The Effects of Exercise Combined with Music on Executive Functioning in Healthy Young Adults

by

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Author’s Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Evidence suggests that both exercise and music improve cognitive functioning. While many individuals listen to music while exercising, whether exercise combined with music produces greater effects on cognitive functioning compared to either method alone is not well understood. This study examined changes in executive functioning (inhibitory control, working memory) in healthy young adults after exercise with music compared to music listening only and exercise only. It was hypothesized that exercise combined with music would show greater improvements in inhibitory control and working memory compared to exercise or music only. Using a repeated measures design, 24 young healthy adults completed three counterbalanced sessions (exercise with music, exercise, and music). Prior to and following the interventions, participants performed assessments for inhibitory control and working memory. The assessments included a Stroop task to assess inhibitory control and a reverse Corsi block task to assess visuospatial working memory. Additionally, affect was assessed pre and post activity using the Physical Activity Affect Scale (PAAS). The data was analyzed using a linear mixed model to compare the effects of exercise with music, music only, and exercise only on cognitive functioning with factors for time (pre/post) and intervention (exercise with music, exercise, music), as well as session number (1, 2,3) to adjust for learning effects within and across sessions.

This study found that working memory improved significantly across time however, the magnitude of changes did not differ significantly between the different conditions. Similarly, improvements in positive affect and fatigue were significant across

time for all conditions but these changes did not differ significantly between conditions. No significant changes were observed for inhibitory control across time or condition. The results of this study suggest that exercise combined with music does not provide any additive benefit to working memory, inhibitory control, or affect when compared to either exercise or music listening. Instead, it appears that all three conditions (exercise with music, exercise, music listening) resulted in similar changes to components of cognitive functioning and affect across time however, these changes depend on the specific domains assessed.

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List of Abbreviations

HR……… Heart rate

fMRI……. Functional magnetic resonance imaging

PET…….. Positron emission tomography

GAQ……. Get Active Questionnaire

RPE…….. Rate of perceived exertion

HRR……. Heart rate reserve

IPAQ…… International Physical Activity Questionnaire

PAAS……Physical Activity Affect Scale

STOMP… Short Test of Music Preference

Chapter 1: Introduction

Cognitive functioning includes a variety of mental activities that include thinking, learning, memory, and communication (Hwang et al., 2016). These processes are important for individuals to acquire knowledge and for effective communication and comprehension (Ludyga et al., 2018). Cognitive functioning is also important for the ability to complete day-to-day tasks effectively (Hwang et al., 2016). As a result, it is important for individuals of all ages to maintain or improve their cognitive functioning.

Increasing evidence in the literature demonstrates that exercise has a small positive effect on brain health among individuals of different ages (Basso and Suzuki., 2017). Specifically, participation in exercise has been shown to have a positive effect on executive functioning (Basso and Suzuki., 2017). Such improvements in executive functioning have been observed following both acute and chronic exercise interventions among older and younger adults (Basso and Suzuki., 2017; Hamer et al., 2018; Tsai et al., 2014). Similarly, there has been increasing evidence to support the idea that listening to music also has beneficial effects on brain health (Sarkamo et al., 2018). Researchers have found that a single session of music listening may elicit improvements in cognitive performance among individuals of different ages (Sarkamo et al., 2013; Xu et al., 2017).

There are preliminary studies investigating the combined effects of exercise and music, but little is known about their relationship and effect on executive functioning (Emery et al., 2003). Some evidence suggests that exercise with music may elicit a positive effect on executive functioning among older adults (Satoh et al., 2014). Other studies have shown that when music tempo and heart rate are matched during exercise there is a positive effect on executive functioning among healthy young adults (Chen et al., 2021). Although the evidence is promising, the research on the effects of exercise with music on cognitive functioning is limited. There has been no research to understand the relative effects of exercise with music compared to music listening, and there are few studies that determine the effects of this type of intervention among younger adults even though these individuals do exercise with music regularly. With an understanding of how these different activities impact cognitive functioning among young adults, these individuals can utilize this information to participate in specific activities that will have a positive effect on different aspects of their lives. The current study aimed to address these gaps to gain an understanding of the impact of exercise with music compared to exercise as well as music listening to determine if there is an additive benefit of exercise combined with music on cognitive functioning and if it is more effective than either method alone. This information is important for determining the most effective interventions for improving day-to-day cognitive functioning.

Chapter 2: Literature Review

2.1 Executive Functioning

Executive functioning involves mental processes that are necessary for day-to-day tasks; executive functioning controls goal-directed behaviours and gives individuals the ability to problem solve, reason, and make decisions (Diamond., 2013; Etnier and Chang., 2009). Higher order cognitive processes, such as executive functions, are necessary to perform more complex tasks such as reasoning, problem solving and planning (Reynolds at al., 2019; Guiney and Machado., 2012). Three core executive functions are often described: inhibitory control, working memory, and cognitive flexibility (Diamond., 2013). These three core functions are necessary to build higher order executive functions that allow individuals to reason, problem solve, and plan (Diamond., 2013). Without normal executive functions, an individual would have difficulty in many aspects of their daily lives including school, jobs, and social and psychological development.

Inhibitory control allows an individual to control their own attention, emotions, and/or behaviour by suppressing interference from irrelevant stimuli to focus on the task at hand (Hwang et al., 2016; Kao et al., 2017). Although attention is not considered an executive function, selective attention is associated with inhibitory control. Selective attention allows individuals to choose which stimuli to attend to and which to ignore and it is accomplished through inhibitory control of attention (Diamond et al., 2013). Inhibitory control and selective attention are important components of self-control which allows individuals to complete a task despite any distractions around them. As such, this is an important skill to have for functioning and achieving success in daily life (Diamond et al., 2013).

Working memory allows individuals to store information, which is no longer perceptually present, in their mind to manipulate the information mentally (Guiney and Machado., 2012; Baddeley, 1992). However, this is not the only function of working memory. It is also responsible for coordination of resources (Baddeley, 1992). Working memory is important for language comprehension, reasoning, learning, retrieval of old information, updating information, and connecting different pieces of information together (Diamond., 2013; Baddeley, 1992).

Cognitive flexibility allows individuals to change perspectives spatially, or interpersonally (Diamond., 2013). This requires both inhibitory control and working memory as the individual would first need to inhibit their initial perspective and use working memory to manipulate the information (Guiney and Machado., 2012). Cognitive flexibility allows individuals to make changes to the way they think about information and consider different perspectives which is very important for problem solving and planning (Diamond., 2013).

2.2 Influence of Aerobic Exercise on Executive Functioning

The effects of physical activity, and specifically aerobic exercise, on cognitive functioning have been examined. Researchers have examined the effects of both exercise training and acute aerobic exercise on cognitive functioning. Individuals that participate habitually in physical activity have better cognitive performance compared to sedentary individuals in most studies (Chen et al., 2021). Furthermore, evidence has shown that aerobic exercise interventions may improve cognitive functioning among individuals of different age groups including children, young adults, and older adults (Ludyga et al., 2020; Northey et al., 2017). A meta-analysis which reviewed studies that investigated aerobic exercise training effects observed improved cognitive performance across different age groups with a small positive effect size (Cohen's d = 0.25) (Etnier et al., 2006). Similarly, researchers have also studied the effects of an acute bout of aerobic exercise and found that it may elicit positive effects on cognitive functioning (Barella et al., 2010; Basso and Suzuki., 2017). This evidence will be reviewed here.

2.2.1 Acute Effects of Aerobic Exercise on Executive Functioning

Even a single bout of aerobic exercise has been shown to have beneficial effects to individuals' cognitive functioning (Barella et al., 2010; Basso and Suzuki., 2017). A meta-analysis concluded that a single bout of aerobic exercise may improve cognitive performance across age groups with an overall small positive effect (Cohen's d = 0.097) (Chang et al., 2012). However, the meta-analysis also reported an effect size of 0.139 (Cohen's d) for changes in cognitive performance when assessed immediately following exercise (Chang et al., 2012). The size of the effect observed in cognitive functioning appears to be dependent on the exercise parameters used, thus larger effects may be possible with the right dose (Chang et al., 2012).

Aerobic exercise seems to have a positive impact on a variety of cognitive domains and sub-domains, with executive function being the focus of this thesis. Most studies support a positive acute effect of exercise on inhibitory control. One study that investigated the effect of a single session of high intensity exercise on inhibitory control among healthy young adults using a Stroop task found significant improvements in response times for congruent and incongruent components following the exercise condition compared to the control condition (Hwang et al., 2016). This agrees with the results of a meta-analysis that reviewed studies on the effects of acute aerobic exercise on cognitive functioning which reported a positive effect (Cohen's d = 0.249) for Stroop task performance (Chang et al., 2012). Other studies have also found significant improvements in inhibitory control among healthy young adults following a single session of aerobic exercise (Davranche et al, 2009; Ludyga et al., 2018; Gmiat et al., 2017; Lambourne and Tomporowski., 2010; Nieman et al., 2021; Shigeta et al., 2021). However, there is some conflicting evidence on the effects of acute aerobic exercise on inhibitory control where some studies have not found any significant changes. One study used a Flanker task as well as a Go/No-Go task to evaluate changes in selective attention and inhibitory control among young adults following exercise, but no significant differences in change were observed between groups for either task (Mehren et al., 2019). It is possible that the Stroop task is more sensitive to the effects of exercise, though other studies have observed positive effects with the Flanker task (Lambourne and Tomporowski., 2010).

The effects of acute aerobic exercise on other components of executive functioning have also been investigated, with some evidence for benefits. Researchers have found that a single session of aerobic exercise may have a positive effect (Cohen's d = 0.31) on working memory among healthy young and older adults however, there is conflicting evidence (McSween et al., 2018; Ludyga et al., 2018). One study that used a variation of the Corsi block tapping task to assess short term memory and spatial working memory observed a moderate positive effect on cognitive performance for young adults, though there was not an improvement among middle-aged adults (Gmiat et al., 2017). Another study that used a 2-back task to assess working memory among healthy young adults found significant improvements following moderate intensity continuous exercise and high intensity interval exercise compared to a control (Mou et al., 2022). In contrast one study, which used the n-back task to assess working memory among healthy young adults, found no significant improvements in working memory following 15 minutes of moderate intensity running compared to 20 minutes of reading (Ludyga et al., 2018).

2.2.1.1 Moderators of the Acute Effects of Aerobic Exercise on Executive Functioning

Though meta-analyses indicate that a single bout of aerobic exercise improves cognitive functioning, results are not as consistent across individual studies (Barella et al., 2010; Basso and Suzuki., 2017; Etnier et al, 1997). Exercise, task, and setting-related moderators may contribute to the variability in results.

Exercise-Related Moderators

Researchers have found that the duration of an exercise session may moderate the effects that the session has on cognitive performance. A meta-analysis found that when assessments were conducted following exercise, duration significantly affected the outcome (Chang et al., 2012). Shorter exercise sessions resulted in negligible effects on cognitive performance and exercise sessions that were longer than 11 minutes resulted in positive effects (Chang et al., 2012). The duration of the session may also impact the concentration of catecholamines within the brain, with concentrations increasing just after 20 minutes of exercise. This will later be discussed (Section 2.2.2) as a potential mechanism for the effect of exercise on cognitive functioning (Winter et al., 2007). In line with the meta-analysis, one study that compared the effects of three different exercise durations (10, 20, and 45 minutes) on information processing and inhibitory control among healthy young men found that 20 minutes of moderate intensity exercise improves cognitive performance (Chang et al., 2015). The longer and shorter exercise durations had negligible benefits (Chang et al., 2015). The current study had participants complete 20 minutes of moderate intensity exercise during each session to maximize the likelihood of observing a positive effect on executive functioning.

There is considerable evidence that exercise intensity moderates the effects of exercise on cognitive functioning following a single bout of aerobic exercise, though the effect of intensity varies somewhat across studies (Basso and Suzuki., 2017; Chang et al., 2012; McMorris et al., 2012). While a number of studies indicate that the different exercise intensities (light, moderate, and high) are each associated with positive changes to cognitive functioning (Basso and Suzuki., 2017; Mou et al., 2022), some research suggests that moderate intensity exercise is the most effective (Pyke et al., 2020). One study compared the effects of low intensity, moderate intensity, and high intensity exercise on cognitive performance using a Go/No-Go task and associated P300 event-related potentials among healthy young men (Kamijo et al., 2004). Cognitive performance improved more following moderate intensity exercise compared to high intensity exercise, and low intensity exercise had no significant impact on cognitive performance compared to the control group (Kamijo et al., 2004). Similarly, another study comparing the effect of low intensity (55-65% heart rate (HR) max), moderate intensity (65-75% HR max), and high intensity exercise (75-85%HRmax) on memory among healthy young adults found that moderate exercise intensity was the most effective at improving memory performance (Pyke et al., 2020). Studies using brain imaging techniques have also found that moderate intensity may be the most effective at improving cognitive performance. With the use of functional magnetic resonance imaging (fMRI), researchers discovered that moderate intensity exercise may increase brain activation in areas related to executive functioning and that high intensity exercise may reduce activity in these areas (Mehren et al., 2019). Together the results of these studies demonstrate that moderate intensity exercise may be the most effective for improving cognitive performance compared to other exercise intensities. The current study had participants exercise at a moderate intensity to increase the likelihood of observing positive effects on executive functioning.

Task-Related Moderators

Factors related to the task used can also impact the effect observed. Evidence has demonstrated that both the timing of the cognitive assessment as well as the cognitive domain assessed may impact the observed effect on cognitive functioning (Chang et al., 2012). These moderators will be discussed in detail to help explain the timing of assessments and which cognitive domains were assessed in the current study.

Evidence shows that the timing of the assessment following an acute bout of exercise may have an influence on the effect size. One meta-analysis indicated that assessments within 1-15minutes following exercise resulted in significant positive effects (effect size = 0.139) on cognitive performance while changes in cognitive performance following a 15minute delay or more after exercise were insignificant (Chang et al., 2012). Another study observed greater improvements in executive functioning at 15 minutes compared to 180 minutes following an acute bout of moderate intensity exercise (Naderi et al., 2019).

There also seems to be an interaction between exercise intensity and the timing of cognitive assessments that may impact the effect of exercise on cognitive performance. A meta-analysis found that there was a decline in cognitive performance after very light exercise whereas more intense exercise (light to very intense) resulted in significant positive effects on cognitive performance, when cognitive functioning was assessed at least a minute after exercise cessation (Chang et al., 2012). The current study had participants perform the assessments after a 10 minute delay following the moderate intensity exercise intervention.

The effects of exercise on cognitive functioning may vary depending on the cognitive domain assessed and the specific cognitive task. Studies have demonstrated that assessments of inhibitory control are sensitive to the effects of acute aerobic exercise, especially when inhibitory control is assessed using the Stroop task (Tomporowski., 2003). Studies have reported larger effect sizes for inhibitory control following exercise compared to effect sizes observed for other cognitive tasks such as working memory, short term memory, and long-term memory (Barella et al., 2010; Chang et al., 2012; Ludyga et al., 2018). Additionally, the effects on working memory following exercise are conflicted, with some studies reporting positive effects while others have reported negative effects. Researchers have found that a single session of aerobic exercise may have a positive effect on working memory however, there is conflicting evidence (McSween et al., 2018; Ludyga et al., 2018). One study found significant improvements in working memory following moderate intensity continuous exercise compared to a control as assessed by a 2-back task (Mou et al., 2022). Similarly, another study, which used a backwards digit span task, found significant improvements in working memory following high intensity functional training compared to walking or a non-exercise control (Wilke et al., 2020). In contrast, another study found no significant improvements on an n-back task following 15 minutes of moderate intensity exercise compared to 20 minutes of reading (Ludyga et al., 2018). Similarly, another study, which used the Corsi block tapping task to assess spatial working memory, found no significant changes in working memory, though assessments occurred following a one hour delay after exercise (Gmiat et al., 2017). Thus, exercise may result in improved working memory, however, this may depend on the type of assessment used as well as exercise duration (Chang et al., 2012). As discussed above, some studies have found significant improvements in working memory using the n-back task and backwards digit span task but other studies have found no improvements when the Corsi block task and n-back task were used to assess working memory (Mou et al., 2022; Wilke et al., 2020; Ludyga et al., 2018; Gmiat et al., 2017). This conflicting evidence may be related to differences in the difficulty of tasks used to assess working memory. Additionally, task duration may also influence the observed effect on working memory as one study found significant improvements in working memory on the n-back task following 20 minutes of moderate intensity exercise (Mou et al., 2022), while another study, which assessed working memory following 15 minutes of moderate intensity exercise, found no significant improvements on the n-back task following 15 minutes of moderate intensity exercise (Ludyga et al., 2018). The current study assessed working memory and inhibitory control following the intervention to increase the likelihood of observing a positive effect on executive functioning among participants.

Setting-Related Exercise Moderators

While research on factors moderating the acute effects of exercise on cognitive functioning have focused on exercise-related factors, and to a lesser extent task-related factors, there is also reason to believe that factors commonly present in exercise settings may influence the magnitude of effects observed. These setting-related factors include other people (socializing) during exercise, sounds (including music), and natural versus built environment. While there has been little research to determine the effect of social engagement during exercise on cognitive function (Nieman., 2019), evidence suggests that people who socially engage more frequently may have greater executive functioning compared to those who do not engage in social interactions as often (Bourassa et al., 2015). Some researchers have also investigated the impact that exercising in different environments has on cognitive functioning. Evidence suggests that exercising indoors will result in greater improvements to cognitive functioning compared to an outdoor environment (Cassilhas et al., 2021). This may be related to air pollution, as one study found that individuals that exercised outdoors in rural areas had greater improvements in cognitive functioning compared to a group that exercised outdoors in urban areas (Bos et al., 2014). Music is another factor that when combined with exercise may impact the magnitude of effect on cognitive functioning (Pauwels et al., 2014), and will be part of the focus of this thesis. Evidence has shown that a single session of listening to music may improve executive functioning and some researchers have begun to study the combined effects of music and exercise (Emery et al., 2003). The influence of music as well as exercise combined with music on cognitive function will later be discussed in detail in sections 2.3 and 2.4 respectively.

2.2.2 Potential Mechanisms for Effects of Exercise on Cognitive Functioning

The mechanisms responsible for the improvements in cognitive functioning following exercise have been investigated and are likely multifactorial and complex. However, two potential mechanisms include changes in catecholamine concentrations and brain derived neurotrophic factor (BDNF) levels in the brain and will be discussed here (Weng et al., 2015; Chang et al., 2012).

Evidence has shown that there is an increase in the concentration of catecholamines, such as dopamine and norepinephrine, during a single session of aerobic exercise (Chang et al., 2012; McMorris et al., 2012; Basso and Suzuki., 2017). This increase in neurotransmitter may elicit a positive effect on processing speed but could potentially cause neural noise that could impact the accuracy in processing working memory tasks (McMorris et al., 2012). It has also been suggested that effects resulting from increased catecholamines may only be observed during exercise or for a short duration post-exercise due to the half-life of peripheral catecholamines (McMorris et al., 2012). However, not all studies agree. One study, which investigated the relative change in dopamine levels using positron emission tomography (PET), found that there were no significant changes in dopamine levels following the exercise session compared to the control (Wang et al., 2000). Thus, the impact of catecholamine concentrations on changes in cognitive functioning following exercise are not clear and should be investigated further as a potential mechanism.

Another potential mechanism for the effects of exercise on cognitive functioning are changes in BDNF levels (Chang et al., 2012; Dahan et al., 2020; Etnier et al., 2016; Weng et al., 2015). An acute bout of aerobic exercise results in an increased concentration of plasma BDNF which binds to receptors initiating signaling cascades that are important for adaptation to exercise (Etnier et al., 2016; Ferris et al., 2007). These signaling pathways affect learning and memory through their effect on neurogenesis and neuroplasticity (Etnier et al., 2016; Ferris et al., 2007). In addition, initiation of these signaling pathways is not immediate during exercise, instead it likely occurs following exercise. Thus, the improved cognitive performance following exercise may result from the cascade of signaling pathways (Lambourne and Tomporowski., 2010). Some studies have found that serum BDNF levels are elevated for up to 60 minutes following exercise (Knaepen et al., 2010). The increases in BDNF levels have been measured peripherally but researchers believe that BDNF crosses the blood-brain barrier and that the concentrations peripherally correlate to central concentrations of BDNF (Etnier et al., 2016). One study found that following a single session of aerobic exercise, there were increases in peripheral BDNF however, in contrast to previous literature this was not dose specific (Etnier et al. ,2016). Participants were assessed at three different exercise intensities including maximal, and above and below the ventilatory threshold, but the increase in BDNF was not significantly different between sessions (Etnier et al., 2016). However, it was mentioned that there could be differences between the concentration of BDNF peripherally compared to centrally which was not measured in this study (Etnier et al., 2016).

2.3 Influence of Music on Executive Functioning

There is good evidence that music listening improves cognitive functioning. Researchers have investigated both the chronic effects of listening to music as well as the acute effects of music listening on cognitive functioning, although most of the research on chronic effects focuses on clinical populations. Researchers have found that long-term music listening can result in improved cognitive performance among individuals living with dementia as well as people who experienced a stroke (Sarkamo et al., 2017; Fang et al., 2017; Sarkamo et al., 2008), though there is considerable variability across studies (Xu et al., 2017). In addition to the chronic training effects of listening to music, researchers have also investigated the acute effects of listening to music, which is also associated with improvements to cognitive performance (Rauscher et al., 1993; Vasionyte and Madison., 2013). However, there is limited research to investigate the effects of music on cognitive functioning following a single session of music listening, as much of the research focuses on the effects of background music.

2.3.1 Acute Effects of Music on Executive Functioning

Results of studies examining the acute effect of music listening on cognitive functioning are promising, indicating that music may improve cognitive functioning across different age groups, including young and older adults, as well as clinical populations (Rauscher et al., 1993; Vasionyte and Madison., 2013). Evidence has shown that acute exposure to music can enhance spatial-temporal reasoning—known as the Mozart effect (Rauscher et al., 1993). The Mozart effect refers to enhanced cognitive performance including improved spatial reasoning skills following a period of listening to a piano sonata by Mozart (K448) (Pauwels et al., 2014; Rauscher et al., 1993). However, this effect may not be limited to Mozart or to spatial-temporal reasoning (Lints et al., 2003; Gupta et al., 2018; Sarkamo et al., 2013). Changes in cognitive functioning after listening to music appear to be related to the heightened arousal, which results in improved cognitive performance in domains such as attention, spatial reasoning, and information processing (Lints et al., 2003; Pauwels et al., 2014). For example, a meta-analysis, which reviewed the results of studies investigating the effects of both long-term and short-term music listening on individuals living with dementia, reported positive effect sizes of 0.24 and 0.39 for category fluency and visuospatial functioning tasks respectively, following short term music listening (Vasionyte and Madison., 2013). In contrast, another review which examined studies that investigated both long-term and short-term effects of music on cognitive functioning among individuals with dementia, reported that some studies found no significant effects on cognitive functioning following short-term music listening (Soufineyestani et al., 2021).

The timing of the cognitive task has not been thoroughly investigated as researchers mainly focus on the effect of background music on cognitive functioning where participants complete the cognitive task while listening to music. However, one study found that when participants listened to music prior to the cognitive task, they showed greater performance on tasks which assessed spatial reasoning compared to the no music group (Rauscher et al., 1993). This enhanced performance lasted for 10-15 minutes following the music session (Rauscher et al., 1993). Similarly, the music listening environment and music volume have also not been thoroughly investigated to understand how these factors may impact the effect of a single session of music listening on cognitive functioning. These factors should be investigated further to understand how they may moderate the effects of music listening on cognitive functioning.

Although the results are promising with the notion that listening to music may improve cognitive functioning (Xu et al., 2017), due to the wide range of music genres to choose from as well as the small samples often used, further research is needed to fully understand the effects of music on the brain.

2.3.1.1 Moderators of the Acute Effects of Music on Executive Functioning

Researchers have found that there are different factors that may moderate the impact that music has on cognitive functioning such as the cognitive task administered (Pauwels et al., 2014; Stevens et al., 2012).

Effect Moderators

Researchers have found that the type of cognitive task administered when listening to music may moderate the observed effect on cognitive functioning. Music listening has been shown to impact cognitive performance on tasks including working memory, attention, inhibitory control, and spatial temporal reasoning (George et al., 2011; Thompson et al., 2011; Johnson et al., 1998). One study, which was the first to investigate the Mozart effect, found that spatial-temporal reasoning may be improved following listening to a piece of music by Mozart (Rauscher et al., 1993). In contrast, other researchers did not observe a significant effect on spatial-temporal reasoning following a session of listening to Mozart despite using the same assessment, a paper-folding and cutting test from the Stanford-Binet intelligence scale (Carstens et al., 1995; Steele et al., 1999). These differences in the results could be due to differences in sample characteristics and individual differences of the participants. Other studies have investigated the impact of music on other aspects of cognitive functioning. One study was conducted to investigate the effect of music compared to exercise and a control on cognitive creativity (Frith and Loprinzi., 2018). Four variables were used to assess verbal cognitive creativity including fluency, flexibility, originality, and elaboration; however, it was found that there was no significant effect of exercise or music on creativity. It is possible that effects of music on cognitive functioning may depend on the cognitive domain assessed, where they are larger for executive functioning than on cognitive creativity (i.e., verbal fluency, flexibility) as well as the task used to assess the participants, though this needs to be explored further. The current study assessed visuospatial working memory among participants to increase the likelihood of observing a positive effect on executive functioning.

2.3.2 Potential Mechanisms for Effects of Music Listening on Cognitive Functioning

The mechanisms responsible for the improvements in cognitive functioning following music listening have been investigated and are, again, likely complex. However, researchers have found that changes in brain activity as well as catecholamines concentrations in the brain may play a role (Weng et al., 2015; Chang et al., 2012).

Researchers believe that changes in brain activity could be a potential mechanism for the improved cognitive performance observed following a session of listening to music. Using EEG to observe changes in alpha band power and functional connectivity in the brain, one study found that listening to music results in a reduction in the flow of information between brain regions (Gupta et al., 2018). This allows the brain to work more efficiently and reallocate those resources for more effective processing within the prefrontal lobes (Gupta et al., 2018) This can contribute to increased arousal and enhanced attention by decreasing distractions which could result from unrelated crosstalk among neural networks (Gupta et al., 2018). Additionally, evidence has shown that different brain regions are engaged during music listening including the amygdala, hippocampus, and nucleus accumbens (Pauwels et al., 2014). Additionally, studies using neuroimaging techniques including PET and fMRI have demonstrated that bilaterally, both the limbic structures (amygdala and hippocampus) and the paralimbic structures (orbitofrontal cortex, parahippocampal gyrus, and temporal poles) are active when listening to music (Pauwels et al., 2014; Sarkamo et al., 2013). The activation of the nucleus accumbens, hippocampus and amygdala during periods of listening to music indicates that music may modulate activity in the brain regions responsible for emotions (Pauwels et al., 2014). The hippocampus, in particular, has important roles in memory and executive functions (O’Shea et al., 2016).

Studies have also demonstrated that tonality of music may impact neural activation; minor keys activate larger brain regions compared to major keys which indicates a difference in neural processing (Pauwels et al., 2014; Suzuki et al., 2008). One study, which used PET to investigate changes in brain activity when listening to music, found that the right striatum, which is involved in reward and emotional processing, appears to be activated by minor consonant chords. In contrast, major consonant chords appear to activate areas in the left middle temporal gyrus, which is involved in information processing, memory, and emotional processing (Suzuki et al., 2008). Other researchers have identified additional brain regions to be activated when comparing minor versus major tonality including the amygdala, brain stem, and cerebellum (Pallesen et al., 2005). Thus, the different characteristics of a music piece may be important to consider when investigating the influence that music may have on the brain.

Another potential mechanism for the improvement in cognitive performance following a session of listening to music is the change in concentration of catecholamines in the brain (Pauwels et al 2014; Fang et al., 2017). Listening to music has been shown to increase the release of neurotransmitters such as dopamine, norepinephrine, and epinephrine in the brain (Pauwels et al., 2014; Fang et al., 2017; Clark et al., 2015). One study used PET to show the release of dopamine in the striatum during peak emotional arousal when listening to music (Salimpoor et al., 2011). This could be responsible for the improved cognitive performance as studies have shown that higher levels of dopamine may improve executive functioning among healthy individuals (Dang et al., 2012; Pauwels et al., 2014). Additionally, researchers found that listening to music reduces cortisol secretion and has a positive effect on mood (Fukui and Toyoshima., 2008). It has been hypothesized that this may facilitate neurogenesis, regeneration, and repair which may be mediated by BDNF levels (Noble et al., 2014). It appears that BDNF may increase in response to listening to music as does its receptor (Angelucci et al., 2007; Pauwels et al., 2014; Fang et al., 2017).

2.4 Influence of Exercise Combined with Music on Executive Functioning

Researchers have also begun to investigate the combined effects of exercise with music on cognitive functioning. Both chronic (after a period of training) and acute (after a single session) effects of exercise with music have been studied among young and older adults, though the majority of research is on chronic training effects among older adults and clinical populations. One study investigated the effects of exercise training while listening to music among older adults over 1 year and found that performance on visuospatial functioning tasks improved significantly when compared to an exercise no-music group (Satoh et al., 2014). Another study similarly found that for people living with dementia, the chronic effects of exercise training combined with music improved visuospatial functioning when compared to a cognitive stimulation control group (Satoh et al., 2017). Improvements have also been found among individual’s post-stroke. In a study that investigated the effect of a training period of exercise with music on individuals’ post-stroke, lesion size in stroke recovery improved more among people who completed their exercise rehabilitation with music compared to no music (Fotakopoulos and Kotlia., 2018). It is likely that other studies also included music listening during exercise but may not have mentioned this as it is such a common and widely accepted practice.

2.4.1 Acute Effects of Exercise with Music on Executive Functioning

In addition to the training effects, some research has been conducted to investigate the acute effects of exercise with music on cognitive functioning. However, to date there is limited research on the acute training effects of exercise with music on cognitive functioning. Preliminary evidence suggests that exercise with music may improve cognitive functioning across a number of domains including working memory, inhibitory control and verbal fluency (Emery et al., 2003; Chen et al., 2021). One study explored the impact of exercise with music on verbal fluency among individuals in a cardiac rehab program (Emery et al., 2003). Participants each completed an exercise session with music and an exercise session with no music. Performance on a verbal fluency task was better in the music condition compared to the no-music control (Emery et al., 2003).

Researchers have found that music tempo may impact the effect of exercise with music on cognitive functioning (Chen et al., 2021). Musical rhythms are similar to many rhythms inside and external to the human body and these rhythms of music can help individuals to synchronize their movements during exercise (Clark et al. 2015). Evidence has shown that humans may have a predisposition for repetitive movement at cadences around 120bpm, which is a music tempo commonly found in Western music (Clark et al, 2015). Another study investigated the effect of music tempo and exercise on executive functioning among younger adults using a Stroop task and N-back task to assess inhibitory control and working memory respectively (Chen et al., 2021). Inhibitory control and working memory were both assessed prior to and immediately following the session. The authors found that both working memory and inhibitory control were improved following a session of exercise with music in which tempo and heart rate were synchronized compared to unsynchronized conditions (Chen et al., 2021).

Although there is emerging research to understand the relationship between music and exercise and their effect on cognitive functioning, research on this topic is still in its infancy. Further research is needed to understand whether the effects are additive and/or synergistic. In addition, there is not yet any research examining the effect of exercise with music compared to music listening or research examining the effects of exercise with music compared to exercise only among healthy adults. Additional work is needed to determine the exercise-, music, person, and setting-related factors that moderate cognitive effects.

2.5 Exercise- and Music-Related Effects on Affect

Changes in affect, the short-term expression of an individual's emotions (Lox et al., 2000), will be a secondary outcome in this study. In addition to improving cognitive functioning, there is good evidence that exercise and listening to music can improve affect (Gerra et al., 1998; Nieman et al., 2021). A number of studies have found that even a single session of exercise can improve affect (Nieman et al., 2021, Schmitt et al., 2020). Components of affect that seem to benefit from exercise include positive affect but not calmness (Nieman et al., 2021; Schmitt et al., 2020). For example, one study examined the effect of a single session of 20 minutes of moderate intensity cycling compared to 20 minutes of reading on changes in affect using the Bond-Lader visual Analog Scale (Nieman et al., 2021). Immediately after the interventions, participants were significantly more alert and content following moderate intensity exercise compared to after reading; however, calmness was similar after both exercise and reading. (Nieman et al., 2021). Similarly, another study, which used the Positive and Negative Affect Schedule (PANAS) found that positive affect improved significantly following 20 minutes of both high intensity exercise and low intensity exercise when compared to a seated control group (Schmitt et al., 2020).

Studies have also found that a single session of music listening can also influence affect (Gerra et al., 1998), but that this may depend on the type of music listened to (Garrido et al., 2015). One study, which investigated the influence of classical music on emotional states compared to techno music, found that listening to classical music improved emotional states where participants felt more calm, relaxed, and serene compared to techno music (Gerra et al., 1998). Listening to techno music resulted in a significant decline in emotional states with participants feeling significantly more tense, anxious, and anguished (Gerra et al., 1998). Another study, which had participants listen to self-selected sad music followed by self-selected happy music, found a significant increase in feelings of depression immediately after listening to sad music and a significant reduction in feelings of depression immediately after listening to happy music (Garrido et al., 2015).

One study investigated the effects of exercise combined with music on affect (Chen et al., 2021). Specifically, they compared the changes in emotional state from pre to post activity following an exercise session in which the music tempo was matched to heart rate compared to two mismatched conditions (Chen et al., 2021). Using the Chinese Mood Adjective Check List to assess changes in emotional states, they found that happy and excited scores were significantly higher for the heart rate matched condition compared to the other two (Chen et al., 2021). The effects of exercise combined with music on affect have not been compared to that of exercise only or music listening only, however. This relationship should be investigated further to understand the potential additive benefits that may be gained from combining the two activities (exercise with music) compared to either activity alone.

2.6 Influences of Mood and Affect on Cognitive Functioning

Mood disorders and their symptoms may influence cognitive functioning in the short and long-term. Meta analyses have found that depressive symptoms may not only reduce cognitive performance but that they may also increase the risk of dementia (Chodosh et al., 2007; Jorm et al., 2000). Additionally, another meta-analysis found that the severity of depressive symptoms is correlated to performance on tasks involving executive functioning as well as components of cognitive functioning including processing speed (McDermott and Ebmeier., 2009). Researchers have also found that in addition to depression, other mood disorders, such as generalized anxiety disorder, are associated with a reduction in cognitive performance as well and can impact cognitive processes including attention and memory (Elliot et al., 2010).

Several studies have found that affect may also influence cognitive functioning in the short term, but that the direction and magnitude of changes may depend on the domain of affect and cognition. For example, studies of induced positive affect have generally, but not always, observed improvements in executive functions, and particularly task-switching tasks (Goschke & Bolte 2014). Similarly, a recent review concluded that negative affect may improve several aspects of cognitive functioning, including memory and judgement (Forgas 2013). However, a study that examined induced sad mood found variable effects depending on the cognitive domain assessed, where it negatively affected facial recognition but not executive function tasks (Chepenik et al., 2007). Thus, it appears that affect may influence cognitive functioning, but this relationship likely depends on the domain of affect (positive, negative, etc.) as well as the cognitive assessments used.

Although very little research has investigated the influence of mood during exercise combined with music on cognitive functioning, one study found that a positive mood during exercise moderates the beneficial effect of exercise on cognitive functioning (Suwabe et al., 2021). Specifically, they found that a positive mood during moderate intensity exercise combined with music was correlated to increased cognitive performance as well as increased activation in brain areas involved in executive functioning (Suwabe et al., 2021). In addition, several studies that investigated the effect of exercise on cognitive functioning and affect within the same study found improvements in both (Nieman et al., 2021; Hognan et al., 2013; Magnan et al., 2012). One study found increased levels of arousal and positive affect as well as improvements in working memory following 15 minutes of moderate intensity exercise among young and older adults (Hognan et al., 2013). Similarly, another study found increased contentedness and alertness as well as improved cognitive control following 20 minutes of moderate intensity exercise among healthy young adults (Nieman et al., 2021).

The mechanisms responsible for the relationship between affect and cognitive functioning are likely very complex. Studies suggest that many of the brain areas involved in cognitive functioning are influenced by affect and that changes in affect may influence activation of these areas, including the dorsolateral prefrontal cortex (Chepenik et al., 2007; Suwabe et al., 2021). For example, one study found a correlation between improved cognitive performance, positive mood, and increased activation of the dorsolateral prefrontal cortex (Suwabe et al., 2021). Another possible mechanism underlying the relationship between affect and cognitive functioning could be changes in catecholamine levels due to changes in affect (Okon-Singer et al., 2015), where catecholamines are known to influence brain and cognitive functions (Arnsten., 2011) and vary with affect (Okon-Singer et al., 2015; Arnsten et al., 2011).

Chapter 3: Current Study

3.1 Rationale

Previous research has found that an acute bout of moderate intensity aerobic exercise has a positive effect on executive functioning (Basso et al., 2015). Similarly, improvements in cognitive performance have been found during a session of listening to classical music (Mammarella et al., 2007; Verrusio et al., 2015). With an understanding of how music and exercise impact cognitive functioning on their own, researchers have begun to investigate the effects of exercise combined with music on cognitive functioning. The majority of this research focuses on the chronic training effects of exercise with music in older adults. Studies have demonstrated that listening to music while exercising may improve cognitive functioning in the long term among older adults relative to a non-music exercise control (Satoh et al., 2014). There has been less research on the acute effects of a bout of aerobic exercise combined with music; however, preliminary evidence indicates that exercise with music may have a positive impact on cognitive functioning among young adults as well. One study indicated that tempo matching pop music with heart rate during exercise may improve executive functioning in younger adults (Chen et al., 2021). Also, when comparing the effects of exercise with music to exercise only on cognitive functioning, researchers have found that exercise with music may have a greater positive effect on cognitive functioning compared to exercise only among older adults (Emery et al., 2003). However, there has been no research to date to determine the effects of exercise with music on cognitive functioning compared to music listening, so it is unknown if exercise with music offers greater cognitive benefits compared to music listening. Additionally, there is limited research on the effects of exercise with music among healthy adults; specifically, no research has been conducted to date to examine the effects of exercise with music compared to exercise alone. It is important to address these gaps to gain a better understanding of the additive benefit that may result from exercise with music compared to either intervention alone. Understanding these differences will provide the necessary information for prescribing interventions or designing exercise programs that are the most effective and efficient at improving cognitive functioning.

This study explored the acute effects of moderate intensity aerobic exercise combined with classical music on executive functioning (inhibitory control and working memory) compared to exercise and music listening among healthy young adults. Measures of affect were also collected prior to and following each condition to determine the influence of exercise combined with music on affect compared to exercise or music listening. The results of this study will help to inform and improve future interventions to improve cognitive functioning among healthy young adults.

3.2 Thesis Objectives and Hypothesis:

Primary Objectives:

Objective 1: To compare changes in inhibitory control following the acute moderate intensity aerobic exercise combined with music, acute moderate intensity aerobic exercise, and music listening sessions using measures from a computerized version of the Stroop task.

Hypothesis 1.1: It was hypothesized that inhibitory control would improve more after acute moderate intensity aerobic exercise combined with music than after acute moderate intensity aerobic exercise only or music listening only.

Objective 2: To compare changes in working memory following the acute moderate intensity aerobic exercise combined with music, acute moderate intensity aerobic exercise, and music listening sessions using measures from a computerized version of the Backwards Corsi block test.

Hypothesis 2.1: It was hypothesized that working memory will improve more after acute moderate intensity aerobic exercise combined with music than after acute moderate intensity aerobic exercise only or music listening only.

Exploratory Objectives:

Objective 3: To explore the effect of acute moderate intensity aerobic exercise combined with music, acute moderate intensity aerobic exercise, and music listening on affect.

Outcome 3.1: It was expected that affect will improve more after acute moderate intensity aerobic exercise combined with music than after acute moderate intensity aerobic exercise only or music listening only.

Objective 4: To explore the role of affect as a mediator on the effects of acute moderate intensity aerobic exercise combined with music, acute moderate intensity aerobic exercise, and music listening on inhibitory control and working memory.

Outcome 4.1: It was expected that affect will mediate the effects of acute moderate intensity aerobic exercise combined with music, acute moderate intensity aerobic exercise, and music listening on cognitive functioning.

3.3 Methods

This study used a repeated measures design in which participants were each asked to complete three sessions: combined (exercise with music), exercise, and music listening. The order of the three sessions was counterbalanced and sessions were scheduled at least one week apart, when possible, to reduce the potential for learning and practice effects on cognitive assessments. The cognitive assessments were administered immediately prior to and immediately following each condition.

3.3.1 Participants

Twenty-four healthy young adults, aged 18-35, were recruited for this study through posters at the University of Waterloo, email lists, social media and by word of mouth. Participants were eligible to participate if they did not have a history of neurological, cognitive, musculoskeletal, or cardiovascular conditions. This was determined based on the participants completion of the Health Screening Form (See Appendix). Participants also had normal or corrected-to-normal vision so their ability to complete the cognitive assessments was not impaired. They also had normal or corrected hearing so that they wereable to clearly hear the music during the music conditions. A full description of the inclusion and exclusion criteria is shown in Table 3.1 below.

Table 3.1: Participant inclusion and exclusion criteria.

Criteria	Inclusion	Exclusion
Young Adults (aged 18-35)	X	
"No" to all health screening form questions*	X	
"No" to all Get Active Questionnaire (GAQ) questions*	X	
Uncontrolled diabetes and/or hypertension (not regulated by medication, diet, or exercise)		X
History of heart disease		X
History of neurological condition (stroke, concussion within the last 6 months, or other neurological condition affecting movement or cognitive functioning)		X
Severe musculoskeletal issues / arthritis		X
Depression (self-reported)		X
Deafness or hearing loss		X

3.3.2 Sample Size

The target sample size for this study was determined prior to recruitment to ensure it would be large enough to detect changes in cognitive functioning between the combined condition and either exercise or music listening conditions. A previous study looked at the effect of exercise with music compared to exercise alone on cognitive functioning among older adults (Emery et al., 2003). A repeated measures design was used in which participants each completed both sessions and cognitive functioning was assessed pre and post exercise using a verbal fluency task. From this study it was determined that the pre-/post- effect sizes of exercise alone was 0.27 (Cohens d) and exercise with music was 0.73 (Cohens d). Another study which compared the effects of 2 music conditions to a white noise and silence on working memory found a pre-/post- effect size of 0.41 (Cohens d) (Borella et al., 2019). Based on this information it should be possible to detect an effect of 0.46 between the combined condition and the exercise condition and to detect an effect of 0.32 between the combined condition and the music condition. As a result, the smallest effect size to be detected in the current study is expected to be the effect of exercise alone (estimated at 0.27).

The current study used a linear mixed model for statistical analysis, however in G-Power, *ANOVA* was selected to determine sample size. A repeated measures within-subjects design with an alpha level of 0.05, a power level of 0.8, and an effect size of 0.27 (Cohen's d) was input into the G-Power software to determine a target sample size of 18 participants. With a sample of 18 participants the study would have an 80% power to detect an effect size of 0.27, however, the sample size was increased to 24 to ensure sessions can be counterbalanced appropriately.

3.3.3 Study Procedures

When possible, sessions were scheduled in the late afternoon as younger adults are expected to have peak cognitive performance at this time (Schmidt et al., 2007). Participants were asked to avoid any moderate to high intensity exercise, caffeine, or alcohol 24 hours prior to the sessions. In the case that participants wished to consume caffeine prior to this study, they were also be asked to maintain consistent caffeine intake on each day of the assessment. The cognitive assessments, which included the Stroop task and the reverse Corsi block task, will be performed prior to and following each of the three conditions (combined, exercise, and music).

3.3.4 Experimental Sessions:

Prior to the first session participants completed the informed consent process, followed by a virtual meeting to complete questionnaires for health screening, to describe the sample, and music preferences. At the start of each session participants were asked to complete questionnaires for physical activity, sleep, and affect. Then, they completed cognitive tasks (Stroop task and reverse Corsi block tasks) (all detailed below). Following the cognitive tasks participants had their resting heart rate and blood pressure measured after a period of at least 5 minutes of sitting (during the combined and exercise conditions only). Participants then completed a 30-minute activity (combined (exercise and music), exercise, or music listening) followed by a repeat of the affect cognitive assessments. The details of each activity are described below. Participants heart rate was measured every minute throughout the exercise and combined conditions to ensure the participant was exercising at the desired intensity.

Blood pressure and rate of perceived exertion (RPE) were also measured halfway through, and at the end of the exercise and combined conditions (ACSM, 2018). Heart rate was measured using a polar heart rate monitor and RPE was assessed using a visual of the Borg 6-20 scale which the participant used to indicate their RPE (ACSM, 2018).

Aerobic Exercise Session

During the exercise condition, participants exercised for 30 minutes on a recumbent cycle ergometer. The 30 minutes of exercise included a 5-minute warm up, 20 minutes of steady state aerobic exercise at a moderate intensity of 55% of their heart rate reserve (HRR), and a 5-minute cool down. The target intensity was chosen because evidence has demonstrated that moderate intensity exercise may be more effective at eliciting positive effects on cognitive functioning compared to other exercise intensities (Basso and Suzuki., 2017). To determine the appropriate intensity for each participant to exercise at, a predictive equation was used to calculate their age predicted HR max ($HR_{age\text{-}predicted\ max}$ = 207 – [0.7 * age]), which was then be used to determine 55% of heart rate reserve (HRR) (55% HRR = 0.55 ($HR_{age\text{-}predicted\ max}$ – HR_{rest}) + HR_{rest}) (Gellish., 2007; ACSM., 2018). Throughout the activity the exercise work rate was adjusted to keep the participants heart rate within +/- 5bpm of 55% HRR. Participants also wore noise cancelling headphones during the exercise session to control for auditory stimuli.

Music Session

During the music session participants sat quietly while listening to a classical music playlist with a pair of noise cancelling headphones for 30 minutes. All participants listened to the same playlist and the music volume was kept consistent for all participants. The playlist consisted of classical songs ranging from 120-140bpm (See Appendix). Studies have found greater improvements in cognitive performance when heart rate and music tempo were matched compared to mismatched, thus a music tempo of 120-140bpm was chosen as it corresponds to the expected heart rate when exercising at a moderate intensity of 55% HRR (ACSM., 2018; Chen et al., 2021).

Aerobic Exercise with Music Session

During the combined condition participants exercised for 30 minutes on a recumbent cycle ergometer as per the exercise condition, except that they listened to classical music (as per the music session) concurrently. The same music playlist was used for the music condition and the combined condition for all participants to control for confounding effects of tempo.

3.3.5 Measures:

The study measures were kept consistent across sessions as well as across participants. Immediately prior to the activity and following a 10-minute delay after the activity, the participants completed the Stroop task followed by the reverse Corsi block task in that order.

Computerized Stroop Task

The Stroop task was used in this study to assess inhibitory control. The Stroop task involves 3 different conditions: congruent, neutral, and incongruent (Langenecker et al., 2004; Aschenbrenner et al., 2015). During each condition participants were presented with words printed in different colours of ink and they were asked to indicate the ink colour of each word. The words were written in one of three ink colours: BLUE, RED, or GREEN. During the congruent task, participants were presented with a colour word that was in the matching ink colour, such as the word “RED” written in red ink. For the neutral task, participants were presented with random words written in one of the three ink colours. During the incongruent task participants were presented with a colour word written in a different ink colour, such as “BLUE” written in red ink (See Appendix). The incongruent condition was expected to be more challenging than the other conditions because the automatic response would be to simply read the word; however, this response must be inhibited to focus on the stimulus of interest which is the ink colour of the word (Langenecker et al., 2004; Aschenbrenner et al., 2015). As a result, this condition was also expected to result in a longer reaction time as the process involves inhibitory control of the conditioned response (reading the word), but in the congruent condition, inhibitory control is not necessary as the ink colours match the colour words (Langenecker et al., 2004; Aschenbrenner et al., 2015). The Stroop task was completed on a computer using 3 coloured keys which the participants used to indicate the ink colour of the words presented on the screen. Participants performed 150 trials for each condition, and they were given the chance to perform 90 practice trials during each session prior to assessment to ensure they are familiar with the task.

The words were presented on screen for a total of 2000ms and there was an intertrial interval of 1000-1500ms. Response time (ms) and error rate (% error) was assessed during each of the three Stroop task components and used for analysis. Significant effects were identified as observed decreases in response time while maintaining accuracy.

Computerized Corsi Block Task

This study utilized a computerized version of the reverse Corsi block task to assess visuospatial working memory. This assessment has been used previously to assess visuospatial working memory in healthy participants as well as clinical populations (Claessen et al., 2014). The reverse Corsi block task is more challenging compared to the forward version because participants must repeat the sequence in the reverse order which increases the demands on executive processing (Vandierendonck et al., 2004). During this assessment participants were presented with an image of 9 blocks on the computer screen (See Appendix). These blocks were each highlighted in a sequence which the participants had to then repeat back in the reverse order by clicking on the boxes using a computer mouse. The first trial included a sequence consisting of two boxes and an additional box was be added to the sequence in each of the following trials up to a maximum of nine boxes in the sequence (Claessen et al., 2014). If a participant failed to accurately repeat a sequence in the reverse order, they were be given a chance to complete a different sequence of the same number of boxes. If they failed to complete the second sequence, the assessment ended stopped and the number of boxes in the last sequence that the participant was able to complete was used as their score. For example, if a participant failed to complete the task at a sequence length of 6 boxes, then they were given a score of 5 since this is the last sequence length that they were able to complete correctly. If the participant accurately repeated the sequence the second time, the test continued until the participant failed to accurately complete two trials of a given sequence. Participants were given the opportunity to practice one run through of the task to ensure they understood how to complete the task. Significant effects were identified as an increase in the number of sequences completed correctly in the reverse Corsi block task.

Additional Measures

Prior to the start of the first session participants were asked to complete a written consent form as well as the GAQ and a health screening form to ensure that it was safe for them to participate in exercise (Canadian Society for Exercise Physiology, 2017). Demographic information such as age, sex, and level of education was collected from the participants which was used to describe the study sample. The Short Test of Music Preference (STOMP) was also used to determine participants' music preference (See Appendix) (Rentfrow et al., 2003). Participants were also asked whether they have had any prior musical training. At the start of each session the participants were asked to complete the International Physical Activity Questionnaire (IPAQ) long version to assess their habitual physical activity levels and the St. Mary's Hospital Sleep Questionnaire to assess participants' previous night sleep (Craig et al., 2003; Ellis et al., 1981). Prior to and following each condition (combined, exercise, and music) the participants were asked to complete the Physical Activity Affect Scale (PAAS) questionnaire to assess participants' change in affect (Lox et al., 2000). The IPAQ, sleep questionnaire, and STOMP were also used to describe the sample. Additionally, the PAAS was used to determine the influence of the combined condition on affect compared to exercise or music listening and to explore the role of affect as a mediator. The IPAQ and sleep questionnaire were used to determine if participants' physical activity levels or sleep patterns varied across sessions as this could impact potentially impact performance on the cognitive tasks.

3.3.6 Statistical Analysis:

Statistical analysis was performed using the RStudio software. Participant characteristics and exercise characteristics were described as mean and standard deviation (SD) or percent. Data for the Stroop task (congruent, neutral, incongruent), reverse Corsi block task, and PAAS scores were assessed for normality using the Shapiro-Wilks test and histograms. The data was also assessed for homogeneity of variance using the Mauchly's sphericity test. Data for the Stroop incongruent error rates, congruent response times, and neutral error rates did not meet the assumption of homogeneity of variance, thus a square root transformation was applied. Similarly, the reverse Corsi block task fails did not meet the assumption of homogeneity of variance, thus a log transformation was applied. All the transformed data met the assumption of homogeneity of variance. Pairwise comparisons were performed for main effects using the emmeans function for pairwise comparisons using a Bonferroni correction. A significance level of $p = 0.05$ was used for all analyses.

For the Stroop task, participants average response times and error rates were analyzed separately for each component (congruent, neutral, and incongruent) and reverse Corsi block scores and fails were also analyzed separately. Linear mixed models (LMMs) were used for analysis in all cases. The LMMs for Stroop response times and error rates as well as reverse Corsi block task scores and fails had within-subject factors for condition (combined, exercise, music), time (pre-, post-), and session (1, 2, 3). Participant was included in the model as random effects.

Data from the PAAS was separated into 4 sub-scales: positive affect, negative affect, tranquility, and fatigue. The scores from each sub-scale were analyzed separately using LMM's with within-subject factors for condition (combined, exercise, music), time (pre-, post-), and session (1, 2, 3). Participant was included in the model as a random effect.

3.4 Results

Participant Characteristics

Twenty-four young adults (mean age (SD) = 23.4 (2.5 years)) participated in the study and over half of the participants were female (n = 14). All of the participants were current university students with some having completed high school (37.5%), undergrad (41.7%), and masters (20.8%). Participants were moderately to highly active with physical activity levels of 3900.7MET-min/week (3264.7MET-min/week) with the recommended number of MET-min/week being 500-1000MET-min/week (ACSM., 2018). The average body mass index (BMI) for participants was 24.4 kg/m^2(3.6 kg/m^2) and their average hours of sleep on the night before each session was 6.9 hours (1.2 hours). Participants had an average of 4.2 years (3.5 years) of musical training and the average classical music preference score was 4.4(1.8) on a scale of 1 (dislike strongly) to 7 (Like strongly). Participant characteristics are outlined in table 3.2. Data from three participants were removed from analysis of Stroop response times and error rates on all components of the Stroop task due to response times and error rates which were greater than 3 standard deviations away from the mean. All data from participants fell within 3 standard deviations of the mean for reverse Corsi block scores and fails thus, no data was removed from the analysis. Full data sets from 21 participants were analyzed for each component of the Stroop task and full datasets for 24 participants were analyzed for the reverse Corsi block task.

Table 3.2: Participant Characteristics

Participant Characteristics	**Mean (SD) or % (n)**
Age, years	23.4 (2.5)
BMI (kg/m^2)	24.4 (3.6)
Female, %	58.3% (14)
Education completed, % by level	Highschool (37.5%) Undergrad (41.7%) Masters (20.8%) PhD (0%) Other (0%)
Music Training, years	4.2 (3.5)
Classical Music Preference Score	4.4 (1.8)
IPAQ Score, MET-min/week	3900.7 (3264.7)
Hours of sleep for previous night	6.9 (1.2)

Exercise Characteristics

A summary of participants exercise characteristics from the exercise condition and combined condition can be found in table 3.3. During both sessions participants exercised at a moderate intensity of 55% of their HRR, however in the combined condition they exercised while listening to a classical music playlist.

Table 3.3: Exercise characteristics by condition (mean, (SD))

Condition	Exercise Characteristic	Exercise	Combined
Pre-activity	HR	69 (9)	68 (9)
	SBP DBP	109 (13) 68 (8)	110 (15) 70 (6)
During activity	Target HR	136 (5)	135 (5)
	HR at Midpoint	134 (10)	133 (9)
	SBP at Midpoint DBP at Midpoint	146 (16) 80 (11)	149 (16) 78 (9)
	WR at Midpoint	97.5 (38)	99 (36)
	RPE at Midpoint	14.2 (1.6)	14.4 (1.2)
Post-activity	HR	88 (12)	89 (11)
	SBP DBP	112 (16) 73 (7)	112 (13) 74 (8)

3.4.1 Cognitive Results

3.4.1.1 Stroop Task

A summary of the Stroop response times (ms) and error rate (%) by task condition (congruent, neutral, and incongruent) can be found in table 3.4 and 3.5 respectively.

Table 3.4: Stroop task response times (ms) for congruent, neutral, and incongruent tasks by condition and time (mean (SD)).

Task Condition	Exercise and Music		Exercise		Music	
	Pre	Post	Pre	Post	Pre	Post
Congruent	629.7 (101.8)	605.8 (91.2)	626.3 (97.5)	601.0 (89.8)	649.1 (108.6)	608.5 (84.3)
Neutral	667.4 (103.1)	647.4 (104.5)	659.5 (102.5)	647.2 (108.2)	671.0 (106.2)	645.3 (95.0)
Incongruent	692.5 (120.3)	687.5 (151.0)	686.0 (134.0)	688.9 (175.1)	700.9 (124.8)	693.4 (160.4)

Table 3.5: Stroop task error rates (%) for congruent, neutral, and incongruent tasks by condition and time (mean +/- SD).

Task Condition	Exercise and Music		Exercise		Music	
	Pre	Post	Pre	Post	Pre	Post
Congruent	1.2 (1.2)	1.4 (1.4)	1.5 (1.3)	1.5 (1.2)	1.8 (1.8)	1.8 (1.6)
Neutral	1.4 (1.7)	2.2 (2.6)	1.8 (1.6)	1.9 (1.3)	2.2 (2.2)	2.6 (1.8)
Incongruent	2.2 (1.9)	2.5 (2.9)	2.2 (2.0)	3.1 (4.9)	2.4 (1.8)	3.2 (2.5)

Congruent Response Time

The analysis showed that there was no significant condition by time interaction for the Stroop congruent response times ($F(2, 96) = 0.552$, $p = 0.578$, $\eta_p^2 = 0.01$). However, there was a main effect of time ($F(1, 96) = 18.309$, $p < 0.001$, $\eta_p^2 = 0.16$), where response times were significantly faster post-activity compared to pre-activity (Mpre= 635ms, Mpost = 605ms). There was also a main effect of session ($F(2, 96) = 5.526$, $p = 0.005$, $\eta_p^2 = 0.10$), where congruent response times were significantly faster in session 2 compared to session 3 (Msession2 = 605ms, Msession3 = 635ms, p =

0.004). There was no significant differences between session 1 and 2 (Msession1 = 620ms, Msession2 = 605ms, $p > 0.05$) or session 1 and 3 (Msession1 = 620ms, Msession3 = 635ms, $p > 0.05$). There was also no significant differences in response times across conditions ($F(2, 96) = 1.963$, $p = 0.146$, $\eta_p^2 = 0.04$). There was no significant time by session interaction ($F(2, 96) = 0.160$, $p = 0.852$, $\eta_p^2 = 3.32e\text{-}03$).

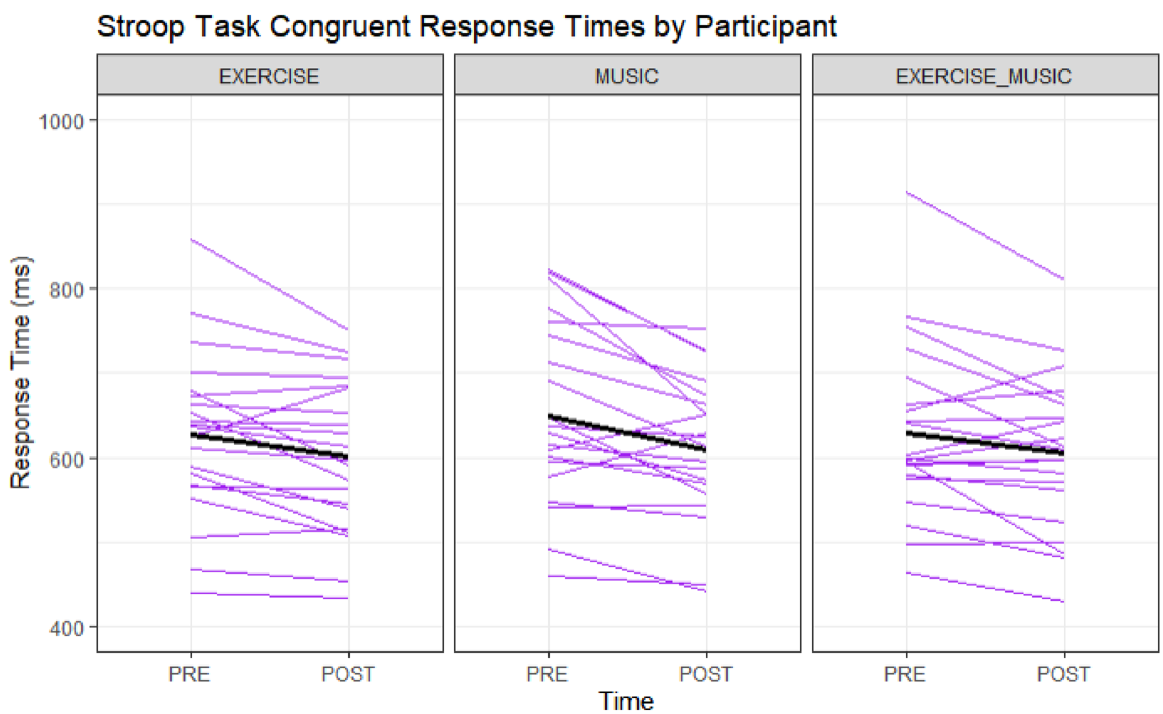

Figure 3.1: Participant response times(ms) for the congruent component of the Stroop task during exercise (left), music (center), and exercise combined with music (right).

Congruent Error Rate

There was no significant condition by time interaction for the Stroop congruent error rates ($F(2, 96) = 0.086$, $p = 0.918$, $\eta_p^2 = 1.79e\text{-}03$). Additionally, there was no significant differences in error rates across time ($F(1, 96) = 0.044$, $p = 0.834$, $\eta_p^2 = 4.60e\text{-}04$). However, the effect of condition approaches significance ($F(2, 96) = 2.778$, $p = 0.067$, $\eta_p^2 = 0.05$), where the congruent error rates were lower during the combined condition compared to the music condition (Mcombined = 1.29%, Mmusic = 1.85%, p = 0.06). Differences between the other conditions did not approach significance (Mexercise = 1.46%, $p > 0.2$). There was also no significant time by session interaction ($F(2, 96) = 1.863$, $p = 0.161$, $\eta_p^2 = 0.04$) of main effect of session ($F(2, 96) = 1.284$, $p = 0.282$, $\eta_p^2 = 0.03$).

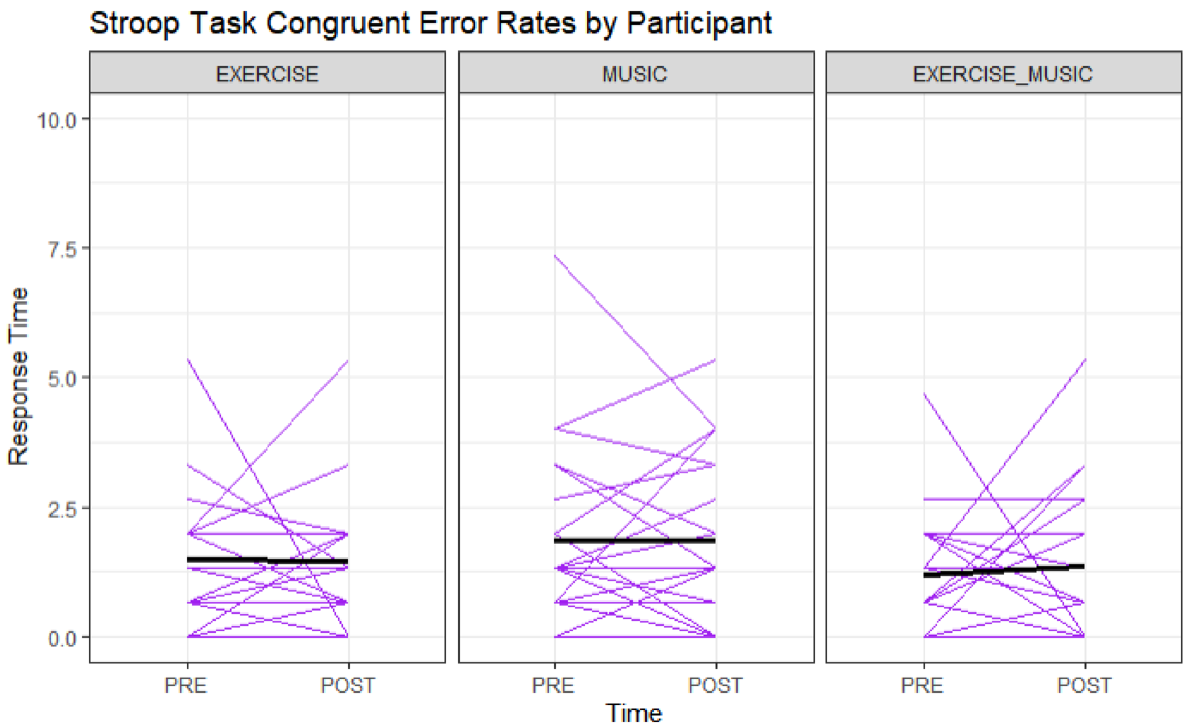

Figure 3.2: Participant error rates (%) for the congruent component of the Stroop task during exercise (left), music (center), and exercise combined with music (right).

Neutral Response Time

There was no significant condition by time interaction for Stroop neutral response times ($F(2, 96) = 0.372$, $p = 0.690$, $\eta_p^2 = 7.70e\text{-}03$). However, there was a main effect of time ($F(1, 96) = 8.621$, $p = 0.004$, $\eta_p^2 = 0.08$), where response times were significantly lower post-activity compared to pre-activity (Mpre = 666ms, Mpost = 647ms). There was no significant time by session interaction ($F(2, 96) = 0.102$, $p = 0.903$, $\eta_p^2 = 2.11e\text{-}03$).

There was also no main effect of condition ($F(2, 96) = 0.282$, $p = 0.755$, $\eta_p^2 = 5.83e\text{-}03$) or session ($F(2, 96) = 1.461$, $p = 0.237$, $\eta_p^2 = 0.03$).

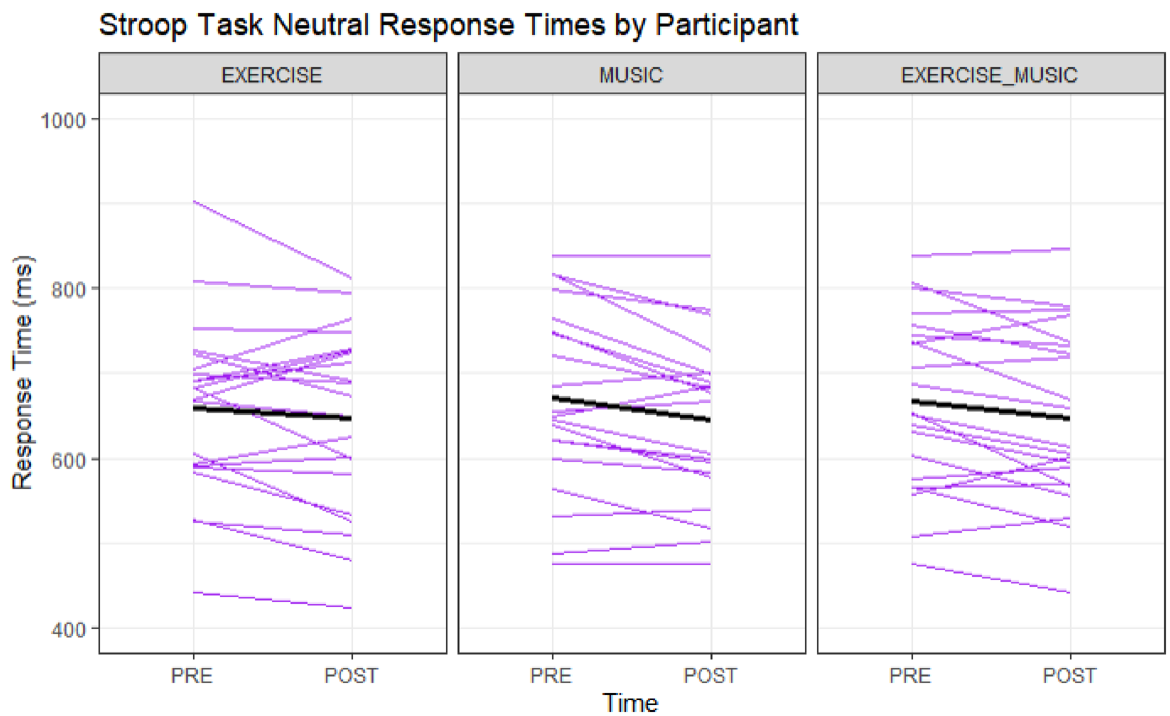

Figure 3.3: Participant response times(ms) for the neutral component of the Stroop task during exercise (left), music (center), and exercise combined with music (right).

Neutral Error Rate

There was no significant condition by time interaction for Stroop neutral error ($F(2, 96) = 0.252$, $p = 0.777$, $\eta_p^2 = 5.23e\text{-}03$). However, there was a main effect of condition ($F(2, 96) = 4.557$, $p = 0.013$, $\eta_p^2 = 0.09$) where participants were less accurate during the music condition compared to the combined condition (Mcombined = 1.79%, Mmusic = 2.41%) . There was no significant difference in error rates between the music and exercise conditions (Mmusic = 2.41%, Mexercise = 1.83%, %, $p > 0.1$) or the exercise and combined conditions (Mexercise = 1.83%, Mcombined = 1.79%, $p > 0.1$). There was also a main effect of time ($F(1, 96) = 4.751$, $p = 0.032$, $\eta_p^2 = 0.05$), where post-activity scores were higher than pre-activity scores (Mpre = 1.81%, Mpost = 2.21%). There was no significant time by session interaction (F(2, 96) = 0.257, p = 0.774, η_p^2 = 5.33e-03) and there was no main effect of session (F(2, 96) = 0.498, p = 0.609, η_p^2 = 0.01).

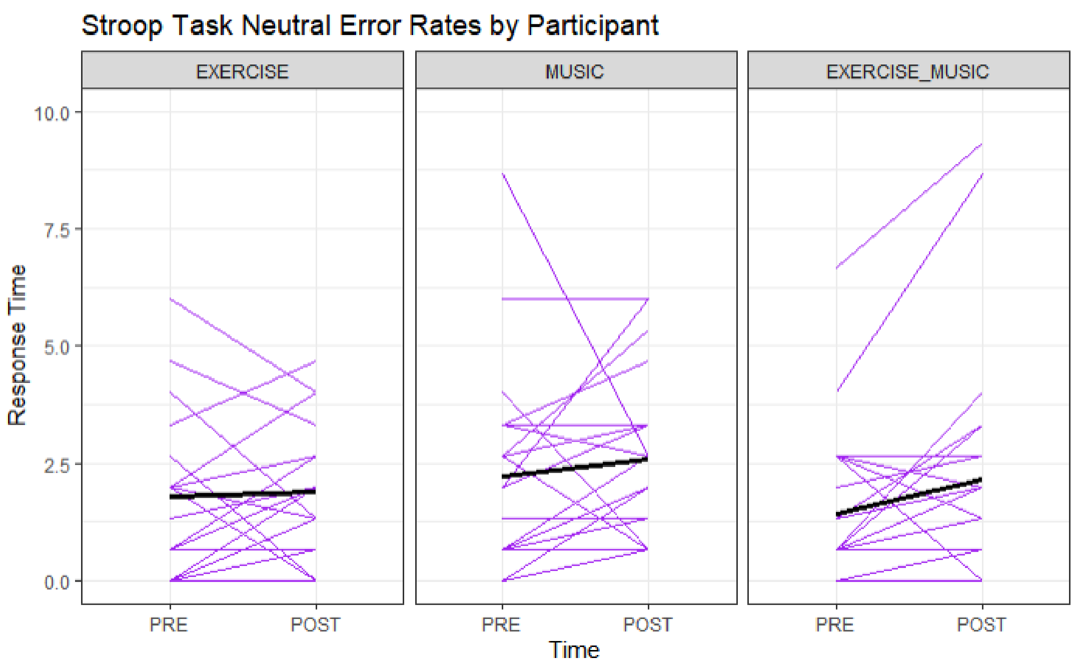

Figure 3.4: Participant error rates (%) for the neutral component of the Stroop task during exercise (left), music (center), and exercise combined with music (right).

Incongruent Response Time

There was no significant condition by time interaction for the Stroop incongruent response times (F(2, 96) = 0.146, p = 0.864, η_p^2 = 3.04e-03). Additionally, there was no significant differences in response times across conditions (F(2, 96) = 0.324, p = 0.724, η_p^2 = 6.70e-03), time (F(1, 96) = 0.091, p = 0.764, η_p^2 = 9.43e-04), or session (F(2, 96) = 0.124, p = 0.883, η_p^2 = 2.58e-03) . There was also no significant interaction of time by session (F(2, 96) = 0.876, p = 0.420, η_p^2 = 0.02).

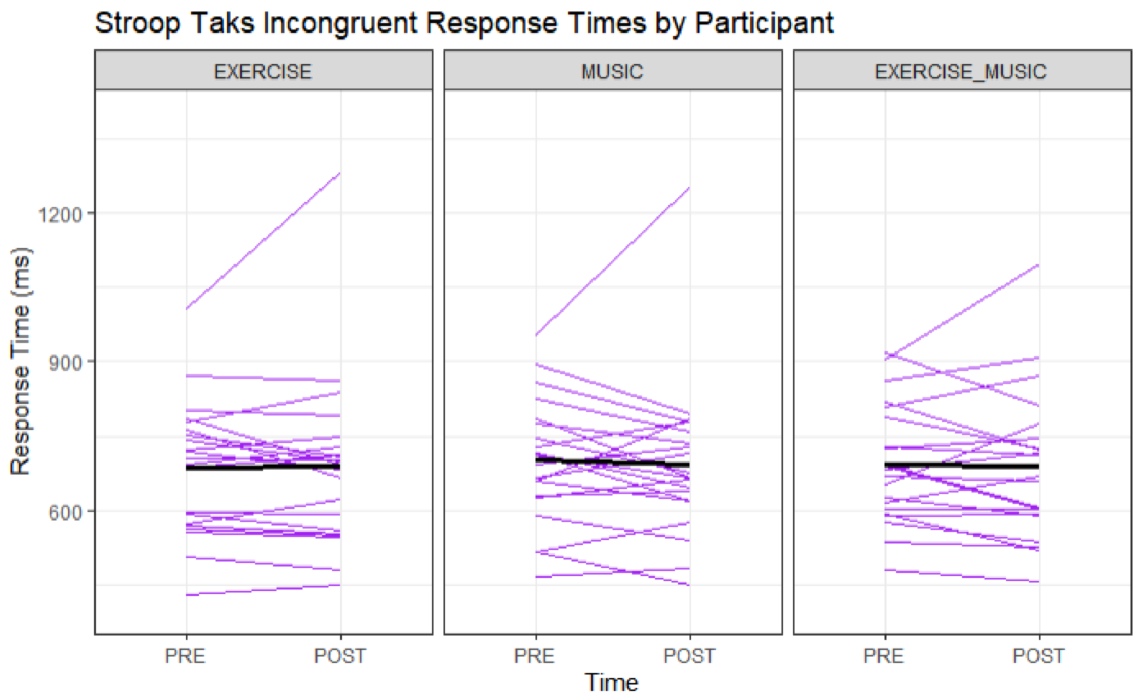

Figure 3.5: Participant response times(ms) for the incongruent component of the Stroop task during exercise (left), music (center), and exercise combined with music (right).

Incongruent Error Rate

Similarly, analysis of the Stroop incongruent error rates did not reveal a significant condition by time interaction (F(2, 96) = 0.252, p = 0.778, η_p^2 = 5.21e-03). There was also no significant differences in error rates across time (F(1, 96) = 1.277, p = 0.261, η_p^2 = 0.01) or condition (F=(2, 96) = 1.144, p = 0.323, η_p^2 = 0.02). There was also no significant time by session interaction (F=(2, 96) = 0.020, p = 0.980, η_p^2 = 4.14e-04). However, the main effect of session did approach significance (F=(2, 96) = 2.767, p = 0.068, η_p^2 = 0.05), however pairwise comparisons did not find any significant differences.

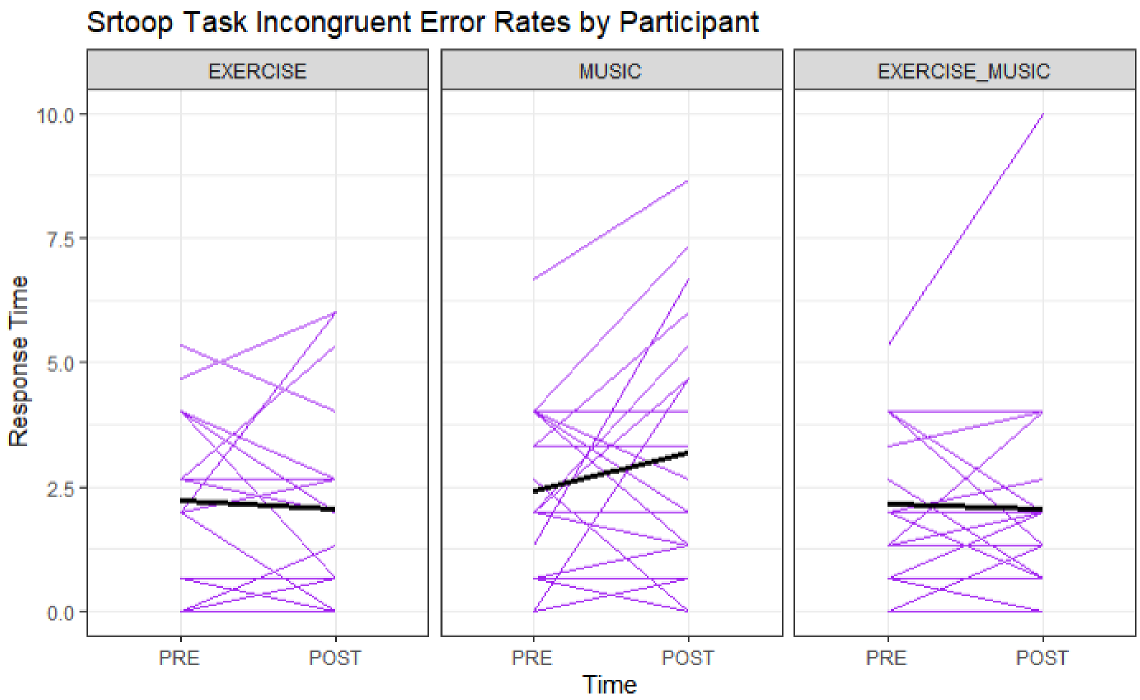

Figure 3.6: Participant error rates (%) for the incongruent component of the Stroop task during exercise (left), music (center), and exercise combined with music (right).

3.4.1.2 Reverse Corsi Block Task

A summary of the scores and fails for the reverse Corsi block task can be found in Table 3.6 below.

Table 3.6: Reverse Corsi Block Scores and Fails by time and condition (mean +/- SD)

Task Measure	Exercise and Music		Exercise		Music	
	Pre	Post	Pre	Post	Pre	Post
Score	6.5 +/- 1.4	7.1 +/- 1.4	6.7 +/- 1.7	7.3 +/- 1.3	6.6 +/- 1.5	6.9 +/- 1.3
Fails	2.7 +/- 0.9	2.3 +/- 1.0	2.4 +/- 1.3	2.5 +/- 1.3	2.4 +/- 0.9	2.3 +/- 0.9

Scores

There was no significant condition by time interaction ($F(2, 111) = 0.476$, $p = 0.622$, $\eta_p^2 = 8.51e\text{-}03$). There was also no significant difference in reverse Corsi block scores across conditions ($F(2, 111) = 0.519$, $p = 0.597$, $\eta_p^2 = 9.26e\text{-}03$). However, there was a main effect of time ($F(1, 111) = 9.732$, $p = 0.002$, $\eta_p^2 = 0.08$), where reverse Corsi block scores were significantly higher post-activity compared to pre-activity ($M_{pre} = 6.58$, $M_{post} = 7.10$). There was also a main effect of session ($F(2, 111) = 7.365$, $p < 0.001$, $\eta_p^2 = 0.12$), where scores during session 3 were significantly higher compared to session 2 ($p = 0.023$) and session 1 ($p = 0.001$) ($M_{session1} = 6.52$, $M_{session2} = 6.73$, $M_{session3} = 7.27$). There was no significant time by session interaction ($F(2, 111) = 2.161$, $p = 0.120$, $\eta_p^2 = 0.04$).

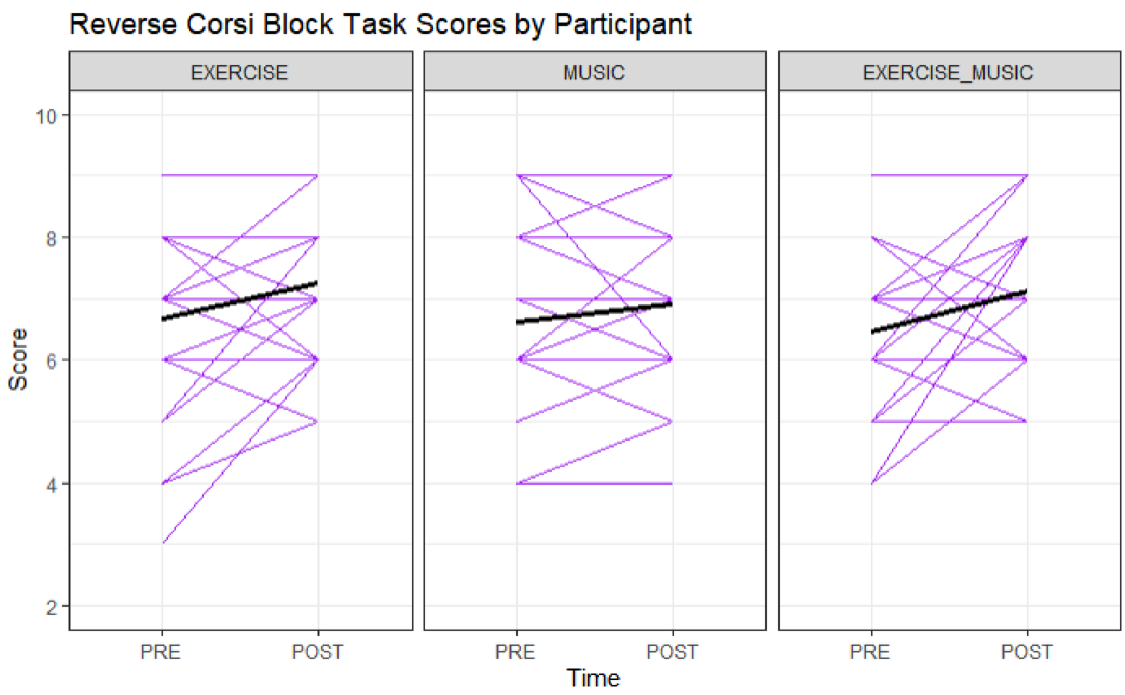

Figure 3.7: Participant scores for the reverse corsi block task during exercise (left), music (center), and exercise combined with music (right).

Fails

There was no significant condition by time interaction for number of fails made during the reverse Corsi block task ($F(2, 111) = 1.302$, $p = 0.276$, $\eta_p^2 = 0.02$). Additionally, there was no main effect of time ($F(1, 111) = 0.629$, $p = 0.430$, $\eta_p^2 =$ 5.63e-03), or condition ($F(2, 111) = 0.907$, $p = 0.407$, $\eta_p^2 = 0.02$). However, there was a main effect of session ($F(2, 111) = 7.953$, $p < 0.001$, $\eta_p^2 = 0.13$), where the number of fails was higher in session 1 compared to session 2 ($p < 0.001$) and session 3 ($p = 0.02$) ($M_{session1} = 2.83$, $M_{session2} = 2.17$, $M_{session3} = 2.29$). There was no significant time by session interaction ($F(2, 111) = 0.410$, $p = 0.665$, $\eta_p^2 =$ 7.33e-03).

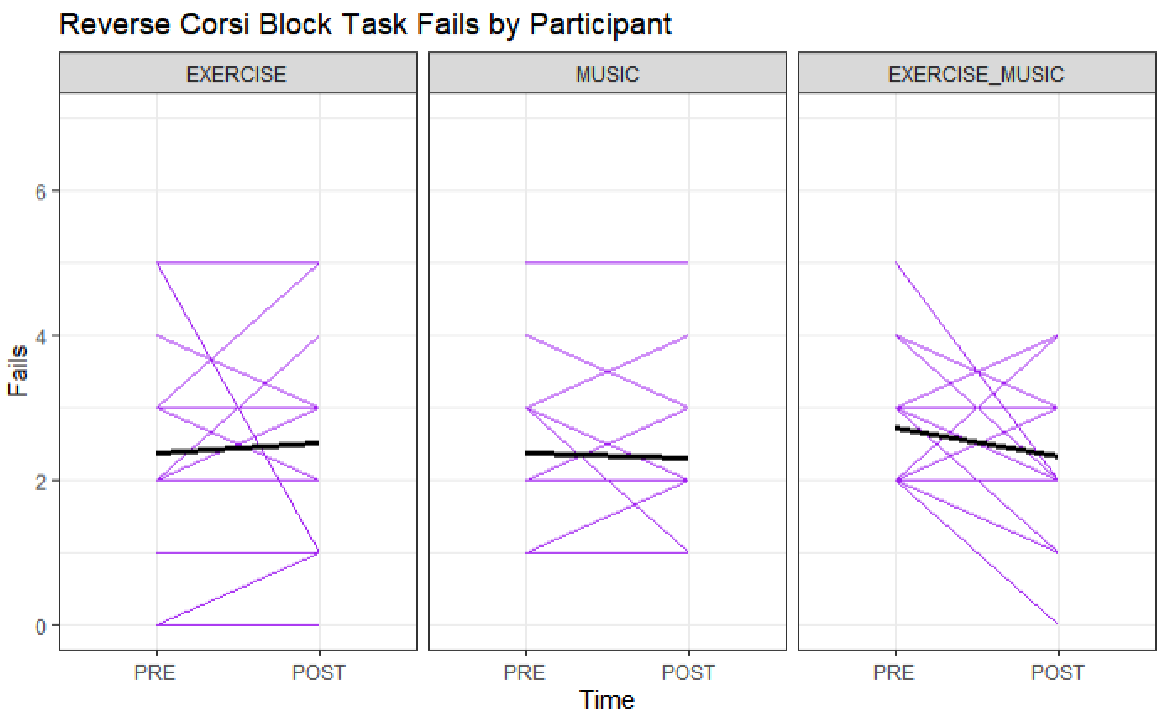

Figure 3.8: Participant scores for the reverse corsi block task during exercise (left), music (center), and exercise combined with music (right).

3.4.1.3 Physical Activity Affect Scale (PAAS)

Figure 9 shows changes in PAAS scores by time and condition.

Positive Affect

The analysis of the PAAS scores for positive affect did not reveal a significant condition by time interaction ($F(2, 111) = 1.041$, $p = 0.356$, $\eta_p^2 = 0.02$). However, there was a main effect of time ($F(1, 111) = 10.914$, $p = 0.001$, $\eta_p^2 = 0.09$), where post-activity positive affect scores were significantly higher compared to pre-activity scores. There was also a main effect of condition $F(2, 111) = 6.238$, $p = 0.003$, $\eta_p^2 = 0.10$), where participants had significantly higher positive affect scores during the combined condition compared to the music condition ($p = 0.002$). The difference between the exercise condition and music condition approached significance ($p = 0.063$) with higher scores during the exercise condition compared to the music condition. There were no differences between the exercise condition and the combined condition ($p > 0.05$). There was no significant time by session interaction $F(2, 111) = 1.048$, $p = 0.354$, $\eta_p^2 = 0.02$) or main effect of session $F(2, 111) = 0.372$, $p = 0.690$, $\eta_p^2 = 6.67e\text{-}03$).

Negative Affect

There was no significant condition by time interaction for PAAS negative affect scores ($F(2, 111) = 0.316$, $p = 0.729$, $\eta_p^2 = 5.67e\text{-}03$). However, effect of time approached significance ($F(1, 111) = 3.142$ $p = 0.079$, $\eta_p^2 = 0.03$), where post-activity negative affect scores were lower compared to pre-activity scores. There was no significant effect of condition ($F(2, 111) = 0.148$, $p = 0.862$, $\eta_p^2 = 2.66e\text{-}03$) or session ($F(2, 111) = 0.112$, $p = 0.894$, $\eta_p^2 = 2.02e\text{-}03$). There was also no significant interaction of time by session ($F(2, 111) = 0.064$, $p = 0.938$, $\eta_p^2 = 1.15e\text{-}03$).

Tranquility

There was no significant condition by time interaction for the PAAS tranquility scores (F(2, 111) = 1.459, p = 0.2.37, η_p^2 = 0.03). However, there was a main effect of condition (F(2, 111) = 4.890, p = 0.009, η_p^2 = 0.08), where participants had significantly higher tranquility scores during the music condition compared to the exercise condition (p = 0.009). There was a trend towards significance (p = 0.067) for the combined condition compared to exercise where participants had higher tranquility scores during the combined condition compared to the exercise condition. There were no significant differences between the music condition and the combined condition (p > 0.05). The analysis found that there was no significant effect of time (F(1, 111) = 0.015, p = 0.903, η_p^2 = 1.36e-04). There was also no significant time by session interaction (F(2, 111) = 0.587, p = 0.558, η_p^2 = 0.01). However, the effect of session did approach significance (F(2, 111) = 2.773, p = 0.067, η_p^2 = 0.05), where pairwise comparisons indicated that the difference between session 1 and session 2 approached significance with higher tranquility scores during session 2 compared to session 3 (p = 0.053).

Fatigue

There was no significant condition by time interaction for PAAS fatigue scores (F(2, 111) = 0.023, p = 0.978, η_p^2 = 4.08e-04). However, there was a significant effect of time (F(1, 111) = 4.583, p = 0.034, η_p^2 = 0.04), where post-activity fatigue scores were significantly lower compared to pre-activity scores. There was no effect of condition (F(2, 111) = 0.759, p = 0.470, η_p^2 = 0.01) or session (F(2, 111) = 1.103, p = 0.336, η_p^2 = 0.02) on fatigue scores. There was also no significant time by session interaction (F(2, 111) = 0.037, p = 0.964, η_p^2 = 6.65e-04).

Another objective of the current study was to investigate the effect of pre-activity mood scores on changes in executive functioning. The relationship between pre-activity mood and executive functioning was examined visually, by examining the slope of change across conditions, to determine if a relationship existed. Additionally, the relationship between music preference and cognitive performance was also visually inspected. However, there did not appear to be any relationship between pre-activity mood or music preference and executive functioning thus, the investigation did not proceed any further.

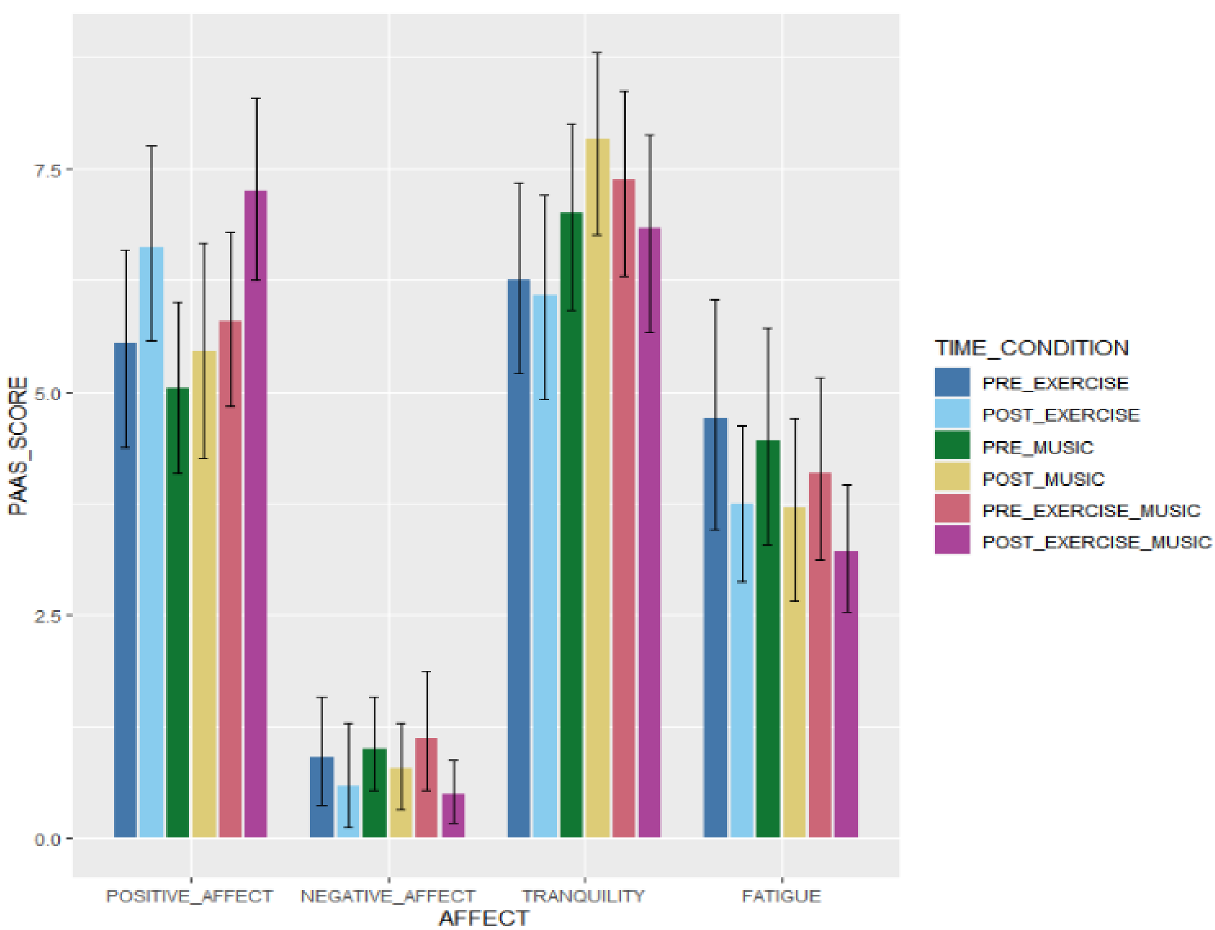

Figure 3.9: Change in affect from pre- to post-activity by condition.

3.5 Discussion

This study investigated the effects of exercise combined with music on executive functioning as well as affect. The hypotheses that the combined condition would result in superior improvements in executive functions and affect were not supported. However, several elements of cognitive functioning (working memory and processing speed) and affect (positive affect) improved across time for all conditions, but with no differences in the magnitude or direction of change between exercise combined with music, exercise only, or music listening only conditions. Fatigue also decreased similarly across all three conditions. While the magnitude of change in cognitive functions and affect was consistent across conditions, there were several between conditions differences when both pre- and post-scores were considered together (a main effect of condition). Specifically, participants were less accurate on the neutral component of the Stroop task during the music listening condition compared to the combined condition. Additionally, tranquility was greater for the music listening compared to exercise condition and positive affect was greater for the combined condition compared to music listening. This suggests that the anticipation of exercise and/or music as well as the actual practice thereof may influence cognitive functions and affect.

In this study, working memory (reverse Corsi block task) and processing speed (Stroop congruent and neutral tasks) improved over time but the improvements were similar across all conditions (combined, exercise, music). In contrast, inhibitory control (Stroop incongruent task) did not appear to change across time or vary by condition, either alone or in interaction. The results do not support the hypotheses that the combined condition would result in greater improvements in inhibitory control and working memory compared to the exercise condition or the music condition. The effect of exercise combined with music on executive functioning compared to exercise only and music listening only has not previously been examined among young adults. Study hypotheses were informed by effect sizes from studies of exercise combined with music, exercise, and music from, which were examined and compared to support the supposition that combined exercise and music would have a greater effect on executive functioning. Specifically, prior work suggested that the effect size for exercise combined with music (0.73) was larger than the effect sizes for exercise (0.27) or music listening (0.41) (Emery et al., 2003, Borella et al., 2019).

It is possible that there is a true effect of combined exercise and music over and above exercise or music listening, at least in some groups, even though that was not observed in this study. There are several reasons why this may be the case. It is possible that healthy young adults are less likely to benefit from combined exercise and music on executive functioning compared to exercise or music listening only. One study found significant improvements in verbal fluency following a single session of exercise combined with music compared to exercise only; however, this study focused on older adult participants in cardiac rehab (Emery et al., 2003). Research has found that individuals experience cognitive decline with aging and that young adults typically have greater cognitive performance compared to older adults (Diamond., 2013). It is possible that the combined effects of exercise and music compared to exercise only or music listening only are greater among older adults compared to healthy young adults, as they may have more potential for improvement, though prior research has not yet investigated this possibility. A meta-analysis, however, concluded that the effects of exercise on cognitive functioning are greater for older adults compared to younger adults (Chang et al. 2012), and the same may be the case here.

Alternately, the tempo of music may have reduced the combined effect of exercise and music. The prior study of combined exercise with music versus exercise only used classical music and found a significant improvement in cognitive performance (Emery et al., 2003), which contrasts with the results of the current study. The current study used a playlist of classical music songs with a tempo of 120-140bpm while the previous study did not report music tempo; it is possible that the differing results could be due to differences in the selected music tempo. Finally, it is possible that the music volume was not loud enough compared to the noise from the recumbent cycle, as the volume was controlled across combined and music only conditions. However, noise cancelling headphones were used so this is unlikely.

It is also possible that the hypothesis was truly incorrect, that exercise combined with music is not more effective at improving executive functioning compared to exercise or music listening. Increases in catecholamine concentrations in the brain have been found to occur in response to both music listening as well as exercise (McMorris et al., 2012; Salimpoor et al., 2011; Pauwels et al 2014). It has also been suggested that increases in catecholamines, at high level, could result in neural noise which may negatively impact performance on cognitive tasks (McMorris et al., 2012; MacDonald et al., 2009). The increase in activated brain areas following exercise as well as music listening (Basso and Suzuki et al., 2017; Pauwels et al., 2014; Pallesen et al., 2005) could potentially result in an increase in neural noise when the two activities are combined (exercise with music) due to higher concentrations of catecholamines.

Though the combined condition did not have superior effects on executive functioning, there were improvements in some elements of cognitive functioning (working memory and processing speed) across all three conditions. This suggests that exercise combined with music listening, exercise, and music listening only may all be beneficial for cognitive functions. This finding is consistent with a number of previous studies that also found improvements in multiple cognitive domains following a single session of exercise, a single session of music listening, or a single session of exercise combined with music listening (Chang et al., 2012; Rauscher et al., 1993; Emery et al., 2003). Specifically, previous studies that have examined the effects of exercise on cognitive functioning have found improvements in working memory, processing speed, attention, and memory (Mou et al., 2022; Wilke et al., 2020; Gmiat et al., 2017; Audiffren et al., 2008; Stranda et al., 2019), though not all studies agree (Ludyga et al., 2018; Chang et al., 2012; Hacker at al., 2020). These conflicting results could be due to different exercise durations (longer versus shorter) as this has shown to influence the effects of exercise on cognitive functioning (Chang et al., 2012). Some studies found improvements in cognitive performance when participants performed exercise for 20 minutes or longer (Mou et al., 2022; Gmiat et al., 2017; Audiffren et al., 2008), whereas results were more inconsistent when participants completed only 15 minutes of exercise (Ludyga et al., 2018; Hacker et al., 2020; Wilke et al., 2020; Stranda et al., 2019). Although the research is very limited, one prior study found that a single session of listening to classical music improves cognitive functioning, which is consistent with the results of the current study (Rauscher et al., 1993), and another found no cognitive effects after listening to pop music (Frith and Loprinzi., 2018). It is possible that the duration (longer versus shorter) of the music listening as well as the type of music listened to may be why studies have observed differing results.

In contrast to the results of the current study, some, but not all, prior studies found improvements in inhibitory control with exercise and/or music. Prior research on exercise only is more substantial, in which there are some studies that have found no change in inhibitory control following exercise when assessed with the Stroop task (Barella et al., 2010; Gmiat et al., 2017), where other studies found an improvement (Yanagisawa et al., 2010; Sibley et al., 2006). These conflicting results could be due to differences in the analysis of the Stroop task response times. The analysis of computerized Stroop task response times typically includes filtering and removal of outliers that likely do not represent real response times (too fast or too slow) (Barella et al., 2010). Unfortunately, in this study, due to errors in the data collection program, removal of outliers was not possible as only mean response times by condition and task type (and not response time for individual trials) were collected. This is a major study limitation. Thus, the analysis may not be representative of participants real response times. Indeed, the response times in the current study were generally faster than prior studies using the Stroop task (Yanagisawa et al., 2010; Langenecker et al., 2004), confirming the possibility that response times outside the expected range may have influenced the results.

It is also important to consider the possibility of learning and practice effects across time and/or sessions. Learning and practice effects occur when a participant shows improvements in task performance resulting from simply performing the task multiple times or on multiple separate occasions rather than a true effect of condition (Sibley et al., 2006). Since there was no full control condition here, it remains possible that improvements in all sessions reflect learning effects. However, in absence of a full control condition, we reduced the effect of learning effects statistically by including session as well as session by time in the analysis to remove variance associated with improvement across sessions or within a session (which would be greater in the first of a series of sessions) (Bergelt et al. 2020). Additionally, participants performed a set of practice trials at the start of each session and sessions were also spaced at least one week apart to reduce carryover of learning effects.

Though there was no difference in the magnitude of change across conditions, there were differences in cognitive performance between conditions (main effect of condition). There were fewer errors made during the neutral component of the Stroop task for the exercise and combined conditions compared to the music condition. These findings may be related to arousal levels leading up to and during the exercise interventions, as previous studies have found that arousal levels change in anticipation of performing exercise (Mantysaari et al., 1988; Tobin et al., 1986). Additionally, one study found that when participants anticipated rest and performed rest or anticipated rest and performed exercise, they performed worse on cognitive control task compared to those that anticipated exercise and performed exercise (Bergelt et al., 2020). This could partially explain the observed effect of condition for the current study as, although participants were listening to music, they were at rest (seated) for the duration of the session. However, condition effects in the current study were not observed across all cognitive domains or across components within the same cognitive task.

In analyses to support exploratory objectives, the current study found improvements across time for positive affect and fatigue (two elements of affect), although these changes did not vary across conditions. These results are in line with prior research that found that exercise, exercise combined with music, and music listening can all improve positive affect among individuals; however, these changes have not been compared within the same study (Nieman et al., 2021; Chen et al., 2021; Garrido et al., 2015).

Other studies also found that exercise reduces feelings of fatigue when compared to a non-exercise control (Crush et al., 2018), similar to the current results. Although the effect of music listening on fatigue has not been examined, studies have found that exercise combined with music reduces perceived RPE, an indicator of the perceived difficulty of exercise (Yamashita et al., 2006).

While the current study did not find any improvements in tranquility across time, tranquility was significantly higher during the music condition compared to the exercise condition. Prior research supports this finding, where results found that classical music improves tranquility when compared to a control condition (Rea et al., 2010) and that anxiety levels are reduced following a session of music listening (Walworth et al., 2003).

3.6 Challenges, Strengths, and Limitations:

There are several strengths to this study. The study used a repeated measures design to examine the effect of exercise and/or music listening on executive functions and affect. As participants acted as their own controls, this design eliminates confounding due to differences between the intervention and control groups and increases our confidence that the outcome was due to the independent variable. A second strength of the study is that the sessions were counterbalanced to ensure there was an equal number of participants performing the sessions in each order, which helped to control for session order effects. Additionally, the sessions were separated by 1 week to reduce carry-over effects between sessions. The time of day in which the participants complete the sessions was also consistent whenever possible, reducing time of day effects on cognitive functioning and affect.

Although there are several strengths to this study there are also some limitations that should be considered. The first limitation is that it is difficult to control the tempo of classical music, as songs often have several movements which vary greatly in tempo. Although songs were chosen to have a consistent tempo, songs still had variation across song movements. These variations in tempo could affect the results of the study, as tempo, and its relationship with heart rate, influence the cognitive effects of exercise and music in another study (Chen et al., 2021). The current study aimed to have participants heart rate match the music tempo during exercise, as this may accentuate positive cognitive effects (Chen et al., 2021). Variability in tempo may have made this accentuation of positive cognitive effects less consistent. In addition, during the exercise conditions it was difficult for some participants to reach or maintain their target heart rate as their legs became fatigued early in the session before reaching the target heart rate. Similarly, due to their inability to maintain the target heart rate, their heart rate may not have matched the music tempo and positive effects to cognition may be less.

However, the participants that did have difficulty reaching or maintaining their target heart rate in the current study did not appear to differ significantly from the other participants in terms of observed changes to cognitive functioning.

Another limitation is that mental fatigue could have occurred during the cognitive assessments, which could have affected cognitive performance, making condition effects more difficult to detect. In particular, we would expect to see a decline in cognitive performance over time on the cognitive assessments. This may be why we did not see an effect on inhibitory control (assessed last). Additionally, caffeine consumption could also be a limitation of this study as caffeine can affect arousal and attention levels. However, information on whether participants consumed caffeine prior to the session was collected and upon investigation, caffeine consumption did not appear to influence cognitive performance. Another limitation is that exercise intensity was determined using a predictive equation for maximum heart rate. This is less accurate than performing a maximal exercise assessment but was more pragmatic as a maximal exercise test would have required a fourth assessment and may have been unappealing to potential participants. Additionally, there was very limited data to inform the sample size calculation for this study which means it is possible that the sample size was too small. That is, the sample size calculations may have overestimated the effect size associated with exercise and music versus either alone, making it difficult to detect significant changes in cognitive functioning. One major limitation in this study was that raw response times for the Stroop task could not be obtained due to errors with data collection and instead only average response times were measured. As a result, the data could not be filtered to remove any times that did not represent real response times which may have affected the outcomes observed in this study. Finally, the current study did not include a non-exercise/non-music control condition. Since this study found similar improvements across all three conditions, this is a major limitation of this study because it is not possible to determine for certain whether the results of the study occurred due to the interventions or some outside factor such as learning and practice effects. The decision to not include a control session was not made lightly. Based on the timeline and study design, it would have been difficult to have each participant complete all four sessions, each one week apart; thus, it was more feasible to only have three sessions. The current study aimed to determine the combined benefit of exercise with music and to fully understand this relationship it was necessary to include an exercise as well as a music listening condition.

3.7 Conclusion & Future Directions:

This study was the first to examine the effect of a single session of moderate intensity exercise combined and/or classical music listening on executive functioning and affect among young, healthy adults. Optimistically, results suggested that working memory, processing speed, and components of affect (positive affect and fatigue) improved over all of the conditions, though changes were not observed for inhibitory control. These results suggest that exercise combined with music may not provide any additive benefit to executive functioning or affect when compared to exercise or music listening. In practice, this is beneficial as individuals could participate in any one of these activities for cognitive and affective benefits, according to their preferences. However, future studies should further investigate the relationship between exercise and music by comparing different exercise intensities or durations as well as different types of music to understand how these factors might influence the effects on executive and cognitive functioning as well as affect.

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Appendix

Health Screening Form:

This questionnaire asks some questions about your health status. This information is used to guide us with your entry into the study.

Contraindications to participation in this study include any injury that makes exercise uncomfortable, any kidney problems, or any cardiovascular diseases including bleeding disorders, or any respiratory diseases.

Health Screening Form

STUDY: The Effects of Exercise Combined with Music on Executive Functioning in Healthy Young Adults

PARTICIPANT #:

SELF REPORT CHECKLIST:

Past Health Problems:

[ ] Rheumatic Fever
[ ] Epilepsy
[ ] Heart Murmur
[ ] Varicose Veins
[ ] High Blood Pressure
[ ] Disease of the Arteries
[ ] High Cholesterol
[ ] Emphysema, Pneumonia, Asthma, Bronchitis
[ ] Congenital Heart Disease
[ ] Back Injuries
[ ] Heart Attack
[ ] Kidney and liver disease
[ ] Heart Operation
[ ] Heartburn
[ ] Diabetes (diet or insulin)
[ ] Enteritis/Colitis/Diverticulitis
[ ] Ulcers
[ ] Bleeding Disorders
[ ] Bleeding from Intestinal Tract

Neurological conditions (i.e., stroke, epilepsy, Parkinson's disease or dementia):

Yes No

Details: ____

Chronic Obstructive Pulmonary Disease: Yes No

Details: ____

Mild Cognitive Impairment (MCI): Yes No

Details: ____

Musculoskeletal issues or severe arthritis : Yes No

Details: ____

Have you had any concussions Yes No

How many? __________ When was your last concussion? _______________________

Did you lose consciousness? __________________

Details: ____

Have you ever been diagnosed with depression or any other mood disorders?

Yes No

Details: ____

Have you experienced symptoms within the last 2 years? _________________________

Do you take medication for your symptoms? ___________________________________

Have you experienced symptoms of untreated or undiagnosed depression or any other mood disorders? Yes No

Have you experienced symptoms within the last 2 years? _________________________

Details: ____

Other Conditions: ____

____

-

Present Health:

List current problems:	List medications taken now or in last 3 months:
1.	1.
2.	2.

3. 3.

For Females: Pregnant ________ Nursing ________

List Symptoms:

[ ] Irregular Heart Beat
[ ] Chest Pain
[ ] Shortness of Breath
[ ] Persistent Cough
[ ] Wheezing (Asthma)
[ ] Fatigue
[ ] Cough up blood
[ ] Back Pain/Injury
[ ] Leg Pain/Injury
[ ] Dizziness

-

Current Physical Training Status:

I consider my physical training status to be: High [ ], Average [ ], Low [ ]

List the types of physical activities that you do on a regular basis:

Habits:

Smoking: Never [ ] Ex-smoker [ ] Regular [ ] Average # cigarettes/day [ ]

Song List:

Songs with an average music tempo of 120-140bpm were selected from Spotify.

The Nutcracker Suite, Op. 71a Trepak-Russian Dance (137bpm)
https://open.spotify.com/track/69wYC9jrD93YjzmbaK9hcV?si=18ed6d12ba274799

Don Giovanni, ossia Il Dissoluto Punito, K.527: Overture (140bpm)
https://open.spotify.com/track/1ehFmRDalvIVxbPBk6lULw?si=77120fec91b647ac

Symphony No. 41 in C Major, K.551, “Jupiter”: 4. Molto Allegro (138bpm)
https://open.spotify.com/track/4UKJ8gAZR24FjDGjEF8ZHs?si=2d261cbe75c94ac2

Divertimento in D Major, K. 136 “Salzburg Symphony No. 1”:. Allegro (137bpm)
https://open.spotify.com/track/1GUa8Gk0WKVubtJp8c6QWK?si=1c8bc0201d084542

Ronda Alla Turca (133bpm)
https://open.spotify.com/track/4k038uwzZINTcDz1ApzHJ8?si=876aa5d7b0c34198

The Marriage of Figaro, K. 492: Lenozze di Figaro (The Marriage of Figaro), K.492: Overture (139bpm)
https://open.spotify.com/track/6EOeShUFPfLcOGF9OpIPLt?si=8e3e78e252ca4228

Serendae No. 13 in G Major, K. 525 “Eine Kleine Nachtmusik”: I. Allegro (139bpm)
https://open.spotify.com/track/2O0tYnL4ZgIntR1J7HWwh6?si=6c098ea2d7c34660

Computerized Stroop Task

CONGRUENT	NEUTRAL	INCONGRUENT
BLUE	DOOR	GREEN
GREEN	HOUSE	RED
RED	DOG	BLUE
RED	TREE	BLUE
BLUE	CHAIR	GREEN

Figure A1: This image demonstrates the 3 tasks included in the Computerized Stroop task including the Congruent, Neutral, and Incongruent tasks.

Computerized Corsi Block Task

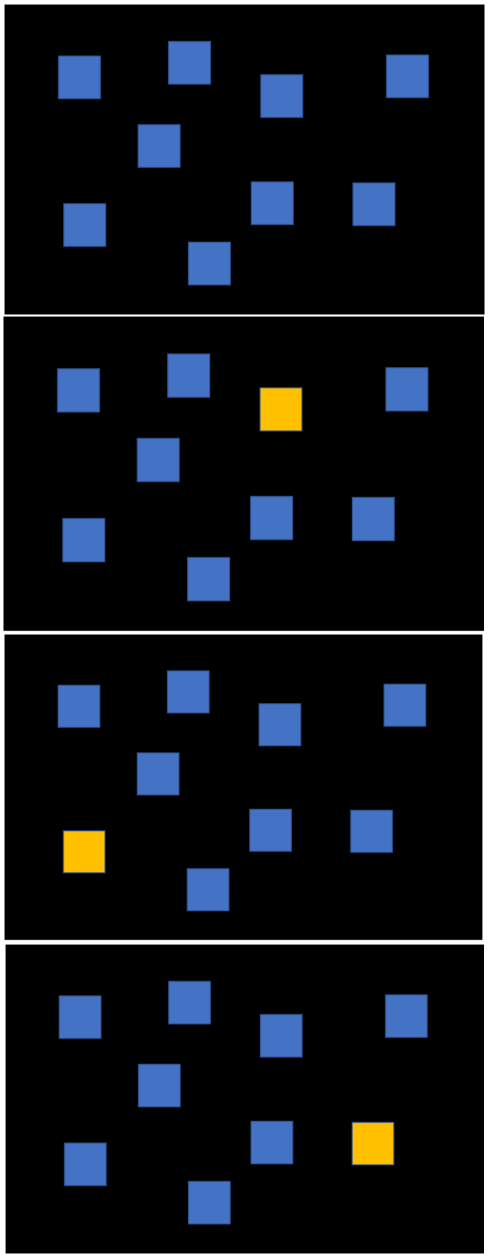


Figure A2: This is an example of what will be presented to the participants during the Backwards Corsi block task**.** Initially participants will be presented with a screen of 9 blocks. Once the task begins each block will light up individually in a sequence that the participant will then be asked to repeat back in the reverse order by clicking the boxes with a computer mouse,

STOMP Questionnaire

STOMP-Revised

Please indicate your basic preference for each of the following genres using the scale provided.

1	2	3	4	5	6	7
Dislike Strongly	Dislike Moderately	Dislike a Little	Neither like nor dislike	Like a Little	Like Moderately	Like Strongly

1. _____ Alternative
2. _____ Bluegrass
3. _____ Blues
4. _____ Classical
5. _____ Country
6. _____ Dance/Electronica
7. _____ Folk
8. _____ Funk
9. _____ Gospel
10. _____ Heavy Metal
11. _____ World
12. _____ Jazz
13. _____ New Age
14. _____ Oldies
15. _____ Opera
16. _____ Pop
17. _____ Punk
18. _____ Rap/hip-hop
19. _____ Reggae
20. _____ Religious
21. _____ Rock
22. _____ Soul/R&B
23. _____ Soundtracks/theme song

Figure A3: This is an example of the Short Test of Music Preferences (STOMP) Questionnaire that participants will be asked to complete.

Scoring instructions for the STOMP-R

Scoring for the four dimensions reported in: Rentfrow, P. J., & Gosling, S. D. (2003). The do-re-mi's of everyday life: The structure and personality correlates of music preferences. Journal of Personality and Social Psychology, 84, 1236-1256.

Compute the average score for each dimension using the items listed next to each label.

Reflective & Complex: 2, 3, 4, 7, 11, 12, 13, 15
Intense & Rebellious: 1, 10, 17, 21
Upbeat & Conventional: 5, 9, 14, 16, 20, 23
Energetic & Rhythmic: 6, 8, 18, 19, 22

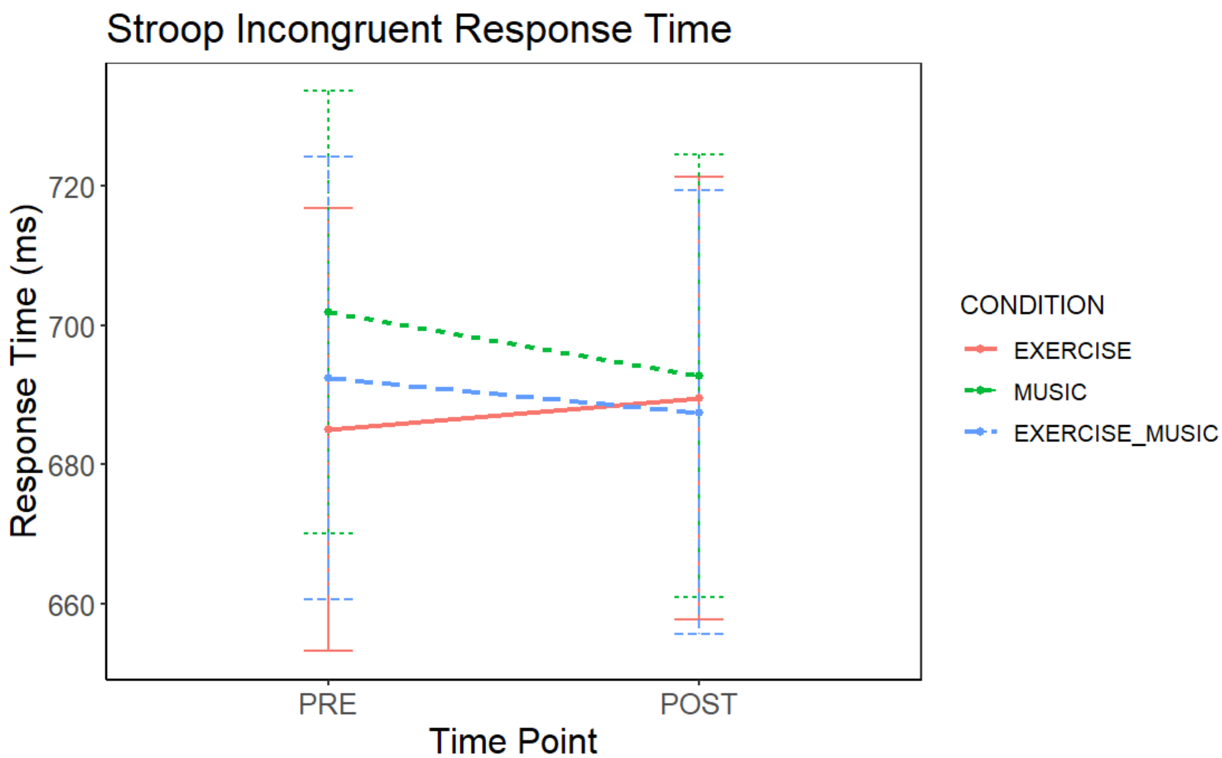
Scale Reliabilities:

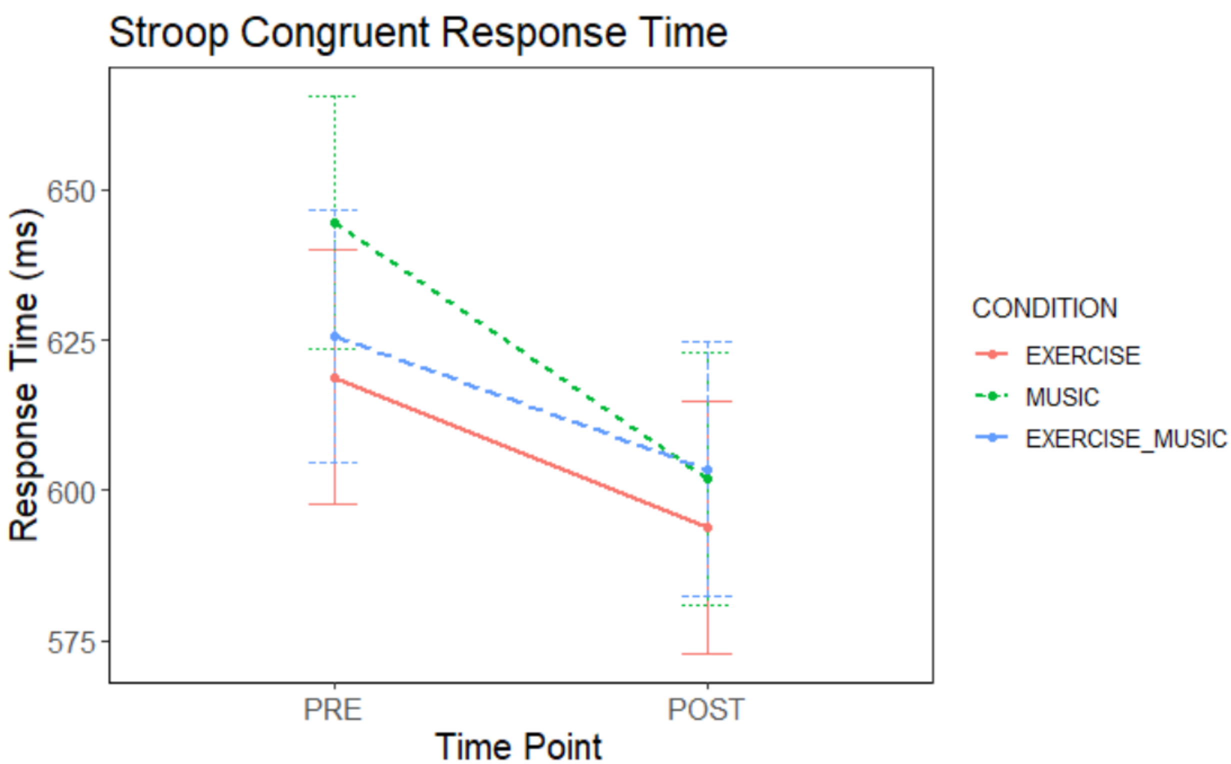
Reflective & Complex: alpha = .81
Intense & Rebellious: alpha = .74
Upbeat & Conventional: alpha = .70
Energetic & Rhythmic: alpha = .71

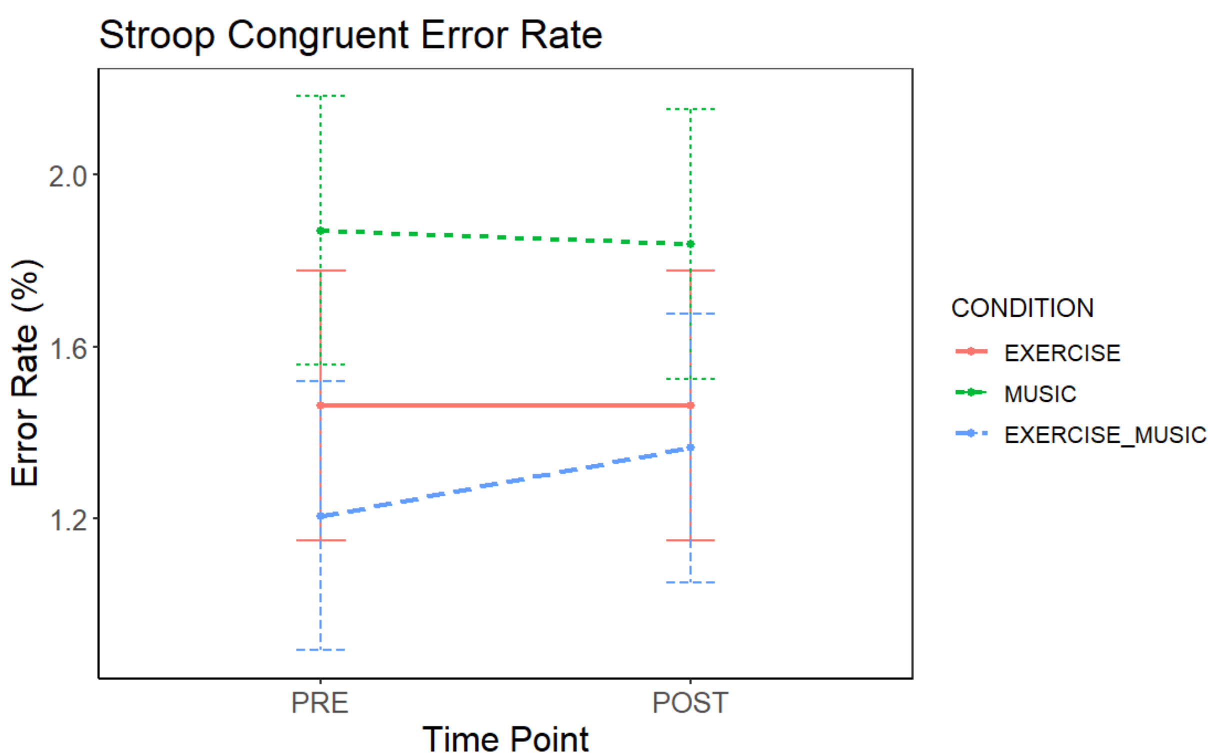
Figure A4: This is an example of the instructions that are used for scoring on the STOMP questionnaire.

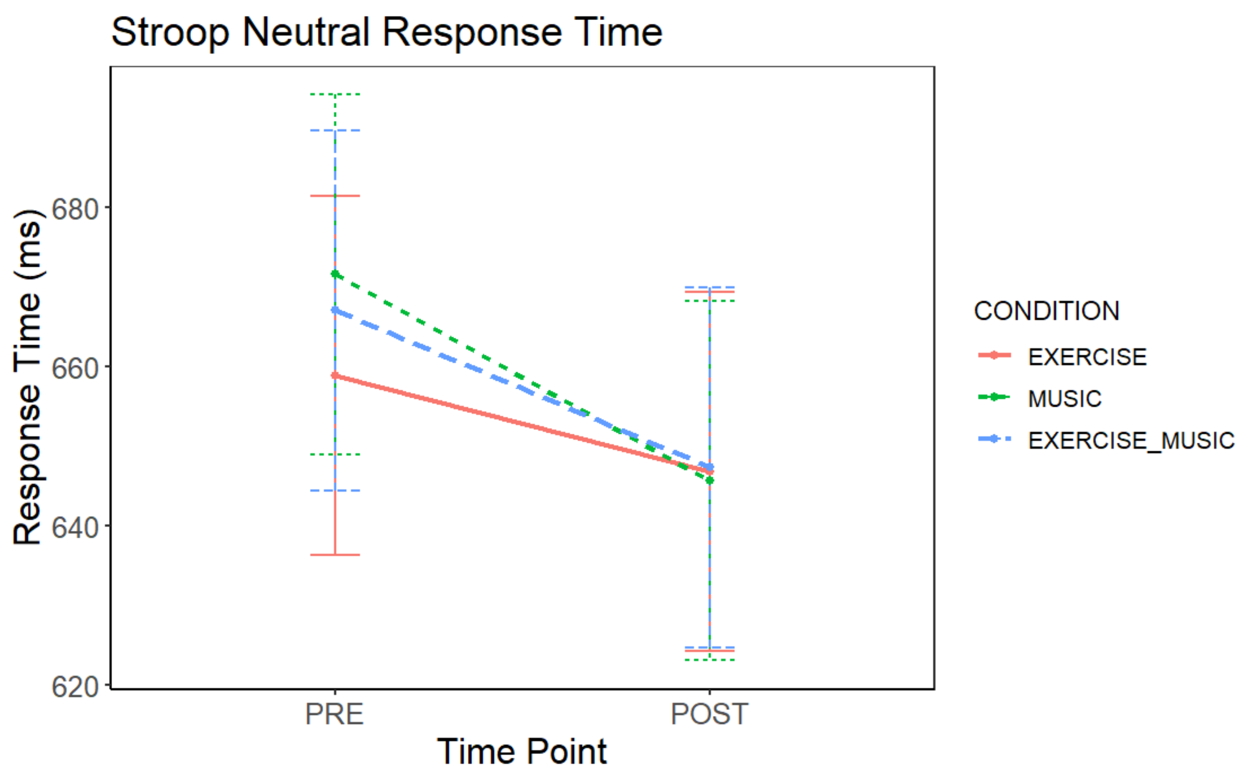
Additional Graphs

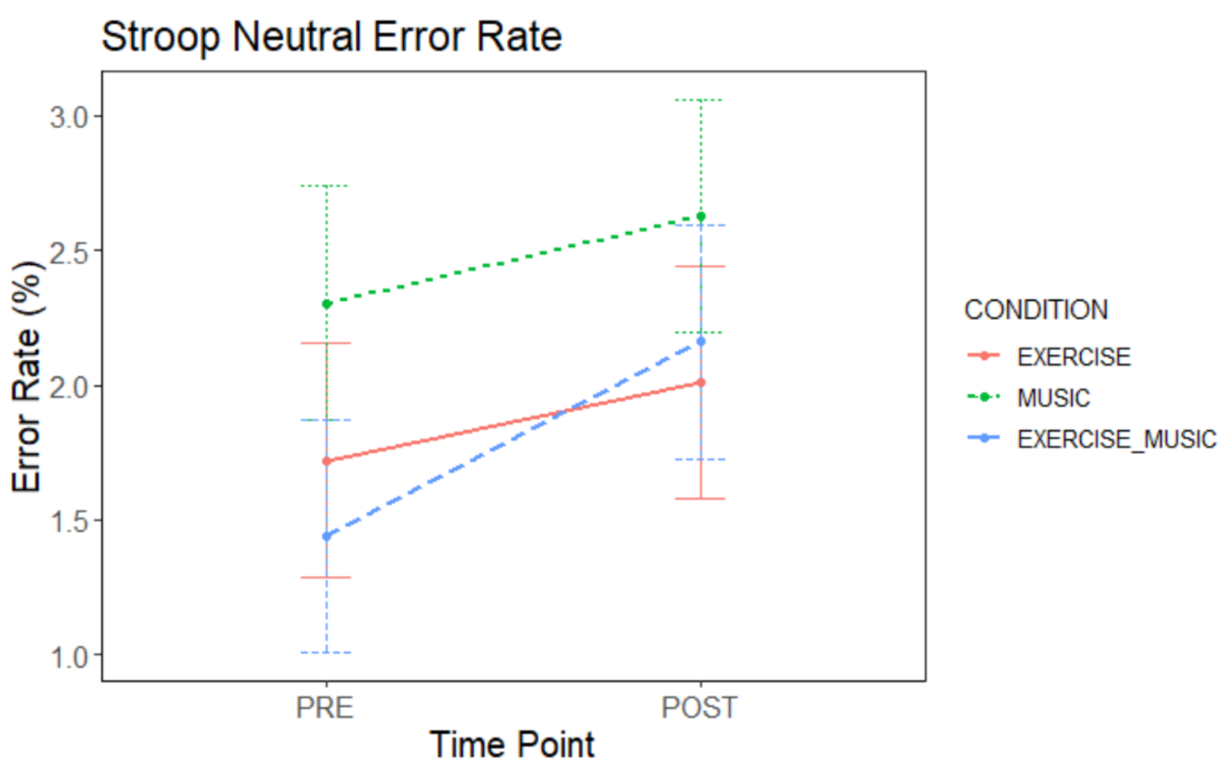
Stroop Task:



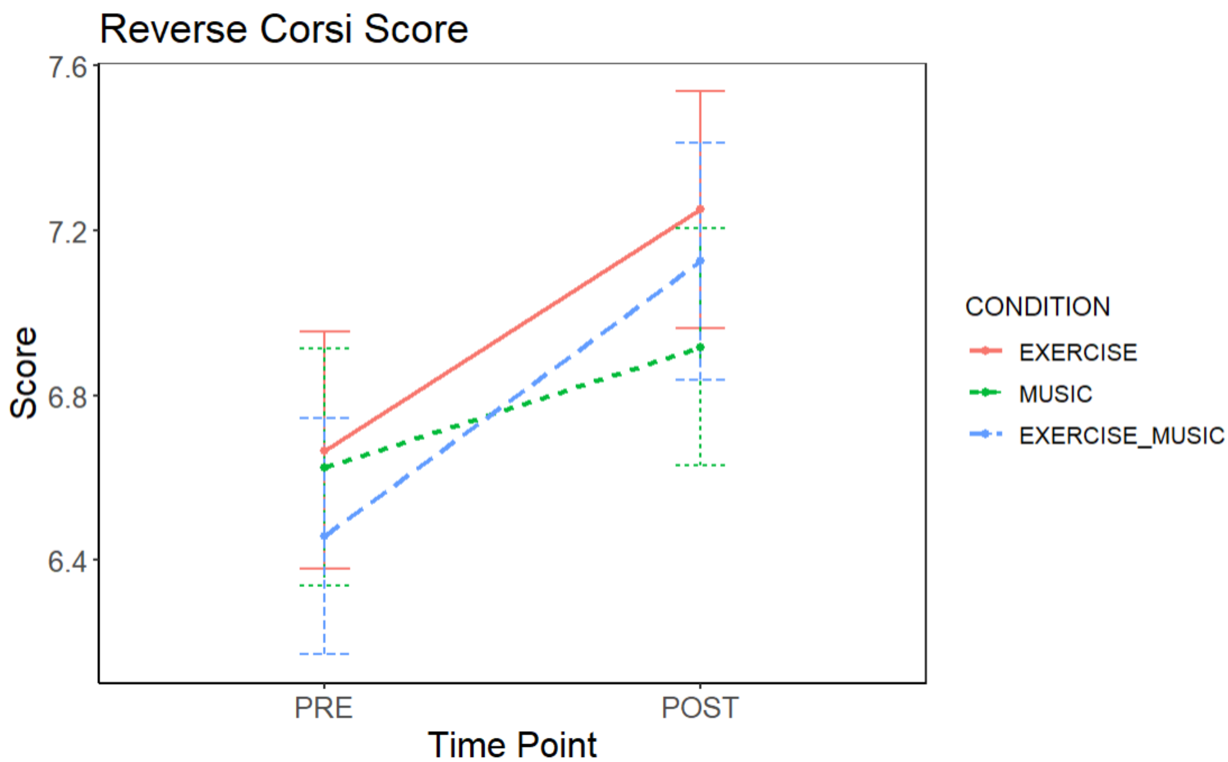

Stroop Congruent Response Time
Response Time (ms)
650
625
600
575
PRE
POST
Time Point
CONDITION
EXERCISE
MUSIC
EXERCISE_MUSIC

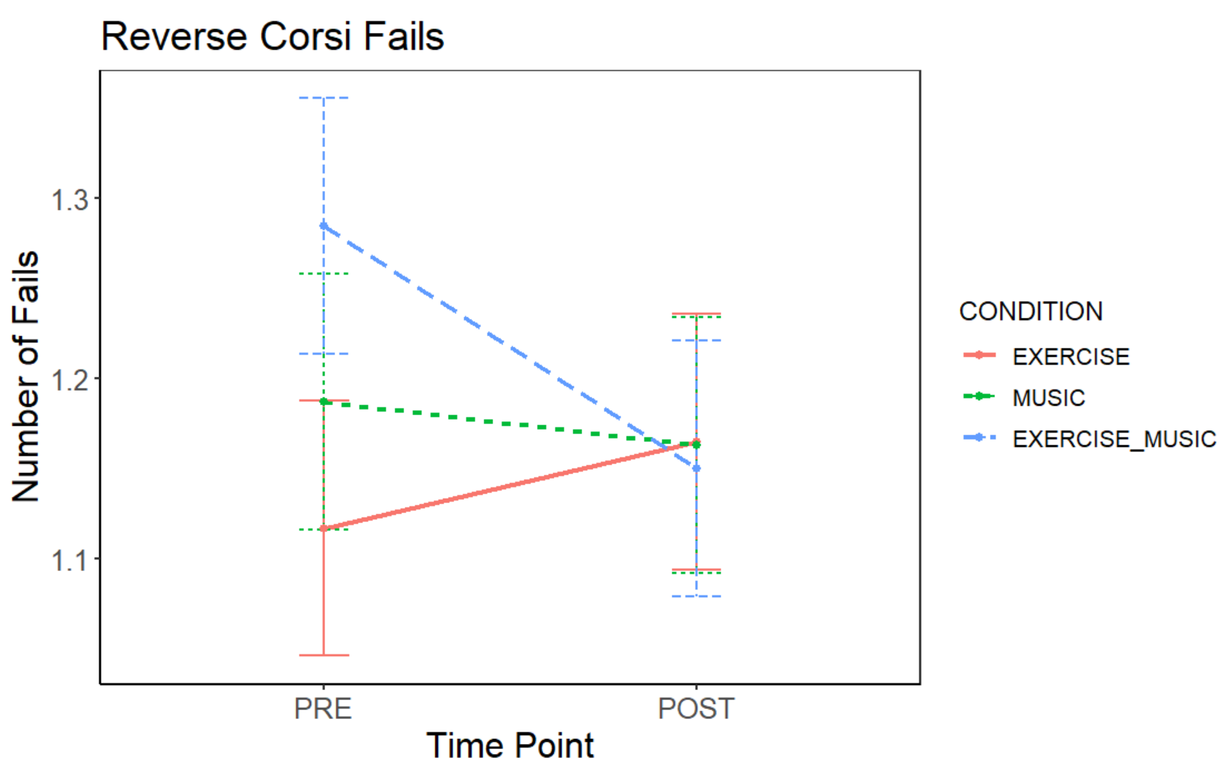

Stroop Congruent Error Rate
Error Rate (%)
2.0
1.6
1.2
PRE
POST
Time Point
CONDITION
EXERCISE
MUSIC
EXERCISE_MUSIC


Stroop Neutral Response Time
Response Time (ms)
680
660
640
620
PRE
POST
Time Point
CONDITION
EXERCISE
MUSIC
EXERCISE_MUSIC

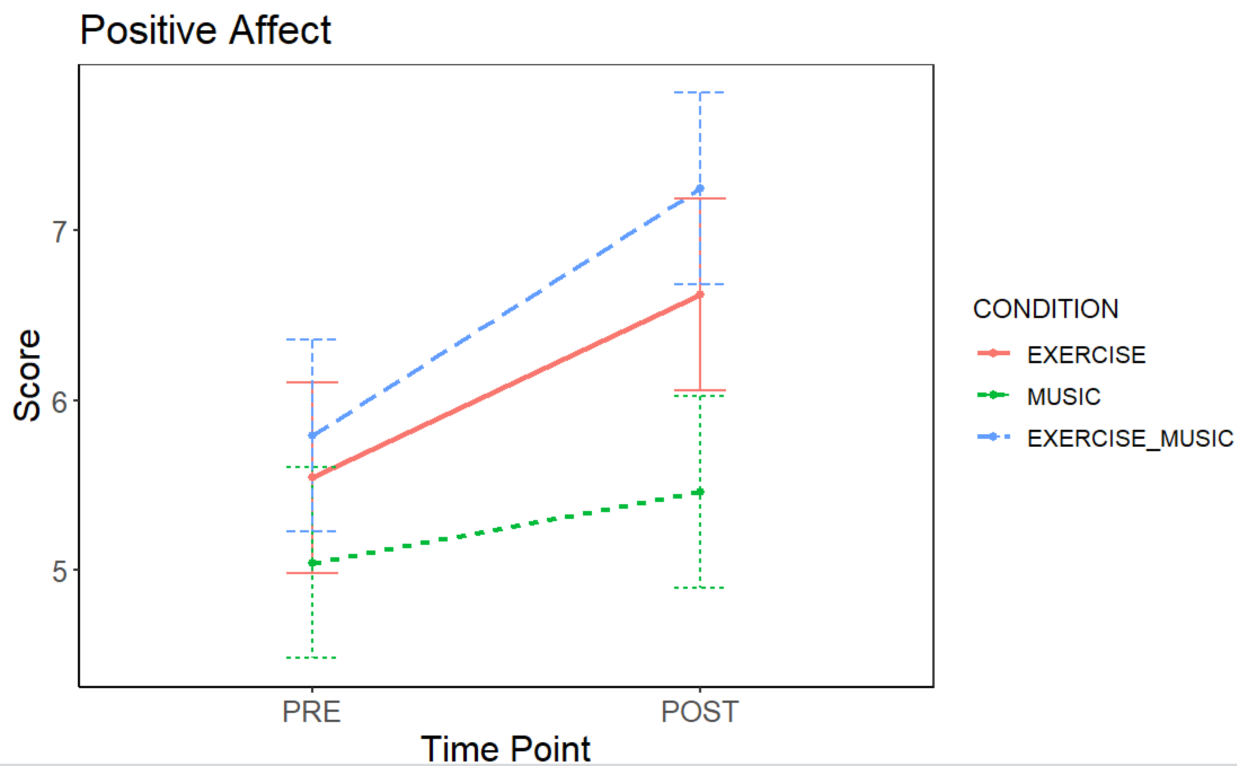

Stroop Neutral Error Rate
Error Rate (%)
3.0
2.5
2.0
1.5
1.0
PRE
POST
Time Point
CONDITION
EXERCISE
MUSIC
EXERCISE_MUSIC

Reverse Corse Block Task

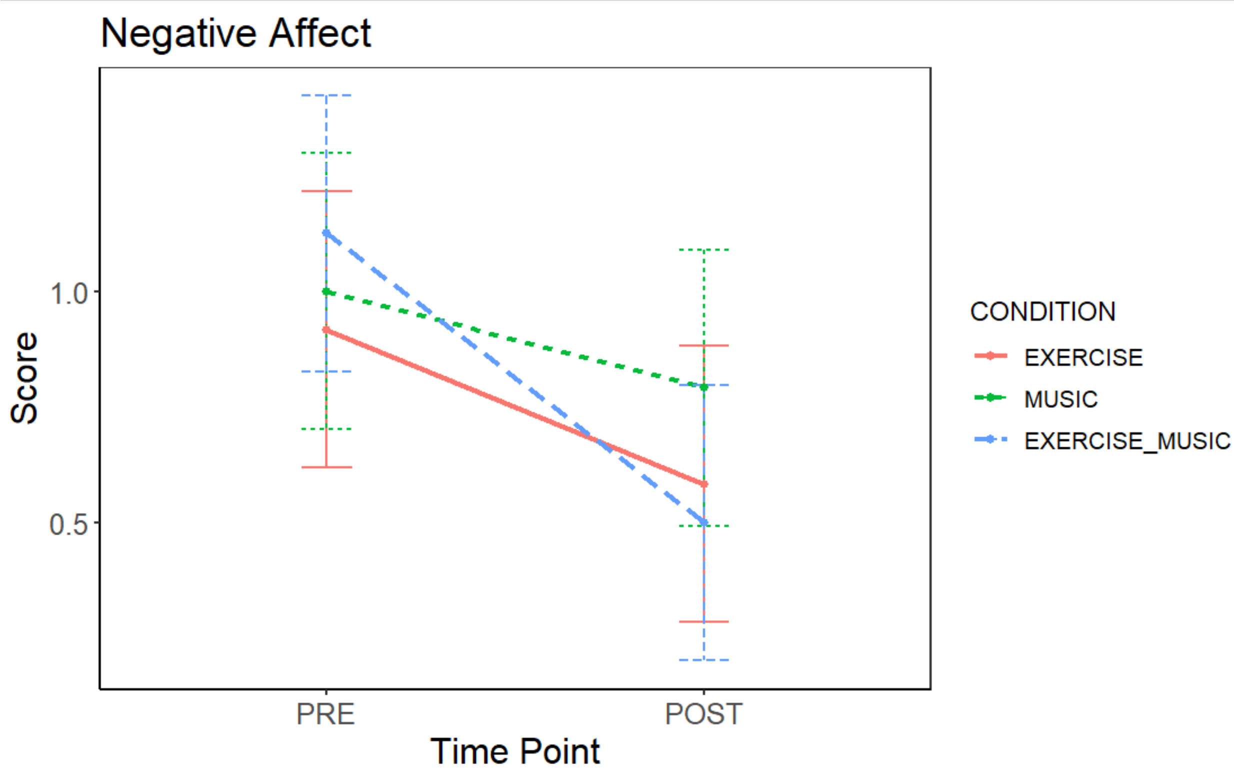




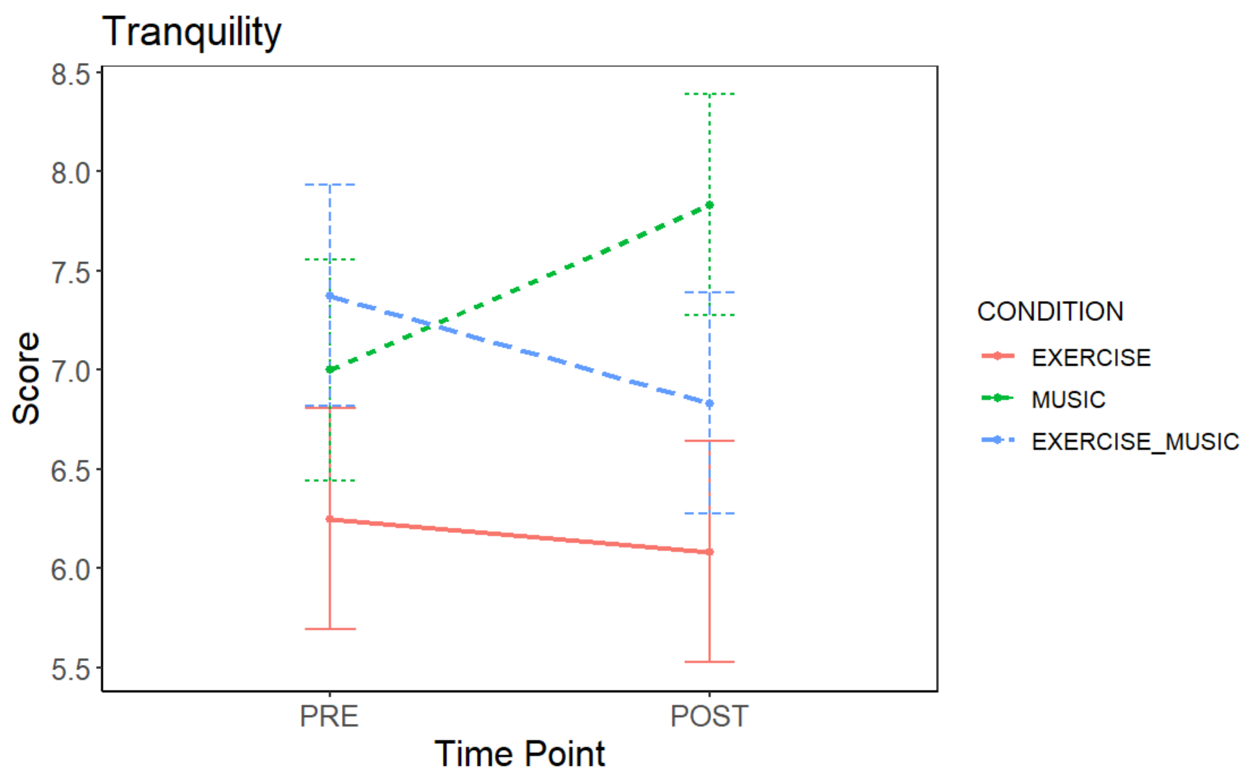
Affect

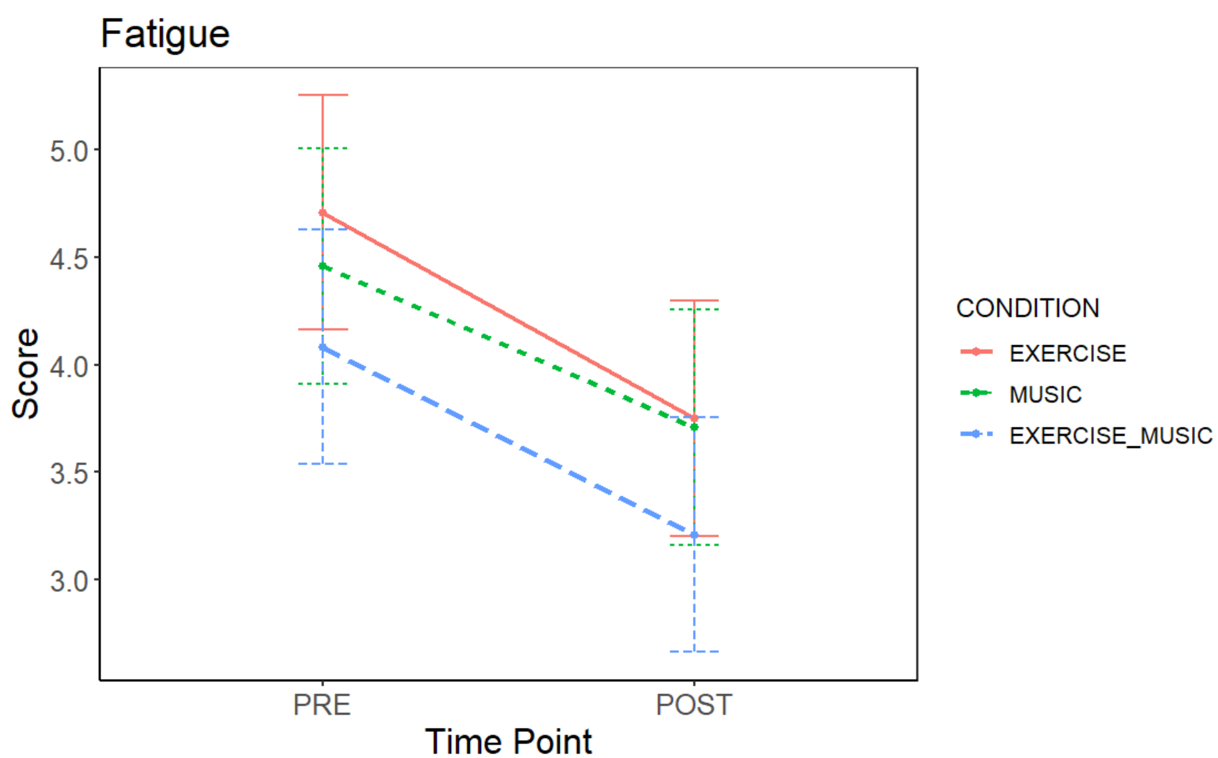


Positive Affect
Score
7
6
5
PRE
POST
Time Point
CONDITION
EXERCISE
MUSIC
EXERCISE_MUSIC



Negative Affect
Score
1.0
0.5
PRE
POST
Time Point
CONDITION
EXERCISE
MUSIC
EXERCISE_MUSIC


Tranquility
8.5
8.0
7.5
7.0
6.5
6.0
5.5
Score
PRE
POST
Time Point
CONDITION
EXERCISE
MUSIC
EXERCISE_MUSIC


Fatigue
5.0
4.5
4.0
3.5
3.0
Score
PRE
POST
Time Point
CONDITION
EXERCISE
MUSIC
EXERCISE_MUSIC