>
<td>S2</td>
<td>0</td>
<td>S2</td>
<td>0</td>
<td>-0.00153</td>
<td>0.02106</td>
<td>9.00</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>1</td>
<td></td>
<td>-0.00735</td>
<td>0.00416</td>
<td>9.00</td>
<td>0.348</td>
</tr>
</tbody>
</table>

Appendix 9.
Repeated Measures ANOVA

Three-way ANOVA for response time condition*session and VO2max group as between subject factor

Within Subjects Effects
<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>0.00461</td>
<td>2</td>
<td>0.00230</td>
<td>0.2558</td>
<td>0.777</td>
</tr>
<tr>
<td>Condition * VO2max_median_split</td>
<td>0.02170</td>
<td>2</td>
<td>0.01085</td>
<td>1.2051</td>
<td>0.323</td>
</tr>
<tr>
<td>Residual</td>
<td>0.16210</td>
<td>18</td>
<td>0.00901</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Session</td>
<td>0.02476</td>
<td>1</td>
<td>0.02476</td>
<td>33.9130</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Session * VO2max_median_split</td>
<td>7.94e-5</td>
<td>1</td>
<td>7.94e-5</td>
<td>0.1087</td>
<td>0.749</td>
</tr>
<tr>
<td>Residual</td>
<td>0.00657</td>
<td>9</td>
<td>7.30e-4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condition * Session</td>
<td>3.59e-5</td>
<td>2</td>
<td>1.79e-5</td>
<td>0.0314</td>
<td>0.969</td>
</tr>
<tr>
<td>Condition * Session * VO2max_median_split</td>
<td>4.49e-4</td>
<td>2</td>
<td>2.25e-4</td>
<td>0.3924</td>
<td>0.681</td>
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<tr>
<td>Residual</td>
<td>0.01030</td>
<td>18</td>
<td>5.72e-4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* Type 3 Sums of Squares

### Between Subjects Effects

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO2max_median_split</td>
<td>0.124</td>
<td>1</td>
<td>0.1239</td>
<td>2.23</td>
<td>0.169</td>
</tr>
<tr>
<td>Residual</td>
<td>0.500</td>
<td>9</td>
<td>0.0556</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* Type 3 Sums of Squares
Appendix – Informed consent, online questionnaire and study protocol

Appendix 10

Informed consent form

Projekttitel: Omedelbara effekter av fysisk träning på biologiska och psykologiska faktorer av betydelse för psykisk hälsa (pilotering av studieprotokoll)

Samtycke till att delta i projektet

Jag har fått muntlig och/eller skriftlig information om studien och har haft möjlighet att ställa frågor. Jag får behålla den skriftliga informationen.

- Jag samtycker till att delta i projektet Omedelbara effekter av fysisk träning på biologiska och psykologiska faktorer av betydelse för psykisk hälsa (pilotering av studieprotokoll)

- Jag samtycker till att uppgifter om mig behandlas på det sätt som beskrivs i forskningspersonsinformationen.

<table>
<thead>
<tr>
<th>Plats och datum</th>
<th>Underskrift</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Namnfördyigande
Appendix 11

Online screening questionnaire – created in Survey & Report and sent out via mail

I följande frågeformulär kommer du få besvara frågor som berör din hälsostatus innehållande Ja/Nej-frågor och även frågor som kräver kort svarstext.

Lycka till!

1. E-postadress: ______________________

2. Ålder: _______________


   JA

   NEJ

   Kommentar: _______________________________

4. Äter du för närvarande några läkemedel? Om ja, vilka läkemedel?
5. Har du någon skada som hindrar dig att prestera fysiskt? Om ja, vilken skada?
JA
NEJ
Kommentar: ________________________________

6. Är du medveten om du har något övrigt hinder för att prestera fysiskt? Om ja, vilket hinder?
JA
NEJ
Kommentar: ________________________________

JA
NEJ
Kommentar: ________________________________

8. Röker du?
JA
NEJ

9. Deltar du i någon annan studie samtidigt?
JA

NEJ


JA

NEJ

Appendix 12

Study protocol - intervention

**SP2-pilot - INTERVENTION**

fNIRS Bundle ska vara kopplad överst på NIRSport-2 enhet

<table>
<thead>
<tr>
<th>Bundle [A eller B]:</th>
<th>SD bundle [1 eller 2]:</th>
</tr>
</thead>
</table>

**Intensitet, belastning, RPM och fNIRS-mössa storlek:**

<table>
<thead>
<tr>
<th>Intensitet:</th>
<th>RPM:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belastning [Watt]:</td>
<td>fNIRS-mössan [storlek]:</td>
</tr>
</tbody>
</table>

**WIFI:** 4guest@GIH

**Spara filer enligt nedan:**

**Deltagarens studie ID:** FP01 = första deltagaren

**Session (S):** S1 = pre; S2 = post
**Condition (C):**
C1 = låg [40%]; C2 = medel [60%]; C3 = hög [80%];

**Frågeformulär:** PANAS+VAS+BORG = S1-4

**Spara som:** FPX_CX_SX

### 1.0 Förberedelse (30 min)

#### 1.1 Förberedelser utrustning och programvara

##### 1.1.1 N-Back

- Logga in på N-Back dator med Lösenord Winter2023
- Se till att C-Pod USB kabel nr.2 är kopplad till N-Back datorn
- Öppna utforskaren → data → skapa mapp FPX → skapa mapp för **Condition** (ex. FP01_C2)  
  → skapa 3 mappar för **Session** (PRAC, S1 och S2) ex.:
  * FP01_C2_PRAC
  * FP01_C2_S1
  * FP01_C2_S2
- Öppna PsychoPy – klicka på PsychoPy ikonen längst ner till höger på skrivbordet
- I PsychoPy klicka på **Open File** → Utforskaren → Olga Phd → PhDSP2-nback-17digits  → Välj nBack17_fnirs_pract
- Välj **Run Experiment** (playknapp)
- Fyll i deltagarens Studie-ID, Condition och Session
- När en vit text nBack dyker upp på den svarta skärmen  
  = allt är redo för att starta N-Back när deltagaren är redo

##### 1.1.2 fNIRS

**Sätta på fNIRS - NIRSport-2 = nya systemet**

- Svartvit sladd är kopplad till datorn
- Sätt på NIRSport-2: power - håll in 3 sek bakom NIRSport-2 enheten - Ljusblått = På
  - Se till att rätt bundle är inkopplad högst upp, bundle A eller B
  - är det bundle B så koppla fNIRS optoder på fNIRS-mössan enligt nedan:
• Starta **fNIRS-datorn** (Lösenord: **Winter2023**)
  - se till att både **NIRSport-2** system och **fNIRS-datorn** laddar/är laddad
  - både fNIRS-datorn och NIRSport-2 kan laddas hela tiden under datainsamlingen

• **Skapa mappar för deltagare**

  Dokument à NIRx à Data à OLGA-PhD à SP2-PILOT
  à Ny mapp för **Deltagare** (FPX)
  à Ny mapp för **Condition (C)**: C1 = låg [40%]; C2 = medel [60%]; C3 = hög [80%]
  à Ny mapp för **Session (S)**: S1 = pre eller S2 = post

• Klicka på **Aurora 2021.9** på skrivbordet
• Klicka på **Configurations à Prefrontal Short 8x8**
• Klicka så att du ser en översiksbild och att det står Detectors 15.
• Klicka på **Select**
  à en bild på hur Source and Detector är satta ska komma upp
  à titta om det överensstämmer med montage på fNIRS-mössan
• Gå till **Settings** och “bläddra-ikonen” i **Aurora** Data Root Directory
  à använd rätt mapp FP-ID-Condition-Session
• När rätt mapp är inställd gå till ikonen “**Open signal optimization page**”
  à Då är allt redo för fNIRS kalibrering med Aurora mjukvara.

1.2 Förberedelser formulär

**Skapa mapp för deltagare (Moas dator)**
Ex. FP01 à Fp01_intervention à intervention C3 à alla filer samlas här

Ex. PANAS+VAS+BORG_S1 för första session på PANAS m.m.

- Se till att alla formulär finns tillgängliga på IPad
- SQS
- KSS
- Hälsotillstånd och fysisk aktivitet
- PANAS + VAS + BORG

1.3 Förberedelse cykel + andra hjälpmedel

Pulsmätare H10, nr.1: serienummer BFAE 7128

Reserv pulsmätare H1, nr.2: serienummer pfaf7a22

- Bak-fram-sits:
- Bak-fram styre:
- Styrhöjd:
- Sadelhöjd:

- Se till att polarklocka (Vantage M2) finns på plats och ladda den innan start i Moas dator
- Se till att IPad är laddad

2.0 Deltagare anländer till GIH (15 min)

2.1 Inledande frågor kring testförberedelser

- Testledare möter upp deltagare i receptionen och visar vägen till Neurofysiologilabbet
- Fråga på vägen: “Behöver du gå på toaletten?”
• Testledare försäkrar sig om deltagare inte har intagit någon kraftig måltid/dryck (endast vatten) närmre än 2 timmar före intervention, om ja notera det.

  “Har du intagit någon kraftigare måltid under de senaste 2 timmarna?”

  Notering:

• Har deltagaren genomfört ett hårt träningspass senare än 2 dagar innan intervention, om ja notera det.

  “Har du genomfört ett hårt träningspass senare än 2 dagar innan intervention?”

  Notering:

• Lämna mobiltelefonen vid dörren (avstängd eller på ljudlös)

  “Kan du stänga av eller sätta din mobiltelefon på ljudlös?”

• Fråga deltagaren hur hen mår (om hen tagit någon medicin)

  “Hur mår du idag? Har du tagit någon medicin? Till exempel *ipren*?

Om deltagaren har tagit någon medicin, påminn om att vi helst ser att man inte tar någon medicin i samband med studien

  Notering:

  | Medicin: | Dos: |

• Förklara dagens upplägg:

  “Idag kommer du först att fylla i korta frågeformulär, du kommer därefter att få öva en gång på tankemässiga testet som senare också genomförs två gånger (innan och efter
träningen). Du kommer att ha på dig fNIRS-mössa samt pulsmätare under besöket. Du kommer att genomföra ytterligare frågeformulär som upprepas 4 gånger under dagen. Du kommer att cykel träna 20 minuter på en randomiserad intensitet under dagens besök.”

“Känns det okej för dig?”

### 2.2 Frågeformulär och sittande vila - Hälsotillstånd och fysisk aktivitet, SQS, KSS (5 min)

#### Starttid:

- Placera deltagare i sittande vila medan deltagare svarar på frågeformulär
- Ta fram IPad och öppna dokument med frågeformulär-länkar
- Deltagare svarar på frågeformulär Hälsotillstånd och fysisk aktivitet
  – frågeformulär om deltagarens hälsostatus och nivåer av FA en vecka före testdagen
- Deltagare svarar på frågeformulär SQS
  – frågeformulär om sömnkvalité den senaste natten
- Deltagare svarar på frågeformulär KSS
  – frågeformulär för sömnighet de senaste 10 minuterna
- **Om deltagare uppger sjukdomssymptom, avbryt tilltänkt träningsintervention (screening med Hälsotillstånd och fysisk aktivitet)**
- Testledare 1 går igenom deltagarens svar på frågeformulären och sparar Hälsotillstånd och fysisk aktivitet som PDF
- Frågeformulär SQS och KSS sparar som Excel
  - i deltagarens INTERVENTION-mapp (ex. Fp01) på Moas dator
- Testledare 2 ger verbal instruktion av N-Back för deltagaren

### 2.3 N-Back-träning (10 min)

- Förklara N-Back för deltagare
  - ge en verbal introduktion av övningen och förbered deltagaren på att instruktioner kommer ges på skärmen innan uppgiften, under uppgiften och efter uppgiften
- Testledare trycker på **DELETE** för att öppna N-Back

**Standardiserad information:**
“Nu kommer du genomföra exakt samma tankemässiga övnings-test som du gjorde under besök 1. Minns du?”

OM PÅMINNELSE BEHÖVS:

“(1-tillbaka) Du kommer att se en siffra i taget som visas på skärmen, din uppgift är att svara om den siffran har visats ett steg tidigare”. = (första instruktion för 1-back sedan stanna upp och upprepa vid 2-back och 3-back.)

Om siffran är samma som N steg tillbaka trycker du på vänster pil (pekfinger höger hand) om siffran inte är samma trycker du på höger pil (långfinger höger hand)

Du kommer först att få feedback om du har rätt eller fel för att lättare förstå hur testet går till, sedan kommer endast siffror visas och du kommer INTE få reda på om du svarade rätt.

Första siffran alltid kommer att bli olika, tryck på högerpilen vid första (1-tillbaka).

3-tillbaka är svår, och det är meningen att den ska vara svår. Bli inte orolig om du tappar bort dig, det är normalt, det viktiga är att du inte ger upp.

DU kommer att få vidare instruktioner hur testet går till på skärmen, när du har läst klart och känner dig redo trycker du på SPACE

HÖGER pil = olika

VÄNSTER pil = lika

• Fråga om deltagare tappade bort sig under testet eller gav upp

  “Tappade du bort dig vid något tillfälle?”

  Ja Nej

  “Gav du upp vid något tillfälle under testet?”
3.0 fNIRS förberedelse och kalibrering samt placering av pulsmätare (10 min)

- Be deltagaren ta av sig tjocktröja om deltagaren har en på sig
- Placera pulsmätare på deltagare runt bröstet
  - Använd huvudmätning från tillvänjningsbesöket för att bestämma fNIRS-mössa storlek

  **fNIRS-mössan [storlek]:**

- Markera med penna i pannan på **varsin sida** om måttbandet på deltagaren för riktmärke för fNIRS-mössan placering och notera avståndet nedan
  - avståndet från näsroten till kanten av fNIRS-mössan ska vara ca 2 cm

  **Avstånd [cm]:**

- Sätt på fNIRS-mössan

“Jag kommer nu sätta på dig mössan?”
“Kan du hålla i framkanten av mössan?”

“Känns det okej med hur vi har satt på dig mössan?”

- Fäst fNIRS-banden med kardborre klämmen i deltagarens tröja/t-shirt

”Blunda och slappna av” Nu kalibrerar vi så att mössan sitter som den ska på dig.

- Kalibrera fNIRS i fNIRS-datorn. Tryck på Play.
  - max 2 gula är acceptabelt. Om fler än 2, pilla bort hår eller justera så att max 2 är gula (max 3 försök)

Ifall det är några gula/röda så klicka på två roterande pilar istället för att kalibrera om

| Antal gröna/vita/röda: | Antal försök: |

4.0 För-test fas

4.1 Frågeformulär och HRV (10 min, varav 5 min sittande vila)

- Förbered genom att starta N-Back pre (nBack17_fnirs_main)
- Se till att rätt mapp är vald (ex. FP01_C2_S1)

HRV inspelningen
• Deltagaren befinner sig i sittande vila
• Starta inspelningen av deltagarens puldata (HRV) med polarklocka, spela in 5.30 min

Starttid:

• På fNIRS-datorn: Open recording page à Start recording in preview mode
• Kontrollera signaler och ändra Lowpass filter till 1.0
  à scrolla ner och se att allt ser bra ut
  à ändra Lowpass filter till 0.5
• Välj Lineplot för att följa pulseringar
• ”Stop recording preview” och var redo att börja spela in
• Stäng av deltagarens puldata (HRV)

Sluttid:

Frågeformulär startar

Ha borgskalan till hands så deltagaren kan titta på den när hen genomför testet

Starttid:

• Deltagaren genomför PANAS-SF+ VAS + BORG _S1

Sluttid:

Om deltagaren är klar med formulär innan 5 minuter, gå vidare till nästa steg
4.2 N-Back-test före intervention (15 min)

Standardiserad instruktion:

“Nu kommer du att få genomföra det tankemässiga testet som pågår i 15 minuter. Skillnaden mot övnings-testet är att du inte kommer att få någon feedback mellan dina svar. När den vita pricken dyker upp på skärmen så ska du räkna 1, 2, 3.. 20.”

- Starta fNIRS inspelningen (ta bort pekaren från startknappen)
- Starta N-Back så fort som möjligt efter start av fNIRS inspelningen

**Starttid:**

- Se över ovanstående punkter medan deltagare genomför N-Back.

- SPARA PANAS+VAS+BORG_S1 i rätt mapp i Moas dator

**Sluttid:**

- När N-Back-test är slut trycker testledare på STOP på fNIRS-datorn å sedan Exit
- Tappade deltagaren bort sig under testet eller gav upp?

“Tappade du bort dig vid något tillfälle?”

Ja Nej
“Gav upp vid något tillfälle under testet?”

Ja  Nej

Kommentar:

4.3 Frågeformulär och HRV (10 min)

Frågeformulär startar

Ha borgskalan till hands så deltagaren kan titta på den när han genomför testet

**Starttid:**

- Deltagaren genomför PANAS-SF+ VAS + BORG _S2

**Sluttid:**

Om deltagaren är klar med formulär innan 5 minuter, gå vidare till nästa steg

HRV inspelningen

- Deltagaren befinner sig i sittande vila
- Starta inspelnings av deltagarens pulsdatala (HRV) med polarklocka, spela in 5.30 min
• Förbered genom att starta N-Back post (nBack17_fnirs_main)
• Se till att rätt mapp är vald (ex. FP01_C2_S2)
• Förbered rätt fNIRS-mapp (S2)
• Stäng av deltagarens pulsdata (HRV)

5.0 Intervention (1+19 min)

• Förbered deltagaren på att cykelträningen kommer att inledas
• Meddela deltagaren om vilken intensitet och Watt hen ska jobba på

<table>
<thead>
<tr>
<th>Intensitet:</th>
<th>Watt:</th>
<th>RPM:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sänkning av Watt vid behov [10, 20 eller 30%]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Watt 10% ↓:</td>
<td>Watt 20% ↓:</td>
<td>Watt 30% ↓:</td>
</tr>
</tbody>
</table>

• Påminnelse → Kalibrera cykel
• Ställ in uppvärmningsbelastning på den stationära cykeln
• Ryggen mot skrivbord, var försiktigt när deltagaren ska upp på cykeln
• Fråga deltagaren om det känns okej att påbörja cykelträningen
  o “Mår du bra? Känns det okej att genomföra cykelträningen?”
  o “Skulle du av någon anledning behöva avbryta, så säg bara till.”
  o “Helst ska du inte prata under testet, men jag som testledare kommer att peppa på.”
  o “Du kommer ej kunna dricka vatten under testet, men direkt efter går det bra.”
• Starta datainsamling av puls med polarklocka
• Starta cykelträningen
  - meddela deltagaren att innan träningen värmer hen upp 1 min på valfri intensitet
• Se över ovanstående punkter medan deltagare genomför intervention.
  
  o Kan du förbereda något? Är allt avcheckat? Ja Nej

• Träningsinterventionen pågår under 20 minuter som i genomsnitt ska vara på den randomiserade intensiteten för dagen antingen 40, 60 eller 80 % av deltagarens VO$_2$ max
• Se till att testpersonen håller RPM 70 = 40%, RPM 80 = 60% och RPM 90 = 80%
• Peppa deltagaren efter behov. T.ex. om deltagaren tappar i RPM, eller märkbart förlorar kraft. Peppande är mer nödvändigt vid 80% men bara när du märker att det behövs.
• Testledare frågar vart på Borgs RPE-skala deltagaren befinner sig och har även uppsikt över deltagarens puls för att säkerställa rätt intensitet:

<table>
<thead>
<tr>
<th>5 min</th>
<th>Borg:</th>
<th>Puls:</th>
<th>Watt:</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 min</td>
<td>Borg:</td>
<td>Puls:</td>
<td>Watt:</td>
</tr>
<tr>
<td>15 min</td>
<td>Borg:</td>
<td>Puls:</td>
<td>Watt:</td>
</tr>
<tr>
<td>20 min</td>
<td>Borg:</td>
<td>Puls:</td>
<td>Watt:</td>
</tr>
</tbody>
</table>

Kommentar:

• Avsluta datainsamling av puls med polarklocka
• **Starta timer** på en telefon (ska vara 10 min tills N-Back börjar)
• Låt deltagaren varva ner på cykel 1 min
• Hjälp deltagaren med avslutning av cykelträning
  
  o “Mår du bra / känns det okej / vill du ha vatten?”
6.0 Efter-test fas

6.1 Frågeformulär och HRV (10 min, varav 5 min sittande vila)

HRV inspelningen

- Deltagaren befinner sig i sittande vila
- Starta inspelningen av deltagarens pulssdata (HRV) med polarklocka, spela in 5.30 min

Starttid:

- Kalibrera om fNIRS samtidigt som vilan pågår
  - På fNIRS-datorn: Open recording page à Start recording in preview mode
  - Kontrollera signaler och ändra Lowpass filter till 1.0
    - å scrolla ner och se att allt ser bra ut
    - ändra Lowpass filter till 0.5
  - Välj Lineplot för att följa pulseringar
  - "Stop recording preview" och var redo att börja spela in
  - Stäng av deltagarens pulssdata (HRV)

Sluttid:

Frågeformulär startar

Ha borgskalan till hands så deltagaren kan titta på den när hen genomför testet

Starttid:
• Deltagaren genomför PANAS-SF+ VAS + BORG _S3

Sluttid:

Om deltagaren är klar med formulär innan 5 minuter, vänta tills timer är på 10 min

Notering, ifall det är längre än 10 minuter till N-Back:

6.2 N-back-test efter intervention (15 min)

Standardiserad instruktion:

“Nu kommer du att få genomföra det tankemässiga testet som pågår i 15 minuter. Skillnaden mot övnings-testet är att du inte kommer att få någon feedback mellan dina svar. När den vita pricken dyker upp på skärmen så ska du räkna 1, 2, 3.. 20. ”

• Starta fNIRS inspelningen (ta bort pekaren från startknappen)
• Starta N-Back så fort som möjligt efter start av fNIRS inspelningen

Starttid:

• Se över ovanstående punkter medan deltagare genomför N-Back.
  o Kan du förbereda något? Är allt avcheckat?   Ja  Nej
SPARA PANAS+VAS+BORGS_S1+S3 i rätt mapp i Moas dator

Sluttid:

- När N-Back-test är slut trycker testledare på STOP på fNIRS-datorn å sedan Exit
- Tappade deltagaren bort sig under testet eller gav upp?

“Tappade du bort dig vid något tillfälle?”
Ja  Nej

“Gav upp vid något tillfälle under testet?”
Ja  Nej

Kommentar:

6.3 Frågeformulär och HRV (10 min)

Frågeformulär startar
Ha borgskalan till hands så deltagaren kan titta på den när hen genomför testet

Starttid:

- Deltagaren genomför PANAS-SF+ VAS + BORG_S4
Om deltagaren är klar med formulär innan 5 minuter, gå vidare till nästa steg

**HRV inspelningen**

- Deltagaren befinner sig i sittande vila
- Starta inspelningen av deltagarens pulsdata (HRV) med polarklocka, spela in 5.30 min

**Starttid:**

- Stäng av deltagarens pulsdata (HRV)

**Sluttid:**

**7.0 Avslut**

**TID:**

Har alla föregående steg genomförts?   Ja   Nej

Om nej, varför? ____________________________________________________________

- Montera av fNIRS-mössan från deltagaren
- Montera av pulsmätaren från deltagaren
• Förklara för deltagaren att de har tillgång till omklädningsrum för dusch och ombyte samt visa vägen
• Påminn deltagaren om vilka pass som återstår vid nästa besök
• Uttryck tacksamhet till deltagaren för hans deltagande i studien och önska återseende vid nästa besök (påminn ses om en vecka, nämn veckodag).

8.0 Checklista efter avslutat besök

8.1 Rengöra/spara

• Stäng PsychoPy på N-Back dator
• Öppna utforskaren å data å kopiera dagens “FPX_CX_PRAC/S1/S2” å klistra in under rätt mapp för deltagare så att N-Back sparas å se till att det är tre filer per test = 9 filer totalt för ett besök
• Logga ut ur N-Back datorn, sedan håll in power i 3 sek
• Sätt i polarklockan i Moas dator och synka den → dubbelkolla att det är 5 filer från dagen per deltagare Lösenord se post-it i pärmen
• Rengöra allting- tvätta mössa
• Förbered fNIRS-mössa till nästa dag i rätt storlek
• Se till att det finns 7 filer sparade i Moas dator per deltagare, (PANAS S1-4, Hälsotillstånd & FA, KSS, SQS)
• Se till att fNIRS data är sparad- S1+S2 i rätt mapp
• Se till att alla filer är sparade med rätt namn
• Sätta i laddaren i fNIRS-datorn, logga ut
• Sätta i laddaren i fNIRS systemet, stäng av

Checklista tisdagar

• Backup N-Back
• Kopiera till DATA → kopiera in i backup-mappen
• Backup filer och fNIRS data

Checklista onsdagar

• Skydda tippar på den mössa som ligger på bordet (röda och blåa)
Byte och rengöring av mössa

- Avlasta sladdarna så att de ej faller på golvet. Skruva av svart behållare för SD detector tills den släpper, skruva sedan tillbaka toppen utan sladdarna som är avlastade. (låt behållare hänga)
- Plocka fram 3 plastbehållare
- Plocka av alla svarta plastlock för optoderna från mössan, placera i plastbehållare 1
- Plocka av hälften av optoderna från mössan (source & detector) och sedan respektive “träd” håll i dom i handen
- Plocka av andra hälften av optoderna från mössan (source & detector) och sedan respektive “träd”
- Lägg av samtliga optoder, trådar och “träd” på sidan på bänken
- Lyft av mössan och vänd den ut och in
- Lyft av 3 gummi “skydd” som sitter för pannan på mössan och placera i plastbehållare 2
- Avlasta SD-detector säkring (minsta runda cirkel) och placera i plastbehållare 2
- Lyft av alla “hästskor” från mössan (som sladdarna sitter i). stadigt grepp
- Använd tången för att hitta hålen på “undre hästsko”. Tryck sedan med tången för att lyfta av och sätta på varje source och detector för att de inte ska falla av
- Ta bort trådarna som sitter i hästkorna ur hålet i mitten av nacken

Förbered montage av nytvättad mössa

- Utgångsläget på mössan är ut och in
- Ta bort säkringar med tången, lägg dem i orangea fNIRSlådan (näst längst upp till höger)
- Sätt tillbaka behållaren i nacken som är kopplad till hästkorna, för att sedan placera hästkorna vid ledig ring
- Dela upp dem i två olika högar
- Varje tråd för sig, så att trådarna är sorterade och inte korsade.
- Placera SD-detector säkring (minsta runda cirkel) 1-2 per sladd, 2 stycken till dem vid pannan
- Se till att sladdarna ej är korsade och spända, se till att de ej är spända dom när mössan är på huvudet
- Sätt på 3 gummi “skydd” på pannan av fNIRS-mössan
- Vänd mössan och sätt den på huvudet

Mössan på huvudet:

- Titta på siffrorna på mössan och på sladdarna så att de är på rätt sida av mössan, häng på stolen
- Koppla på träden för att slippa att hålla i sladdarna, de är uppdelade i två olika- short och long-sladdar
• Koppla rätt färg + siffra, säkra sedan med en optod för att de inte ska falla av, sätt på dem försiktigt och tryck inte hårt i huvudet
• Skruva i svarta behållaren som sista steg

Rengöra sladd etc:

• Ta en pad och dra försiktigt på sladdarna och även på gummipluttarna (3) som sitter vid pannan, sedan rengöra med paden på själva source och detector.

Rengöra mössa:

• Använda röd hink och håll i ljummet vatten och tvål och lägg i mössan, skölj med ljummet vatten och häng upp den på tork på kranen en liten stund, sedan hänga på vita krokar.

Vid trasig plast som behöver bytas:

• Börja på undersidan, ta bort stora runda på motsatt sida, håll i röd/blå hela tiden för att säkra,
• Byt plast och tryck tillbaka den svarta rundan och justera in den med hjälp av att dra isär tyget, säkra på undersidan med hjälp av tången och tunn “hästsko”
Purpose and questions:

Purpose:
- The purpose of this study was to investigate if there was any different acute effects of different intensities of physical exercise on working memory performance.

Questions:
Could the intensity of acute physical exercise matter for improvement of working memory performance?  
When including a delay between physical exercise and cognitive test, could higher intensity positively influence the working memory performance?  
Can fitness level moderate the outcome?  
Can n-back difficulty moderate the outcome?

What keywords did you use?

Keywords and synonyms:
- Single bout of exercise and cognitive/working memory performance
- Acute physical exercise and cognitive/working memory performance
- Working memory performance and physical exercise
- Cognitive functions and physical exercise
- Working memory
- Cognitive functions
- Brain derived neurotrophic factor
- Linear relationship
- U-shaped curve theory
- N-back

Where and how did you search?

<table>
<thead>
<tr>
<th>Databases and other sources</th>
<th>Search combinations</th>
</tr>
</thead>
</table>
| - GIH library search directory  
- Pubmed  
- Sportdiscus | - Single bout of exercise and cognitive performance  
- Single bout of exercise and working memory performance  
- Acute physical exercise and cognitive performance  
- Acute physical exercise and working memory performance  
- N-back and working memory  
- Working memory performance and physical exercise  
- Cognitive functions and physical exercise  
- Working memory and acute physical exercise meta-analysis  
- Working memory and exercise and young adults  
- Executive functions  
- Brain derived neurotrophic factor  
- Brain derived neurotrophic factor and cognitive functions and exercise  
- Acute aerobic exercise and working memory |
My search strategy was to find articles as systematic reviews or meta-analysis, read the articles and use their reference lists and citations. Therefore, I could identify additional articles with a specific interest that matched mine.