PHYSICAL ACTIVITY AND EXECUTIVE FUNCTIONS IN YOUNG ADULTS: A SYSTEMATIC AND EMPIRICAL INVESTIGATION

by

Jennifer Leckey

Submitted in partial fulfilment of the requirements
for the degree of Doctor of Philosophy

at

Dalhousie University
Halifax, Nova Scotia
April 2025

Dalhousie University is located in Mi'kma'ki,
the ancestral and unceded territory of the Mi'kmaq.
We are all Treaty people.

DEDICATION

For my parents, who illuminated the path and walked alongside me

every step of the way.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Young adults rely on executive functions (EFs) to navigate the transition to adulthood, and those with poor EFs are more likely to engage in unhealthy behaviours. A greater understanding of factors that improve EFs in young adults can inform health promotion and intervention strategies among this population. Physical activity (PA), particularly physical exercise, is a promising strategy for enhancing EFs. However, there is limited research with young adults and there is ongoing debate about the optimal intensity, frequency, duration, and type of exercise. The first step in this research was to conduct a systematic review of randomized controlled trials examining the effects of exercise interventions on performance-based EFs in healthy young adults. Forty-three studies (*N* = 3,124, ages 18–30) met eligibility criteria. Moderate-intensity and moderate-duration exercises, including aerobic, mind-body, and martial arts activities, were generally beneficial for EFs (e.g., inhibitory control, cognitive flexibility, working memory, planning). Both single- and multi-session interventions demonstrated benefits across various EF measures, though the long-term cumulative effects of exercise on EFs among young adults remain unclear. Based on these results, the second step was to conduct a cross-sectional study examining how longer-term PA patterns relate to young adults' self-reported and performance-based EFs. Undergraduate students (*N* = 212) completed a questionnaire assessing PA, EFs, and related constructs (e.g., musical training, sleep, affect, stress) prior to completing nine performance-based EF tasks online. Results indicated that PA had a limited role in predicting EFs, whereas musical training, positive affect, and sleep quality were stronger predictors. Latent profile analyses revealed two EF profiles (Higher and Lower EFs), and musical training was the only significant predictor of profile membership. Individuals with a history of musical training were more likely to belong to the Higher EFs profile. Overall, moderate-intensity, moderate-duration exercise has well-documented short-term benefits for performance-based EFs in young adults, while research on the long-term cumulative effects remains limited. Our findings highlight the importance of considering various lifestyle factors, such as musical training, and different approaches to EF measurement in this field. Integrating these insights could enhance strategies for optimizing cognitive health in young adults.

LIST OF ABBREVIATIONS AND SYMBOLS USED

%M	Percentage of males/men
aBIC	Adjusted Bayesian Information Criterion
AIC	Akaike Information Criterion
ANT	Attention Network Test
B	Unstandardized regression coefficient
BIC	Bayesian Information Criterion
BIS	Barratt Impulsiveness Scale-11
CF	Cognitive Flexibility
CFS	Canada Fitness Survey
CG	Control group
CI	Confidence interval
d	Cohen's d
D-KEFS	Delis-Kaplan Executive Function System
DalCAB	Dalhousie Computerized Assessment Battery
df	Degrees of freedom
EFs	Executive Functions
EPV	Events per variable
F	Statistic value for analysis of variance
FIST	Flexible Item Selection Task
HRMax	Maximum Heart Rate
HRR	Heart Rate Reserve
HRresting	Heart Rate at Rest
HVLT-R	Hopkins Verbal Learning Test-Revised
IC	Inhibitory Control
IG	Intervention group
Int.	Interference
k	Number of classes
LEAF	Learning, Executive, and Attention Functioning Scale
lmg	Lindeman, Merenda and Gold
LMR-A-LRT	Lo-Mendell-Rubin adjusted and Vuong-Lo-Mendell-Rubin likelihood ratio tests
Log-Lik.	Log-likelihood
LPA	Latent Profile Analysis
LSBQ	Language and Social Background Questionnaire
M	Mean
Mdn	Median
METs	Metabolic equivalent of tasks
Min	Minutes
MOS	Medical Outcomes Study
MUSE	Music USE questionnaire
N	Overall sample size
n	Sub-sample size

NCI	Nature Connectedness Index
p	P-value for testing significance
PA	Physical Activity
PANAS	Positive and Negative Affect Schedule
PASAT	Paced Auditory Serial Addition Test
POMS	Profile of Mood States
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PSS	Perceived Stress Scale
r	Pearson's correlation coefficient
R^2	Coefficient of determination
RCT	Randomized Controlled Trial
RI	Relative Importance
RPE	Ratings of Perceived Exertion
RPM	Revolutions Per Minute
RT	Response Time
SD	Standard Deviation
SE	Standard Error
SPSS	Statistical Package for the Social Sciences
SQRT	Square Root
sR^2	Semi-partial squared correlation
TMT	Trail Making Test
TOL	Tower of London
Tot.	Total
VIF	Variance Inflation Factor
VLMR-LRT	Vuong-Lo-Mendell-Rubin likelihood-ratio test
VO_2Max	Maximum Oxygen Uptake
WCST	Wisconsin Card Sorting Test
WM	Working Memory
y	Years
ηp^2	Partial Eta Squared
$\chi 2$	Statistic value for chi-squared analysis

ACKNOWLEDGEMENTS

I would first like to thank my supervisors, Dr. Shannon Johnson and Dr. Sophie Jacques, for supporting me through this degree. Together you created a space for me to grow personally and professionally more than I knew was possible. Thank you for your mentorship, modelling the application of research to make meaningful change, and equipping me with the skills to move forward with confidence. I would not be where I am today without the time and effort put forth by both of you. Thank you.

To my committee members, Dr. Margo C. Watt and Dr. David Westwood, thank you for your valuable perspectives and consistent encouragement. You have been instrumental in shaping this dissertation and I am grateful to have learned from you both.

I am thankful for the student researchers who dedicated their time, energy, and enthusiasm to my dissertation research. Your involvement was invaluable in propelling this work forward. A special thank you to Cory Munroe, Victoria Foxall, and Vrinda Kathpal, who went above and beyond in their contributions.

I would like to acknowledge Dr. Gail Eskes for sharing the DalCAB with us, as well as Jake Roeker and Cindy Hamon-Hill for their support with implementing the DalCAB for my study. I would also like to extend my gratitude to the Dalhousie librarians, especially Robin Parker, for sharing their expertise and providing guidance on systematic review procedures.

This research would not have been possible without the undergraduate students who participated. My sincere thank you for your engagement and contributions.

I greatly appreciate the organizations that provided me with financial support while doing this work: the Social Sciences and Humanities Research Council, Dalhousie University, and the province of Nova Scotia.

Prior to graduate school, the faculty at Mount Saint Vincent University provided the education and opportunities that were foundational for my learning in the Clinical program at Dalhousie. Dr. Derek Fisher, thank you for your mentorship in my initial research endeavours and while applying to graduate school.

The Clinical faculty at Dalhousie demonstrate dedication to fostering academic and personal growth. I am thankful for each of your contributions to my professional development. Dr. Sean McKinnon, thank you for patiently assisting with statistical analyses, and Dr. Sherry Stewart, thank you for chairing my Comprehensive Committee.

I would like to acknowledge those who supervised my clinical training over the past 5 years. Dr. Shannon Johnson, Dr. Alissa Pencer, Dr. Brad Kelln, Dr. Natalie Stratton, Dr. Daniel LeBouthillier, Dr. Jamie Farquhar, Dr. Dayna Lee-Baggely, Dr. Kristen Higgins, Dr. Doug Kane, Dr. Julie Wershler, and Dr. Tiffany Shepherd, thank you for sharing your expertise with me. The insights you imparted will remain with me throughout my career.

To my cohort – Grace Schwenck, Toni Spinella, Robin Perry, Eli Otis, Yasmeen Ashraf, Teba Hemodat, and Karen Tang – I am grateful to have been on this journey with all of you. Your support, camaraderie, and shared experiences have made this process much richer. Grace, a heartfelt thank you for your friendship, for supporting me through every challenge and success over the past 5 years, and for inspiring me daily.

To my extended family and family friends, thank you for the countless ways you have shown up for me over the years. To my girlfriends, I am endlessly thankful for the joy and strength you bring to my life. Your reliability, encouragement, and contributions to meaningful moments have been empowering. I am lucky to have each of you in my corner.

Miguel, you are a pillar of support and show confidence in me that I sometimes can't find in myself. Thank you for every minute spent listening, laughing, and adventuring. You make the good days better and the busy days feel lighter.

Most importantly, I would like to acknowledge my family: Rob, Brenda, and Will Leckey. Your unwavering support makes closeness a feeling that transcends distance on a map.

Dad, you are the first person I call when I experience a success (or when I need help with something). Thank you for answering every phone call no matter what. Thank you for being my biggest fan in everything that I do and for having an endless supply of knowledge to share with me in the process.

Mom, thank you for imparting your wisdom and beloved "Brenda-isms" in conversations that last for hours, yet feel like seconds. You've had my back since day one and your guidance often reminds me that you know me better than I know myself. Thank you for reminding me to take breaks, celebrate the big things and enjoy the small things, and for being the source of many of those enjoyable moments.

Will, I am fortunate to have you as my first and forever best friend. Thank you for always putting me at the top of your "social calendar" and infusing humour into my life daily. Your demonstration of genuine care and encouragement to step out of my comfort zone have been a constant source of strength for me. Thank you for your support every step of the way.

CHAPTER 1: INTRODUCTION

Executive functions (EFs) involve higher-order neurocognitive processes that allow for decision-making and engagement in purposeful, goal-directed, and future-oriented behaviours (Suchy, 2009). While there is not a universally agreed upon definition of EFs — and many interrelated processes contribute to its conceptualization (Suchy, 2009)—common core EF processes that are widely recognized as foundational to applied goal-directed behaviour (Diamond, 2013; Hoffman et al., 2012; Miyake et al., 2000) include working memory (the ability to retain and manipulate information in the mind), inhibitory control (the ability to resist temptation and impulsive reactions), and cognitive flexibility (the ability to change perspectives and approaches to adjust to new demands; Diamond, 2013). Individuals with more advanced working memory, inhibitory control, and cognitive flexibility are more likely to successfully navigate complex decision-making tasks, demonstrate greater self-regulation, and engage in adaptive problem-solving strategies (Diamond, 2013; Hoffman et al., 2012).

Executive functions have been extensively studied in children and older adults, largely due to the critical developmental transitions and cognitive changes that occur in these populations (Best & Miller, 2010; Diamond, 2013; Vaughan & Giovanello, 2010; Zelazo et al., 2016). In children, EF research has focused on its rapid development during early childhood and its role in academic achievement, social-emotional regulation, and long-term life outcomes (Best & Miller, 2010; Castellanos et al., 2023; Zelazo et al., 2016). Similarly, research in older adults has emphasized age-related declines in EFs and their implications for independence and quality of life (Diamond, 2013; Vaughan & Giovanello, 2010).

Comparatively little attention has been paid to young adults, despite ongoing structural and functional brain development well into the mid-twenties, with maturing neuronal pathways and strengthening synapses that enhance EFs (Tomporowski et al., 2008). Moreover, the early adult period is marked by significant life transitions, including independent living and entry into higher education and/or the workforce, all of which rely heavily on EFs (Othman et al., 2019). Young adults with poorer EFs are also more likely to engage in risky and unhealthy behaviours, such as unhealthy dietary habits (Allan et al., 2016) and substance abuse (Reynolds et al., 2019), and report more health issues during stressful situations (Shields et al., 2017). Conversely, those with more advanced EF skills are more likely to report greater engagement in health behaviours (Hall et al. 2008; McGrath et al., 2021) and exhibit more adaptive coping strategies, such as problem-solving and emotional regulation, which buffer against the negative impact of stress (Müller et al., 2017).

Given the importance of EFs in young adulthood, there is a need to identify interventions that promote EF development during this period. Improvements in cognitive functioning would be expected to improve daily functioning and have the potential to prevent or mitigate the onset of risky behaviours and poor health outcomes associated with low EF. Additionally, enhancing EF skills during this period may provide long-term benefits by fostering healthier lifestyles, improved decision-making, and better stress management strategies, all of which are integral to navigating the challenges of adulthood successfully.

1.1 Exercise and Executive Functions

Ample evidence suggests that EFs can be enhanced at different ages through targeted intervention and training (Friese et al., 2017). There has been particular interest in recent years

in the potential benefits of physical activity (PA) and exercise for cognition more generally, and EFs specifically (Pachava & Shenoy, 2023; Salas-Gomez et al., 2020). PA is defined as any bodily movement produced by skeletal muscles that requires energy expenditure and includes a wide range of activities such as work-related tasks, household chores, and leisure activities (Caspersen et al., 1985). In turn, exercise refers to the subset of PA that is planned, structured, repetitive, and intentional, specifically aimed at improving or maintaining physical fitness (Caspersen et al., 1985). Exercise has high clinical utility due to its accessibility and adaptability, allowing it to be tailored to individual needs and abilities across various cultural contexts (Kiuppis, 2016). Research has increasingly demonstrated the positive effects of exercise on the brain and cognition, which has prompted a focus on identifying the most effective exercise types, intensities, and doses (Abdalkareem Jasim et al., 2024; Ludyga et al., 2020). Understanding these nuances will advance our understanding of the complex relationship between exercise and cognition while laying the groundwork for creating targeted interventions and customized exercise plans that enhance brain health and cognitive resilience across different populations (Abdalkareem Jasim et al., 2024).

Two prominent perspectives – the neuroplasticity hypothesis and the biopsychosocial model – offer complementary explanations for the mechanisms that may underlie the relationship between exercise and EFs. The neuroplasticity hypothesis posits that exercise facilitates structural and functional changes in the brain, which in turn enhance cognitive performance (Umegaki et al., 2021; Voss et al., 2013). Specifically, exercise is thought to promote neurogenesis, reduce inflammation, and improve vascular and neurochemical functions. For example, aerobic exercise has been linked to increased brain-derived

neurotrophic factor (BDNF), a key mediator of neuroplasticity, which supports the growth and resilience of neural pathways associated with EF processes (Umegaki et al., 2021). While evidence supports the association between exercise and these neurological changes – and links these changes to improved cognitive functioning – the precise mechanisms underlying these effects are not fully understood (Umegaki et al., 2021). Nevertheless, this hypothesis underscores the physiological mechanisms underlying the cognitive benefits of exercise, supporting previous findings that exercise has a positive impact on brain health and cognitive function (Umegaki et al., 2021; Voss et al., 2013).

The biopsychosocial model provides a broader, integrative framework for understanding how exercise impacts EFs by considering overlapping biological, psychological, and social factors. From this perspective, exercise not only drives neurobiological changes but also enhances psychological well-being (e.g., reducing stress and improving mood) and fosters social engagement (e.g., through group activities or team sports), which collectively contribute to improved EF outcomes (Stonerock et al., 2015; Tomporowski et al., 2008). For young adults navigating critical life transitions, the biopsychosocial model provides context for understanding how the interplay of individual and environmental factors shapes cognition and overall functioning, offering insight into how exercise interventions may support holistic development and well-being during this pivotal stage.

Most studies and reviews on the effects of exercise on EFs have focused on children and older adults (e.g., Li et al., 2020; Xiong et al., 2021) and research involving young adults is comparatively limited. Existing reviews that have included young adults often span broad age ranges, such as children, adolescents, and young adults (Verburgh et al., 2014), young, middle-

aged, and older adults (Zhang et al., 2023), or all age groups (Festa et al., 2023) and consistently report that studies focusing specifically on young adults comprise only a small subset (Abdalkareem Jasim et al., 2024). Reviews that have included a greater number of young adult studies have examined exercise only broadly, without systematically addressing how specific exercise variables (e.g., exercise types, intensities, frequencies, and durations) influence EFs in this population (Ludyga et al., 2023). It is not feasible to design intervention studies that encompass the full range of exercise types, intensities, frequencies, and durations, nor to assess their effects on every component of EFs. Therefore, most studies examine links between exercise and EFs using targeted and specific interventions. However, guidelines from the American College of Sports Medicine emphasize the importance of simultaneously considering multiple aspects of exercise variables when designing exercise prescriptions to optimize cognitive health (Piercy et al., 2018).

Evidence from non-clinical populations across age groups suggests that variations in exercise type, intensity, frequency, and duration may differentially impact EFs (Ludyga et al., 2023; Zhang et al., 2023). For instance, while aerobic exercise has been studied most frequently and has shown consistent benefits for EFs, emerging evidence suggests that components beyond motor movement, such as mindfulness and coordination, may play critical roles in EF improvements (Diamond & Ling, 2016, 2019; Ludyga et al., 2020, 2023). In a recent review of studies primarily with older adults, Zhang et al. (2023) suggested that the greatest cognitive benefits are observed with moderate-intensity exercise performed 3–4 times per week for 45–60 min over 3–6 months. Clarifying the relative benefits of different types, intensities, and doses

of exercise among young adults is critical for developing evidence-based guidelines for cognitive enhancement.

Although both single-session exercise (also referred to as acute exercise) and multi-session exercise (also referred to as chronic exercise) have been shown to improve EFs in adults (Festa et al., 2023), their potential differential effects specifically among young adults remain unclear. Meta-analyses focusing on children (e.g., Alvarez-Bueno et al., 2017; de Greeff et al., 2018; Song et al., 2023) and older adults (e.g., Contreras-Osorio et al., 2022; Xiong et al., 2021) suggest that chronic exercise tends to be more effective due to cumulative benefits. However, there is limited evidence on whether the same holds true for young adults. Young adults' EFs may respond to exercise differently than other age groups due to key developmental factors, such as ongoing brain maturation, varying levels of stress during significant life transitions, and the cognitive demands of educational and early career milestones. These factors could influence how exercise impacts cognitive performance, making it essential to understand how exercise variables interact with developmental characteristics. For example, compared to other age groups, young adults may experience quicker and more sustained EF benefits due to their high baseline cognitive functioning and ongoing brain development. Alternatively, they might benefit less given that they are already at their lifetime optimal performance (cf. Karbach & Kray, 2020).

The timing and persistence of EF benefits in relation to exercise remain unclear among young adults and may depend on specific exercise variables. For example, EFs are often enhanced shortly after completing an exercise session, but performance may be impaired if assessed during exercise (Lambourne & Tomporowski, 2010). Moreover, the sustained effects of

exercise beyond the immediate post-exercise period are not well-documented. Identifying the timing, sustainability, and nature of EF improvements would contribute to refining exercise guidelines to meet the unique needs and challenges of young adults. For example, recommendations could consider how exercise timing aligns with periods of intense cognitive activity, such as exams or work tasks. Addressing these gaps would not only inform best practices for designing interventions aimed at enhancing EF in young adults but might also help elucidate the relative importance of biological, psychological, and social effects of exercise on EFs in this age group.

1.2 Measuring Outcomes Related to Executive Functions

Performance-based measures have been most used for investigating the relationship between exercise and EFs and exercise appears to enhance performance-based EFs globally (Ludyga et al., 2023; Zhang et al., 2023). These measures, such as the Stroop test (Stroop, 1935), Verbal Fluency (Delis et al., 2001), and Digit Span (Wechsler, 2008), were designed to objectively assess various EF components by evaluating behaviour under controlled conditions (Miyake & Friedman, 2012). Moreover, performance-based tasks are sensitive to change, making them valuable for detecting the effects of interventions (Burgess et al., 2006). However, performance-based measures may not capture the full scope of EFs in real-life settings, as they focus on task-specific performance in controlled settings rather than everyday cognitive challenges (Ziemnik & Suchy, 2019). While there is extensive evidence supporting their ability to predict real-world outcomes in a variety of populations, they have also been criticized for their imperfect relationship with functional outcomes (Burgess et al., 2006; Ziemnik & Suchy, 2019). Therefore,

performance-based EF measures are often best used in combination with assessment of applied skills (Burgess et al., 2006).

One approach to assessing applied skills is through self-report measures of everyday EF behaviours (Chaku et al., 2021), such as the Behaviour Rating Inventory of Executive Function (BRIEF; Gioia, 2000) or the Learning, Executive, and Attention Functioning Scale, LEAF; Kronenberger, 2014). These self-reports offer insights into individuals' perceptions of their cognitive abilities and how these abilities influence their daily functioning. Among young adults, self-reported EF measures have been associated with better health behaviours (McGrath et al., 2021) and more effective self-management during critical life transitions (Plevinsky et al., 2020). Notably, self-reported and performance-based EF measures have been found to be only weakly correlated (Dube et al., 2022; Toplak et al., 2013), highlighting their distinct contributions when assessing EFs.

Whereas both performance-based and self-report measures offer unique and important insights into EFs (Enkavi et al., 2019; Friedman & Banich, 2019; Friedman & Gustavson, 2022), self-reported EF measures remain underutilized in research on exercise-related EF improvements, leaving an important gap in our understanding of how one's perceived functioning in real-world contexts is related to PA and exercise. By integrating both performance-based and self-report assessments, researchers can better capture the complexity of EFs and their relation to exercise.

1.3 Introduction to Dissertation Papers

Exercise is increasingly recognized as a promising approach for enhancing EFs but research on exercise and EFs among young adults remains limited, despite the crucial role of EFs

in optimizing success during the transition to adulthood. Thus, the purpose of this dissertation was to investigate relationships between exercise and EFs in young adults to contribute to health promotion and intervention strategies among this population. A two-step approach was employed to address the research questions. A systematic review followed by a cross-sectional study were conducted to provide complementary insights into the relationships between exercise and EFs in young adults. The systematic review aimed to determine which types, intensities, and doses (i.e., frequency and duration) of exercise are most effective for improving different aspects of EFs, filling an important gap in the literature. The cross-sectional study built on the findings of the systematic review by examining how naturalistic, long-term exercise patterns relate to both self-reported and performance-based EFs in a sample of young adults.

1.3.1 Study 1: Systematic Review

The first step in this research was to synthesize evidence from randomized controlled trials examining the effects of exercise interventions on EFs in young adults. A preliminary search revealed that there were sufficient studies available to focus specifically on randomized controlled trials, allowing for a more rigorous evaluation of the evidence. Given limitations in existing research described previously, a systematic review of existing literature on young adults alone was necessary to identify patterns and to determine if there is sufficient evidence from previous studies to guide clinical interventions.

Knowledge synthesis is a process that involves combining findings from multiple studies to generate a comprehensive understanding of a particular research question (Grant & Booth, 2009). A systematic review is a knowledge synthesis method used to systematically identify, evaluate, and synthesize findings from existing research (Higgins et al., 2022). This approach is

particularly valuable for summarizing evidence across diverse studies, identifying patterns, and highlighting gaps in the literature (Grant & Booth, 2009). Research examining the effects of exercise on EFs has used a range of intervention methods (e.g., exercise type, intensity, duration, and frequency) and outcomes measures for EFs. By synthesizing the findings of these studies, a systematic review provides a clearer picture of the current evidence base, identifies gaps or areas of inconsistency, and establishes a foundation for future research.

Compared to other review types, a systematic review offers advantages for addressing specific research questions with a well-defined scope and methodological rigour (Grant & Booth, 2009). For example, narrative reviews provide broader and more flexible discussions but lack the standardized methodology to ensure comprehensiveness and minimize bias (Grant & Booth, 2009). Similarly, while scoping reviews are useful for mapping a research field and identifying gaps, they typically focus on breadth rather than depth and are less suitable for synthesizing evidence to draw conclusions (Grant & Booth, 2009). Given the specific aim of this research—to synthesize findings on exercise interventions and EF outcomes in young adults—a systematic review was completed to ensure methodological rigour, transparency, and reproducibility.

1.3.2 Study 2: Cross-Sectional Study

The second step was to conduct a cross-sectional study to examine how young adults' PA patterns relate to their self-reported and performance-based EFs while accounting for other lifestyle factors. Whereas exercise interventions were the focus of the systematic review, lifetime and current PA were examined in the cross-sectional study. The cross-sectional study examined relationships between EFs and PA to allow for the exploration of a broader spectrum

of movement behaviours, capturing diverse contexts to examine the potential contributions of PA to EFs.

Cross-sectional studies involve collecting data from participants at a single time point, making them well-suited for exploring relationships between variables and identifying potential predictors (Levin, 2006). This design is particularly advantageous when investigating multiple variables simultaneously and establishing preliminary evidence for associations that can inform future longitudinal research. Although a longitudinal design could provide insights into causality and changes over time, cross-sectional studies are more feasible for an initial exploration of these relationships. This approach allowed for the efficient collection of data on a relatively large sample of young adults, offering valuable insights into potential predictors of EFs and informing future directions.

In the cross-sectional study, we assessed how self-reported PA in undergraduate students (*N* = 212) related to self-reported and performance-based EFs. To examine relationships between PA and EFs, we conducted multiple regression with *relative importance* analyses. Multiple regression assesses the strength and direction of the relationships between variables, while relative importance analyses quantify the unique contribution of each predictor variable to the overall variability in EFs (Grömping, 2006). We also used *latent profile analysis* (LPA) to examine profiles of EFs among young adults and assessed how these profiles related to PA. LPA is a person-centered statistical method used to identify subgroups within a population based on patterns of responses across multiple variables, such as EF measures (Spurk et al., 2020).

Together, the aim of the two studies was to advance our understanding of how exercise

and PA relate to EFs in young adults to inform evidence-based strategies for promoting cognitive and physical health during this critical life stage.

CHAPTER 2: THE EFFECTS OF EXERCISE ON EXECUTIVE FUNCTIONS IN YOUNG ADULTS: A SYSTEMATIC REVIEW

The manuscript prepared for this study is presented below. Jenn Leckey, under the supervision of Dr. Sophie Jacques and Dr. Shannon Johnson, developed the research questions and methodology, led the reviewing and data extraction process, interpreted results, and wrote a substantial amount of the manuscript.

Jenn Leckey, Vrinda Kathpal, Victoria Foxall, Sophie Jacques, & Shannon A. Johnson. The effects of exercise on executive functions in young adults: A systematic review. [Manuscript in Submission Process]. Department of Psychology, Dalhousie University.

2.1 Abstract

The current systematic review examined the effects of exercise on executive functions (EFs) in young adults, a developmental period characterized by peak cognitive performance and increasing demands on self-regulated behaviour. After screening 3559 articles in Covidence, 43 articles (44 studies) were included. Both single- and multi-session interventions, particularly those involving moderate-to-high intensity exercise, showed benefits for performance-based EFs, with aerobic and resistance exercises being the most frequently studied. Improvements were observed for up to 120 min after single-session interventions. In contrast, low-intensity exercise and assessing EFs during exercise resulted in no effects or even decrements in EF performance. Overall, the findings indicate that exercise offers a promising strategy for enhancing EFs in young adults, although gaps remain in understanding the long-term effects of exercise on EF. Future research should continue to explore how different aspects of exercise interact and assess longer-term effects of exercise to clarify the broader impacts of exercise on cognitive performance.

2.2 Introduction

Executive functions (EFs) encompass a set of higher-order cognitive processes that are fundamental to goal-directed behaviour and adaptive functioning (Diamond, 2013). These skills are critical during young adulthood – a period marked by the transition to independence and increasing cognitive demands (Othman et al., 2019). EF development continues into and generally peaks during early adulthood, emphasizing the importance of identifying modifiable factors that support cognitive performance during this life stage (Ferguson et al., 2021).

Physical exercise is increasingly recognized as a promising strategy for enhancing EFs, yet much of the research has centered on children and older adults, with less emphasis on young adults (Ludyga et al., 2023; Zhang et al., 2023). Some reviews have included young adults alongside other age groups (Haverkamp et al., 2020; Ludyga et al., 2020; Zhang et al., 2023), though young adults represent a smaller proportion of the included studies compared to other age groups (e.g., adolescents, older adults). Other reviews focused only on specific types of exercises, such as resistance training (Huang et al., 2022), chronic exercise interventions (Ludyga et al., 2020; Zhang et al., 2023), or acute exercise interventions (Blomstrand & Engvall, 2021). Further, the inclusion of a variety of study designs in these reviews, such as randomized controlled trials, non-randomized controlled trials, and crossover designs, complicate conclusions (Blomstrand & Engvall, 2021; Haverkamp et al., 2020; Huang et al., 2022; Ludyga et al., 2023).

A comprehensive review of randomized controlled studies that examined effects of exercise, including varying types, intensities, durations, and frequencies, on EFs specifically with young adults has yet to be conducted. Hence, in the current review, we summarize and

interpret existing evidence on the effects of exercise on EF among non-clinical and nonspecialized populations of young adults. The findings address gaps in understanding how various aspects of exercise might influence EFs during a developmental period characterized by both peak cognitive performance and unique demands on EF.

2.2.1 Executive Functions in Young Adults

Executive functions refer to the ability to regulate one's thoughts, feelings and actions to achieve desired outcomes (Duckworth et al., 2019). Miyake and colleagues' (2000; see also Diamond, 2013) widely accepted conceptualization indicates that EFs comprise three interrelated core functions: working memory (or updating, the ability to retain and manipulate information in the mind), inhibitory control (the ability to resist temptation and impulsive reactions), and cognitive flexibility (or shifting, the ability to change perspectives and approaches to adjust to new demands). In the current review, we also consider planning, a more complex EF that has a pivotal role in daily activities, including participation in exercise (Diamond, 2013; Ferguson et al., 2021). Planning involves identifying goals and devising as well as executing the steps necessary to achieve those goals (Diamond, 2013). While planning is categorized as a component of EF, it often relies on the integration of the core EFs, such as inhibitory control and working memory, to ensure successful outcomes (Diamond, 2013). Including planning allows for a deeper understanding of how complex skills interact with core EF components.

Executive functions are particularly important for young adults, as they navigate critical developmental transitions, such as pursuing higher education, establishing careers, and managing increasing independence and responsibilities (Othman et al., 2019). Young adults with

poor EFs are more likely to engage in risky behaviours, including harmful substance use (Flexon et al., 2016) and unhealthy diets (Allan et al., 2016), whereas those with more advanced EFs are more likely to engage in health-promoting behaviours (Hall et al., 2008; McGrath et al., 2021). For example, Hall and colleagues (2008) demonstrated that young adults' EFs are crucial for translating health intentions into behaviours, such as engaging in physical activity and maintaining a healthy diet.

Despite their relative optimization during young adulthood, EFs can be further enhanced through modifiable behaviours such as physical exercise (Ferguson et al., 2021). However, research examining the effects of exercise on EFs in young adults is limited compared to the extensive focus on children and older adults (Cox et al., 2016; Ludyga et al., 2023). This may be overlooking a critical developmental window characterized by high baseline cognitive performance, ongoing pre-frontal maturation, and elevated stress and cognitive load due to the academic, occupational, and psychosocial demands of transitioning to adulthood (Cleary et al., 2011; Othman et al., 2019). These factors may make young adults particularly responsive to exercise, with the potential for both immediate and sustained cognitive benefits. For example, young adults may respond more rapidly to EF-enhancing interventions than older adults, whose neural plasticity is more limited. Unlike children, young adults may also be better equipped to apply gains across complex, real-world demands. A clearer understanding of these effects is essential to guide age-appropriate, evidence-based interventions. Alternatively, given that young adults are at their peak lifetime EF performance, they could benefit less given that they have less room for improvement. Previous research on EF training has shown that individuals with lower baseline EF abilities

gain the most from intervention (see Karbach & Kray, 2020, for further discussion). Thus, benefits of exercise in young adults could be limited or only temporary, improving only due to short-term effects on the brain (e.g., increased blood flow).

2.2.2 Effects of Exercise on Executive Functions

Exercise, which is defined as planned, structured physical activity that maintains or improves physical fitness (Caspersen et al., 1985), is a promising intervention as it can be tailored to meet individual needs and abilities across populations and cultures (Sallis et al., 2016). Both single-session exercise (also referred to as acute exercise) and multi-session exercise (also referred to as chronic exercise) have been effective at improving EFs among young adults (Festa et al., 2023). Mechanisms suggested to underlie the effectiveness of exercise for EF improvement include increased cerebral blood flow, increased secretion of brain-derived neurotrophic factor, and over time, improved white matter integrity and preservation of brain volume (Festa et al., 2023; Umegaki et al., 2021). This topic has sparked considerable interest in understanding how different aspects of exercise, such as type, intensity, duration, and frequency, affect EFs. Thus, a comprehensive understanding of the relationship between these factors for young adults is an important next step.

Research exploring the effects of exercise on EFs underscores the complexity of this relationship, with potential variations in type, intensity, duration, and frequency of exercise differentially influencing EFs. While prior research that includes young adults has investigated these variables, most studies have narrowly focused on one aspect of exercise (e.g., intensity, type) within a broad age range (Moreau & Chou, 2019; Zhang et al., 2023). Guidelines from the American College of Sports Medicine emphasizes the importance of simultaneously considering

multiple aspects of exercise variables when designing exercise prescriptions to optimize cognitive health (Piercy et al., 2018). Zhang and colleagues (2023) aimed to address this gap by investigating multiple aspects of chronic exercise interventions. However, the breadth of their focus on various cognitive outcomes did not allow for an in-depth analysis of findings specific to EFs, and the effects of acute exercise interventions were not included. Additionally, only six adult studies, categorized with an age range of 18–60, were included, making it challenging to draw specific conclusions for young adults.

Most prior research suggests that moderate-to-high intensity exercise results in greater cognitive benefits compared to low-intensity exercise among adults (Festa et al., 2023; Huang et al., 2022; Zhang et al., 2023). For example, Festa and colleagues' (2023) review demonstrated that moderate-to-high intensity acute exercise was superior to low-to-moderate intensity acute exercise for adults. Huang and colleagues (2022) and Zhang and colleagues (2023) reported that moderate-intensity acute and chronic exercise most consistently lead to EF improvements compared to low and high intensities. Dose-response studies have reflected an inverted-U shaped relationship between acute exercise and cognitive performance, with peak performance at moderate intensity (Chang et al., 2009; Huang et al., 2022). However, not all findings are consistent (Ludyga et al., 2020; Moreau & Chou, 2019), reflecting the importance of considering other aspects, such as duration and frequency of exercise. Notably, cognitive benefits have been observed following moderate-to-high intensity sessions as brief as 20 min (Festa et al., 2023) and durations around 2 hours have resulted in detrimental impacts on EF in young adults (Lambourne & Tomporowski, 2010). In chronic exercise interventions, Zhang et al. (2023) found the greatest benefits for moderate-intensity exercise performed 3–4 times per week for 45–60

min per session over 3–6 months, though these findings primarily reflect effects for older populations and require replication in young adults.

Various types of exercise, including aerobic training, resistance training, mind-body exercise, and martial arts have demonstrated effectiveness in enhancing EFs in different populations, though there is ongoing debate about the type of exercise that is most beneficial (Diamond & Ling, 2016, 2019; Hillman et al., 2018). It is generally suggested that, beyond motor movement, other components of exercise, such as mindfulness (Diamond & Ling, 2016, 2019) and coordination (Ludyga et al., 2020) are also important. Comparing different exercise types among adults of all ages, evidence for EF benefits following aerobic exercise (i.e., requires large muscles to move rhythmically for a sustained period) is most consistent, whereas a few findings suggest that coordination exercises (i.e., that aim to improve fine- and gross-motor body coordination) are more effective (Ludyga et al., 2020; 2023; Zhang et al., 2023).

In addition to the aspects of exercise, the method and timing of EF assessment can significantly influence the observed outcomes of exercise interventions. While some researchers propose that exercise enhances cognition and EFs globally (Zhang et al., 2023), others suggest its effects may vary across specific EF components (Huang et al., 2022). Moreover, the timing of EF measurement, whether during exercise, immediately after, or following a delay, has been shown to yield differing results in adults (Lambourne & Tomporowski, 2010; Moreau & Chou, 2019). In an earlier review, Lambourne & Tomporowski (2010) highlighted that acute exercise consistently improves EF immediately post-exercise, whereas measuring EF during exercise often results in detrimental outcomes among young adults. Longer-term improvements associated with chronic exercise interventions have been consistently documented in older

adults (Festa et al., 2023; Zhang et al., 2023).

2.2.3 Current Study

Given the limited understanding of how different aspects of exercise relate to EFs among young adults, the objective of this systematic review of randomized controlled studies was to summarize and interpret the effects of different exercise interventions, compared to other exercise interventions or control groups, on EFs in non-clinical populations of young adults (aged 18-30). Synthesizing the effects of different types, intensities, durations, and frequencies of exercise interventions on EF during a critical developmental window will contribute to a more comprehensive understanding of the interplay between exercise and EFs in young adults. Findings are expected to inform the development of cost-effective exercise interventions to improve EF outcomes for non-clinical, non-specialized young adult populations.

2.3 Method

The current systematic review was completed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021).

2.3.1 Eligibility Criteria

Eligibility criteria included that the study: i) was published in English, ii) was peer-reviewed, iii) examined the effects of an exercise intervention on EF, iv) was a randomized control trial, v) compared the exercise intervention to another form of exercise or a control group not expected to improve EF (e.g., resting control, casual reading), vi) measured EF (e.g., complex attention, working memory, cognitive flexibility, inhibitory control, planning) with neurocognitive tasks (e.g., Stroop task, Tower of London, Digit Span), vii) included participants

aged 18-30, and viii) included participants who were not defined by a clinical or other specialized characteristic (e.g., professional athletes), with the exception of being students. Studies were excluded if they: i) involved a clinical or other particular population, ii) only included individuals younger than 18 or older than 30, or the mean age of participants was not between 18 and 30, iii) only had a comparison group involving an activity expected to improve EF outcomes (e.g., cognitive training), and iv) only measured applied EF skills (i.e., risk-taking, emotion regulation, delayed gratification).

2.3.2 Information Sources and Search Strategy

The following six databases were selected for the search: CINAHL, Embase, PsycInfo, Pubmed, Scopus, and SPORTDiscus. These databases were selected to cover a broad range of disciplines including psychology, life and behavioural sciences, medicine, psychiatry, recreation, and the psychology of sport. To identify potentially relevant studies, a title, abstract, keyword (if applicable), and index (if applicable) search was completed on June 11, 2023. The search terms aimed to identify studies capturing exercise interventions, EF, and randomized controlled trials (see Table 2.1). Exclusionary terms specifically related to common disorders, older adults, and children were searched for only in titles to help omit likely irrelevant studies. Terms were selected based on previous reviews of similar topics, guidance from university Librarians, and findings from a pilot review conducted to refine search strategies and ensure comprehensive coverage of relevant studies. The specific search terms formatted for each database are shown in Appendix A. Articles identified with the search were imported into Covidence, an online review software (Veritas Health Innovation, 2022).

2.3.3 Selection Process

Seven reviewers (L.A., Z.B., V.F., M.G., V.K., J.L., N.S.) independently screened titles and abstracts in Covidence. A tagging system was used to indicate the relevancy of each study. Tags indicated if the study was published in English, if exercise was the predictor, if EF was the outcome, the study design (i.e., intervention, randomized control trial, meta-analysis, review, correlational, longitudinal, proposal), sample characteristics (i.e., clinical, non-clinical, age group), and if the comparison/control group was appropriate. Full texts were reviewed independently by two reviewers (J.L., V.K). All titles, abstracts, and full texts were double reviewed, and discrepancies were resolved through discussion. Agreement between reviewers for title/abstract screening was 95% and full-text screening was 96%. Cohen's Kappa was .83 for abstract screening and .92 for full-text screening, which are considered "Strong" and "Almost Perfect", respectively (McHugh, 2012).

Data were extracted for included studies in Microsoft Excel (Microsoft Corporation, 2024) using a spreadsheet adapted from the Cochrane Handbook for Systematic Reviews of Interventions Template (Higgins et al., 2022). Information extracted included study characteristics, participant demographics, intervention characteristics, control and comparison group characteristics, EF measures, and relevant study results. Data extraction for five articles was conducted independently by two authors (V.K., J.L.) and subsequently compared to ensure consistency. The remaining data extraction was completed by one author (V.K.) and reviewed by the first author (J.L.).

2.3.4 Methodological Quality Assessment

The methodological quality of the included studies was assessed using the Checklist for

Assessing the Quality of Quantitative Studies (Kmet et al., 2004). This checklist evaluates 15 categories of methodological rigour, including aspects such as study design, sample size justification, outcome measure validity, statistical analysis, and adequate reporting of results. Each category was scored on a three-point scale: 2 for full compliance (criteria fully met), 1 for partial compliance (criteria partially met), and 0 for non-compliance (criteria not met). Two independent reviewers (J.L. and V.K.) assessed each study, and the mean score for each study was calculated to ensure reliability. Quality ratings are presented in Tables 2.2 and 2.3.

2.3.5 Data Charting

The information extracted from the articles were summarized in results synthesis tables, which include the following information: author(s), year of publication, country, sample size, participants' age and sex/gender, intervention characteristics (intensity, frequency, and duration), EFs assessed and how they were measured, results relevant to our review, and the quality assessment score. Significant group x time statistics were also included. Single session and multi-session interventions were summarized separately.

2.4 Results

2.4.1 Study Selection

The PRISMA diagram for the process of identifying eligible studies is depicted in Figure 2.1. The search resulted in 7452 articles. After 3593 duplicates were removed, 3859 titles and abstracts were screened and 3727 were excluded. Of the 132 full-text articles sought for retrieval, 18 were not retrieved as they were conference presentation abstracts without an identifiable corresponding peer-reviewed article (*n* = 4), a brief synopsis (*n* = 1), and articles that did not have an available full-text in English (*n* = 13). Thus, 114 full-text articles were assessed

for eligibility and 43 articles were included in the systematic review, which involved 44 studies. Articles were excluded during the full text review for the following reasons: exercise was not measured or was not the predictor (*n* =16), EFs were not measured or were not the outcome (*n* = 6), non-randomized or within subjects design (*n* = 20), mean age was not 18-30 (*n* = 11), sample characteristics (e.g., clinical population, elite athletes; *n* = 11), ineligible comparison group (*n* = 4), the article was not peer reviewed (*n* = 1), the full text was not published in English (*n* = 1), there was a duplicate dataset/results in an included article (*n* = 1).

2.4.2 Study Characteristics

The characteristics of included studies are summarized in Tables 2.2 and 2.3. The studies were published between 2009 and 2023 across Australia, Canada, China, France, Germany, India, Israel, Italy, Japan, Republic of Korea, South Korea, Taiwan, and USA. Collectively, they involve a total of 3,124 participants aged 18-39, with a mean age typically in the early 20s. Most studies (*n* = 37) explicitly identified their participants as university or college students; the remaining studies (*n* = 6) did not specify whether their participants were students or belonged to another population. Study quality ranged from .80 – 1.00, reflecting good methodological quality overall.

Most studies involved single exercise sessions (*n* = 35) and few involved multi-session interventions (*n* = 9). Exercise intensity was commonly categorized by researchers as high, vigorous, moderate, light, or low. For consistency, we labelled high and vigorous intensity as "high" intensity and low and light intensity as "low" intensity. When exercise intensity was not labeled, we categorized it as high, moderate, or low based on available heart rate and Ratings of Perceived Exertion (RPE) data following the widely accepted American College of Sports

Medicine's Guidelines for Exercise Testing and Prescription (2020). We labelled Kim (2015) as Moderate-High intensity and labelled Sudo et al. (2017) as High intensity. Thomas & D (2017) did not state anything about intensity and Jaffrey et al. (2018) stated "self-selected intensity" and thus, we did not categorize intensity for these studies.

2.4.3 Single-Session Intervention Outcomes

Results of 35 single-session intervention studies are summarized in Table 2.2. Exercise session duration ranged from 5–60 min. Three studies (Brown & Bray, 2015; Chang et al., 2017; Chang & Etnier, 2009) provided number of repetitions and sets of resistance exercise rather than duration. A range of aerobic and resistance exercise interventions were employed: active video gaming (*n* = 1), resistance training (*n* = 4), handgrip exercise (*n* = 3), high-intensity functional training (*n* = 1), stationary cycling (*n* = 18), treadmill exercise (*n* = 9), stepping exercise (*n* = 1), trail jogging (*n* = 1). Intensity, when reported, was primarily moderate and/or high: high (*n* = 20), moderate-high (*n* = 3), moderate (*n* = 20), low (*n* = 8), self-selected intensity (*n* = 1).

EF outcomes included the following performance-based measures: Attention Network Test (*n* = 1), Corsi Block Test (*n* = 1), Controlled Oral Word Association Test (*n* = 1), Delayed Match-to-Sample Memory Task (*n* = 1), Delayed Response Task (*n* = 1), Digit Span (*n* = 3), Dynavision Working Memory Task (*n* = 1), Feature Match (*n* = 1), Flanker (*n* = 3), Go/No-Go (*n* = 3), Grammatical Reasoning (*n* = 1), HVLT-R (*n* = 2), Iowa Gambling Task (*n* = 1), Modified Benton Visual Retention Test (*n* = 1), Non-Verbal Memory Test (*n* = 1), Oral Trails B (*n* = 1), Paced Auditory Serial Addition Test (*n* = 1), Phonemic Fluency (*n* = 1), Polygon (*n* = 1), Psychomotor Vigilance Task (*n* = 1), Semantic Fluency (*n* = 1), SDMT (*n* = 1), Spatial Span (*n* = 2), Spatial Slider (*n* = 1), Stroop (*n* = 17), Trail-Making Test (*n* = 11), Tower of London (*n* = 4), Visual Discrimination

Test (*n* = 1), Wisconsin Card Sorting Test (*n* = 2). EF was primarily assessed pre- and post-intervention (*n* = 32). Few studies assessed EF during exercise (*n* = 2) or post-intervention only (*n* = 1). Post-intervention assessments were conducted: immediately (*n* = 9), with a 30s –5 min delay (*n* = 9), with a 6–15 min delay (*n* = 8), with a delay greater than 15 min (*n* = 4), or when heart rate returned to a specified level (*n* = 4). Three studies did not specify when the assessments were completed (Chang & Etnier, 2009; Douris et al., 2018; Elkana et al., 2018).

Several studies (*n* = 23) noted improvements in at least one EF domain after the exercise intervention with medium-to-large effect sizes when reported. Some studies noted no effects (*n* = 9) and a few noted a decrement in EF (*n* = 3). Aerobic (e.g., treadmill exercise, stationary cycling) and resistance exercise (e.g., weight training) at moderate intensity were most consistently effective. The one study investigating active video gaming noted improvements in working memory (Hwang & Lu, 2018). Handgrip exercise yielded inconsistent results, with Razon et al. (2019) noting improved cognitive flexibility for high intensity handgrip exercise in one study and no effects in their second study, whereas Brown and Bray (2015) noted a decrement in inhibitory control for high intensity handgrip exercise.

Low intensity exercise tended not to affect EF, even after 60 min (Larson et al., 2015), and when compared to moderate and high intensity exercise, moderate/high intensities were more impactful (Chang & Etnier, 2009; Loprinzi & Kane, 2015; Su et al., 2022). Moderate and moderate-high intensities were most consistently effective at enhancing EF, including measures of inhibitory control, cognitive flexibility, working memory, and planning (Aly & Kojima, 2020; Brown & Bray, 2018; Chang et al., 2011, 2017; Chang & Etnier, 2009; Douris et al., 2018; Elkana et al., 2018, 2022; Hwang & Lu, 2018; Hung et al., 2013; Loprinzi & Kane, 2015; Su et al., 2022;

Wilke et al., 2020). Although high intensity exercise often resulted in significant EF improvements (Aguirre-Loaiza et al., 2022; Basso et al., 2015; Hwang et al., 2016; Khandekar et al., 2022; Tsai et al., 2014; Murray & Russoniello, 2012, Wilke, 2020), some studies reported that it led to decrements (Brown & Bray, 2015; Moore et al., 2012; Wang et al., 2013).

Benefits in EF were observed across durations, from 5–60 min. Two 60-min exercise studies (Moore et al., 2012; Larson et al., 2015) did not improve working memory or inhibitory control. However, when comparing different exercise durations, Crush and Loprinzi (2017) reported that 60 min of treadmill exercise yielded greater working memory improvement compared to shorter intervention times. One study noted that a 5 min exercise intervention resulted in improved cognitive flexibility (Jaffrey et al., 2018).

Moreover, there is some evidence that the timing of EF assessment in relation to exercise completion may moderate effects. That is, EF assessment during exercise resulted in no effect for inhibitory control (Larson et al., 2015) and a decrement in cognitive flexibility (Wang et al., 2013), respectively. In contrast, most studies found improvements in EF immediately after and at various intervals up to 120 min post-session (e.g., Basso et al., 2015; Murray & Russoniello, 2012). However, studies that directly compared length of delay periods before EF assessments following exercise generally found that the duration of the delay period did not affect EF results (Basso et al., 2015; Brown & Bray, 2018; Moore et al., 2012; Razon et al., 2019 Study 2). In their comparison, Hung et al. (2013) noted that planning accuracy improved only immediately following exercise, whereas planning response time improved only at 30- and 60-min following exercise. This pattern was not evident in other studies.

2.4.4 Multi-Session Intervention Outcomes

Results of the 9 multi-session intervention studies are summarized in Table 2.3. Interventions ranged from 4-12 weeks in duration and involved 3-5 sessions weekly. Each session duration ranged from 8 min to 85 min, with a total duration of 228–3,400 min. One study (Thomas & D, 2017) provided number of repetitions and sets of yoga poses rather than duration. Intervention types included aerobic, mind-body, and martial arts activities: high-intensity interval training (*n* = 3), continuous training (*n* = 1), stationary cycling (*n* = 1), Taekwondo (*n* = 1), Tai Chi (*n* = 2), walking (*n* = 1), mixed exercise (i.e., sports, games, running, *n* = 1), and Superbrain yoga (*n* = 1). Intensity, when reported, was Moderate and/or High: High (*n* = 3), Moderate (*n* = 5), Moderate-High (*n* = 1). EF outcomes included the following measures: Flanker (*n* = 3), N-back (*n* = 1), Visual 2-back (*n* = 1), Stroop (*n* = 1), Trail Making Task (*n* = 2), working memory span measures (*n* = 1). EF was assessed pre- and post- intervention in all studies, and Thomas & D (2017) also assessed N-back performance during each week of the intervention.

Across studies, improvements were observed in EF measures, including inhibitory control, cognitive flexibility, and working memory when reported. However, Kim (2015) reported improvements in Stroop control conditions, but not the inhibitory control condition. The other studies collectively indicated the beneficial effects of different exercise types at moderate-high intensity on EF. High-intensity interval training and moderate intensity continuous training led to improved cognitive flexibility (Eather et al., 2019; Liu et al., 2023). Tai Chi, mixed exercise (i.e., sports, games, running), and stationary cycling led to improved inhibitory control (Shen et al., 2021; Zhu et al., 2021a, 2021b). High intensity interval training,

Superbrain yoga, and Tai Chi led to improved working memory accuracy (May et al., 2017; Thomas & D, 2017; Wang et al., 2023). Of note, there were no reports of improved inhibitory control or cognitive flexibility accuracy; only response time improvements were reported.

Benefits in EF were observed across durations, from 8–60 min with frequencies of 3–5 sessions/week. The most demanding intervention, which involved 85 min sessions 5 times/week was the only intervention that did not lead to EF improvement (Kim, 2015).

Some studies highlighted nuances in the relationships between different aspects of exercise and EF outcomes. For instance, Liu et al. (2023) found that cognitive flexibility improved after moderate-intensity exercise, but not high-intensity exercise. When comparing types of exercise, martial arts was more effective than continuous aerobic exercise (Shen et al., 2021) or sports (Wang et al., 2023) in enhancing EF. Similarly, Thomas and D (2017) noted that yoga was more effective than simple squats at enhancing working memory. Thomas and D (2017) uniquely assessed EF weekly during a yoga intervention, capturing both early and sustained improvements.

2.4.5 Summary of Results for Single- and Multi-Session Interventions

Both single- and multi-session interventions resulted in demonstrated benefits for performance-based EF, particularly if the intervention involved moderate-to-high intensity exercise. Low-intensity exercise, in contrast, rarely yielded significant EF benefits, even when conducted for extended durations, such as 60 min. Aerobic and resistance exercise were most often studied and generally led to EF improvements, though other types of exercise, such as active video gaming, yoga, and martial arts also demonstrated effectiveness in enhancing EF. Improvements were observed across a range of durations (5–60 min), although there was

limited evidence for the very short durations (i.e., 5 and 8 min) and longer sessions (i.e., 60 min) were only effective when performed at moderate intensity. Effects following single-session exercise were observed for up to 120 min after the intervention, while most multi-session interventions showed improvements from baseline to post-intervention, with one study reporting cumulative benefits over time. Conversely, EF assessments conducted during exercise itself – examined in a couple of studies – resulted in no effects or decrements.

2.5 Discussion

The objective of this systematic review was to synthesize and interpret the effects of various exercise interventions—differing in frequency, intensity, duration, and type—on EFs in non-clinical young adult populations in randomized control trials. The findings highlight the potential of exercise as a modifiable behaviour to support EF enhancement during young adulthood, a period characterized by peak cognitive performance and unique demands on EFs. Gaps in the existing literature were also underscored, such as the sustainability of EF improvements, and the cumulative effects of chronic exercise interventions on EFs.

2.5.1 Key Findings

The reviewed acute and chronic exercise intervention studies collectively demonstrate that exercise can positively influence all aspects of EFs in young adults, with intensity, duration, and type emerging as important aspects of exercise to consider. The effects of these variables appeared to be similar across both acute and chronic interventions.

Specifically, across acute and chronic exercise interventions, moderate-intensity exercise was consistently associated with the greatest EF improvements, aligning with previous findings of an inverted-U relationship between exercise intensity and cognitive performance (Chang et

al., 2009; Huang et al., 2022; Sudo et al., 2022). This relationship suggests that while moderate arousal from exercise appears to optimize EF performance, low- or high-intensity exercise may not be within the optimal zone for cognitive enhancement (Huang et al., 2022; Sudo et al., 2022). Moderate-intensity exercise has been hypothesized to optimize EF performance by enhancing arousal and promoting the release of dopamine and norepinephrine, which are essential for prefrontal cortex functioning, and BDNF, which promotes neuroplasticity (McMorris, 2016; Sudo et al., 2022). In contrast, low-intensity exercise may not sufficiently stimulate these processes, while high-intensity exercise can induce excessive arousal or fatigue, disrupting prefrontal cortex activity and impairing EF performance (Chang & Etnier, 2009; Sudo et al., 2022).

In terms of exercise duration, beneficial effects were most consistently observed across a range of durations from 5–50 min. A couple of interventions with an exercise duration of less than 10 min (Eather et al., 2019; Jaffrey et al., 2018) noted improved cognitive flexibility. However, improvements were not consistently seen with sessions of 60 min or greater (Kim, 2015; Larson et al., 2015; Moore et al., 2012). The observed relationship between duration and EF performance may mirror the inverted-U pattern suspected regarding exercise intensity, suggesting that an optimal duration exists beyond which additional exercise time may not necessarily enhance EFs. Previous research has emphasized the importance of considering the intersection between intensity and duration (Sudo et al., 2022), and the 60-min interventions in this review supported this notion, with benefits reported only at moderate intensity. However, this pattern was not consistently observed in the results of the current review, which may be attributable to the heterogeneity of intervention methods and EF assessment

procedures. The absence of studies directly comparing varying intensities and durations makes it complicated to identify such patterns.

Aerobic and resistance exercise emerged as the most consistently effective type for enhancing EFs, which may partially be reflective of their frequent use in intervention studies. Alternative types of exercise, such as active video gaming, yoga, and martial arts, also demonstrated EF benefits. Notably, studies comparing exercise types revealed that martial arts were more effective than continuous aerobic exercise (Shen et al., 2021) and sports (Wang et al., 2023) in improving EF, while yoga outperformed simple squats in enhancing working memory (Thomas & D, 2017). These findings align with prior research suggesting that aerobic exercise consistently results in EF improvements in adults but that exercise components that go beyond motor movement, such as mindfulness (Diamond & Ling, 2016, 2019) and coordination (Ludyga et al., 2020), may be even more effective. Still, the present evidence suggests that various types of exercise are effective in enhancing EFs. Therefore, tailoring interventions to individual needs and preferences may be most important.

We did not find evidence that specific EFs were more affected by exercise than others, which aligns with prior research suggesting that exercise enhances EFs globally (Zhang et al., 2023). However, the timing of EF assessment following exercise may be a key factor influencing study findings. In the present review, effects of single-session exercise on EF were observed up to 120 min post-intervention, while most multi-session interventions showed improvements from baseline to post-intervention. In contrast, studies that assessed EF during exercise itself found no effects or even decrements in performance, potentially due to neurobiological factors such as central fatigue, altered arousal states, and dual-tasking (Sudo et al., 2022). These

findings suggest that the cognitive benefits of exercise are most prominent shortly after the exercise.

Researchers have previously recommended moderate-intensity exercise performed 3–4 times per week for 45–60 min per session over a period of 3–6 months as particularly beneficial for adults' cognitive health, primarily based on evidence from older adult populations (Zhang et al., 2023). The findings of the current review do not contradict these recommendations, though suggest that young adults may not require the same frequency or duration to experience EF benefits. This could reflect greater neurocognitive responsiveness to exercise among young adults compared to other age groups. Alternatively, it could reflect methodological constraints related to a sampling bias, as most studies recruited university students for whom single-session protocols may be more feasible. Regardless, the observation that EF benefits emerge immediately following exercise in young adults highlights the potential utility of single-session interventions in this population.

2.5.2 Strengths and Limitations of the Evidence

The evidence reviewed provides valuable insights for understanding the relationship between exercise and EFs in young adults, addressing a gap in the literature dominated by research on children and older adults. The included studies employed randomized controlled trial designs with good methodological quality to assess the effects of both acute and chronic exercise on EFs. The use of diverse exercise protocols and a range of performance-based EF measures contributed to the generalizability of the findings, offering insights into how different exercise modalities, intensities, and durations might influence EFs.

The heterogeneity in study designs, including variations in exercise protocols and EF

assessments, presents challenges for drawing definitive conclusions. These variations limit the ability to generalize findings and obscure potential patterns in the effects of exercise on EFs. While we synthesized findings across a range of exercise variables, few studies systematically examined interactions between these factors, such as how type and intensity might jointly influence EF outcome.

Another limitation is the reliance on short-term outcomes in many studies, particularly for acute exercise interventions. While short-term EF improvements are certainly valuable, long-term impacts of exercise on EFs and their sustainability remain underexplored. For example, it is unclear whether the observed benefits translate into lasting enhancements in real-world cognitive functioning, such as academic or professional performance. Further, most multi-session interventions assessed EF only pre- and post-intervention, making it unclear whether the observed improvements were due to the final session of the intervention or cumulative effects of multiple sessions. One study found evidence of cumulative benefits and concluded that the benefits of yoga for working memory build over time (Thomas & D, 2017). The lack of follow-up assessments conducted even a single day post-intervention limits conclusions about whether these effects extend beyond the immediate physiological responses to exercise. Further research is needed to explore how long the effects persist and whether longer-term exercise leads to longer-term EF benefits to inform practical recommendations.

Although we did not restrict the kind of exercise interventions assessed, nor the kind of EFs cognitive measures examined as outcomes, we did not include self-reported measures of EFs to avoid the potential for biased reporting. However, self-reported EF measures uniquely capture how EFs are used in applied settings and may assess complimentary aspects of EFs

(Friedman & Gustavson, 2022). Notably, self-reported and performance-based EF measures only weakly correlate (Dube et al., 2022; Friedman & Gustavson, 2022; Toplak et al., 2013), highlighting their distinct contributions. Of relevance, self-reported assessments of EFs in young adults are associated with better health behaviours (McGrath et al., 2021) and more effective self-management during critical life transitions (Gutierrez-Colina et al., 2020). While limited research in specific populations, such as breast cancer survivors (Hartman et al., 2018), has shown improvements in self-reported cognition following exercise interventions, the effects of exercise on self-reported EFs in young adults remain unexplored. This represents a critical gap in understanding the broader, real-world implications of exercise-related EF improvements.

2.5.3 Practical Implications

The findings of this review highlight multiple practical strategies for promoting cognitive health in young adults through exercise. Moderate-intensity exercise stands out as an accessible and cost-effective method, with EF enhancements emerging shortly after activity. Various types of exercise have been shown to have cognitive benefit, so tailoring interventions to individual needs and preferences may be most important. Given the rapid EF benefits, engaging in moderate exercise shortly before cognitively demanding tasks, such as academic work or complex decision-making, may be especially beneficial for young adults. For educators, institutions, and workplaces, integrating bouts of exercise into young adults' daily routines could enhance cognitive performance, supporting both academic success and workplace productivity while also promoting physical health.

2.5.4 Future Directions

A key area for further investigation is disentangling the interactions between exercise

variables, such as type, intensity, duration, and frequency, to provide more nuanced insights into how these factors jointly influence EF outcomes. Further research directly comparing diverse exercise modalities is warranted to better understand how specific components, such as mindfulness and coordination, contribute to EF enhancement and to identify optimal strategies for various populations, which will guide more personalized exercise recommendations.

Given the unclear duration of exercise-induced effects, future research should explore the persistence of cognitive improvements after exercise, particularly in relation to applied tasks requiring sustained mental effort, such as exams. They should also incorporate self-reported EF measures. Longitudinal studies and studies examining exercise in real-world contexts would be valuable in determining the cumulative effects of chronic exercise interventions. Additionally, expanding the focus beyond structured exercise to include physical activity more broadly, may offer a more comprehensive understanding of how diverse movement behaviours relate to EFs. One promising direction is the development of naturalistic studies that examine how physical activity patterns influence EF over time in young adults, which could lay the groundwork for large-scale, long-term intervention studies.

The integration of psychosocial and psychological factors, such as mood, stress and sleep, was beyond the scope of this review. These factors could vary significantly across individuals and potentially moderate the observed effects of exercise on EFs (Diamond, 2013). For example, the Canadian 24-Hour Movement Guidelines for Children and Youth emphasize the importance of examining the relationships between physical activity and various other health indicators, such as sleep, when developing activity recommendations (Tremblay et al., 2016). Future research should aim to examine how covariates and individual differences interact

with exercise, as well as how they might relate to EF outcomes in different populations.

2.6 Conclusions

This systematic review highlights the potential of exercise as a modifiable behaviour to support EF development in young adults. By synthesizing findings from randomized controlled trials on the effects of various exercise interventions, this review contributes to a growing body of evidence supporting exercise as a cost-effective, accessible strategy for enhancing cognitive performance at least temporarily. Continued research in this area is essential to refine exercise recommendations and optimize interventions for young adults navigating critical developmental transitions.

2.7 Tables

Table 2.1

Keywords and Boolean Search Terms

Category	Key Terms
Exercise Intervention	Athletic Training, Physical Activity, Exercise, Physical Fitness, Physical Endurance, Sports, Aerobic Exercise, Martial Arts, Yoga, Physical Performance, Resistance, Exergame, Acute, Bout, Intervention, Training, Program, Session, Effect
EF Outcomes	Cognitive Control, Cognitive Flexibility, Executive Function, Executive Functioning Measures, Response Inhibition, Set Shift, Selective Attention, Sustained Attention, Digit Span Testing, Verbal Fluency, Stroop Effect, Stroop Colour Word Test, Wisconsin Card Sorting Test (WCST), Attention Shift, Attention Switch, Cognitive Inhibition, Executive Attention, Inhibitory Control, Mental Flexibility, Set Switch, Sustain Attention, Task Shift, Task Switch, Working Memory, Cambridge Neuropsychological Test Automated Battery, Delis Kaplan, Design Fluency, Digit Span, D-KEFS, Flanker, Go/No-Go, Interference Control, N-back, Paced Auditory Serial Addition Test (PASAT), Ruff Figural Fluency Test, Stop Signal Task, Stroop, Tower of Hanoi, Tower of London, Trail Making, Verbal Fluency, Word Span, Word Fluency
Randomized Control Trials	Between Groups Design, Clinical Trial, Experimental Design, Randomized Clinical Trials, Randomized Controlled Trials, Random Sampling, Between Groups, Between Subjects, Experimental (Design, Study, Method, Trial), Controlled (Design, Study, Method, Trial), Double Blind, Single Blind, Random, Comparison, Control Group
"NOT" terms	Alzheimer, Attention Deficit Hyperactivity Disorder (ADHD), Attention Deficit Disorder (ADD), Autism, ASD, Dementia, Diabetes, Down Syndrome, Multiple Sclerosis, Obesity, Obese, Parkinson, Schizophrenia, Children, Childhood, Preschool, Elementary, Elderly, Older Adult, Elder Adult

Note. EF = executive function. Proximity terms were used (if applicable) in the search and are shown with the search formatted for each database in Appendix A.

Table 2.2

Summary of Results for Single-Session Exercise Interventions

Participant Characteristics			Intervention Components				Results		
Authors, Country	**Overall sample size *(n)* (IG: *n*, CG: *n*)**	***Mage ± SD* (y) (range), Sex/Gender (%M)**	**Exercise type (control)**	**Exercise duration (min)**	**Intensity (intensity measure)**	**EF outcome measures (when they were measured)**	**Summary of relevant results**	**EF skillset affected by exercise over time**	**Study quality**
Aguirre-Loaiza et al. (2022), Colombia	19 (IG: 9, CG: 10)	23.3 ± 1.6 (20-39), 79%M	Stationary Cycling (Waitlist)	20 min	High (90% HRmax)	Stroop (Pre/Post; once HR at rest was reached, ranged between 9 and 15 min)	**Stroop-A:** Stroop-A (RT, accuracy, error scores) x Time interaction ($F(1,18) = 2.08$, $p = .035$, $\eta p^2 = 0.230$). IG RT decreased from pre-test ($M = 88.0$, $SD = 20.8$) to post-test ($M = 71.8$, $SD = 17.7$) ($p = .016$, 95% CI [3–7]). **Stroop-B:** Stroop-B (RT, accuracy, error scores) x Time interaction ($F(1.5, 25.5) = 846.9$, $p < .000$, $\eta p^2 = 0.980$). IG RT decreased post-exercise ($p < .001$, 95% CI [-83.4, -80.3]), accuracy increased ($p < .002$, 95% CI [-29.5, -7.82]), and error rate increased ($p < .001$, 95% CI [52.7, 68.4]). CG error rate decreased ($p < .001$, 95% CI [59.1, 74.0]).	Improved IC for IG (RT only)	0.80
Aly & Kojima (2020), Japan	40 (IG: 20, CG: 20)	IG: 22.90 ± 2.40; CG: 23.10 ± 2.20 (19-25), 70%M	Stationary Cycling (Resting)	20 min	Moderate (60-70% HRmax)	Flanker (Pre/Post; once HR returned to within 10% of pre-exercise level)	**Flanker RT:** Main effect of trial type, with longer RTs on incongruent trials than congruent trials. Group x time interaction ($F(1, 38) = 9.17$, $p < .01$, $\eta p^2 = 0.19$). Post hoc analyses indicated RT decreased from pre- to post-test for IG ($p < .01$), but not for CG. IG had shorter RT than CG in post-test ($p < .05$), with no difference in pre-test. No time x trial type x group interaction. **Flanker Error Rate:** Main effect of trial type, with higher error rate in incongruent vs. congruent trials. No other main effects or interactions for error rate.	Improved IC for IG (RT only)	0.87

						HVLT-R, Modified Benton Visual Retention Test, Stroop, SDMT, the Digit Span, Trail Making Test, and Controlled Oral Word Association Test (Pre/Post, either 30, 60, 90 or 120 min after session)			
Basso et al. (2015), USA	85 (IG: 43, CG: 42)	22.21 ± 0.45 (18 – 35), 40%M	Stationary Cycling (Video Watching)	50 min	High (85% of HRmax)	Composite score for PFC function: Stroop, SDMT, HVLT-R Total Recall, Digit Span, TMT Composite score for hippocampal function: HVLT-R Delayed Recall, Retention, and Recognition Discrimination Index, MBVRT	**PFC Composite Score:** Group x time Interaction ($F(1,77) = 10.890$, $p = .001$, $\eta p^2 = 0.124$). No differences between groups at pre-test; post hoc analyses indicated improvement over time for IG ($F(1,77) = 6.613$, $p = .012$, $\eta p^2 = 0.079$), but not for CG. IG had higher scores at post-test than CG (mean difference = 0.291, 95% CI [0.066, 0.516], $p = .012$). No time x delay period x group interaction. **Hippocampal Composite Score:** Main effect of time; scores decreased over time. Hippocampal functioning decreased over time for CG, not IG. No time x group interaction, no time x delay period x group interaction.	Improved IC, CF and some aspects of WM	0.87

Brown & Bray (2015), Canada	55 (Low Intensity IG: 14, Moderate Intensity IG: 13, High Intensity IG: 14, CG: 14)	20.58 ± 2.20 (Range NR), 39%M	Isometric Handgrip (Nominal Isometric Handgrip)	Maintained handgrip contraction for as long as possible	Low (30% max. voluntary contraction), Moderate (50% max. voluntary contraction), or High (70% max. voluntary contraction)	Stroop (Pre/Post; 1 minute after session)	**Effect of Exercise:** Main effect of time with improvement pre-post, no between- group differences. CG had greater improvement in error frequency (i.e., fewer errors) compared to IG at post-test ($F(3,51) = 3.42$, $p = .024$). Post-hoc comparisons indicated that the CG had fewer errors than both the High Intensity ($p = .003$, $d = 1.47$) and Low Intensity IGs ($p = 0.034$, $d = 0.77$). CG differed significantly from the High Intensity IG ($p = 0.014$, $d = 1.33$) in relative error frequency. No effect was found for response speed. **Intensity Effects:** Dose-response effect in error frequency, with a linear increase in errors with greater exercise intensity ($B = 0.11$, $SE = 0.04$, $F(1, 53) = 7.26$, $p = .009$, $R^2adj = .104$). Similarly, a linear relationship was observed for relative error frequency ($B = 0.03$, $SE = 0.02$, $F(1, 53) = 4.26$, $p = .044$, $R^2adj = .057$). No effect was for response speed.	Decrement in IC, particularly for High Intensity	0.83
Brown & Bray (2018), Canada	107 (High-Intensity Interval IG: 22, High Intensity Continuous IG: 22, Moderate-Intensity Continuous IG: 21, Very-Light Intensity Continuous IG: 22, CG: 20)	High-Intensity Interval: 19.95 ± 1.96, High Intensity Continuous: 19.68 ± 1.91, Moderate-Intensity Continuous: 20.14 ± 1.90, Very-Light Intensity Continuous: 19.45 ± 1.74, CG: 20.85 ± 1.66 (Range NR), 47%M	Stationary Cycling (Resting Control)	20 min	High-Intensity Interval (~80%–90% of HRmax during the high-intensity intervals), High-Intensity Continuous (~80-90% HRmax), Moderate-Intensity Continuous (65-75% HRmax), Very-Low Intensity Continuous (cadence of 60-90 RPM at a fixed workload of 10W)	Stroop (Pre/Post; immediately and 10 min after session)	**Stroop:** Main effect of time, with improvement over time. Pairwise comparisons revealed Moderate-Intensity Continuous IG had greater improvement than the Very-Light Intensity Continuous IG ($p = .05$). No other differences between groups were significant. Time × group interaction, improvements from Baseline to Post-0 for Moderate- and High-Intensity continuous IGs ($p < .01$), from Baseline to Post-10 in High-Intensity Interval IG, High, Moderate, and Very-Light Intensity Continuous IGs ($p < .05$), and from Post-0 to Post-10 in the Very-Light Intensity IG ($p < .01$). No differences were found from Baseline to Post-0 in the High-Intensity Interval IG, Very-Light Intensity, and CG, from Baseline to Post-10 in the CG, or from Post-0 to Post-10 in the High-Intensity Interval, Moderate-Intensity Continuous, High-Intensity Continuous IGs, and CG.	Improved IC, particularly for Moderate Intensity	0.87

Chang & Etnier (2009), Country NR	69 (Low Intensity IG: 16, Moderate Intensity IG: 16, High Intensity IG: 17, CG: 20)	25.95 ± 3.20 (Range NR), 51%M	Resistance Exercise (Watched a video on resistance training)	NR, 2 sets of 10 reps for each of six muscle groups with a rest period between sets and between exercises of 2-4 min	Low (40% of 10-repitition max.), Moderate (70% of 10-repitition max.), High (100% of 10-repitition max.)	Stroop, PASAT (Pre/Post)	**Stroop:** Stroop Colour completion time improved linearly with increasing intensity ($F(1, 62) = 3.72$, $p < .05$, $R^2 = 11\%$). Intensity predicted Stroop Colour-Word completion time quadratically ($F(1, 62) = 7.34$, $p < .001$, $R^2 = 19$). No effects for Stroop Word. No differences between groups pre-test. **PASAT:** Intensity predicted PASAT number of correct responses on trials 2, 3, and 4 quadratically (F (1, 62) = 7.06, $p < .01$). These results accounted for 23%, 35%, and 39% of the variance in PASAT scores, respectively. No effects for PASAT trial 1. No differences between groups pre-test.	Improved IC and WM, particularly for Moderate intensity	0.87
Chang et al. (2011), Taiwan	42 (IG: 20, CG: 22)	M: 22.26 ± 1.94, F: 21.97 ± 1.66, (Range NR), 31%M	Stationary Cycling (Reading about aerobic exercise)	20 min	Moderate-High (50–70% HRR)	TOL (Pre/Post, immediately after session)	Main effect of time for total move score with improvement pre-post; no main effect of group. Group × time interaction, simple effects indicated total move score decrease in IG ($F(1, 21) = 26.39$, $p < .01$, $R^2 = .58$), but no change for CG. Main effect of time for total correct score, no main effect of group, and group × time interaction with an increase in total correct score in the IG ($F(1, 19) = 48.06$, $p < .01$, $R^2 = .72$), but no change for the CG. Main effect of time for time violation score, indicating fewer violations at post-test. Main effects of time for task time-related variables (total initial time, total executive time, and total planning-solving time), with shorter times at post-test. No significant main effect of group or Group × Time interaction for these variables. No effects emerged for rule violation score.	Improved planning accuracy, no effect for RT	0.83

Chang et al. (2017), South Korea	36 (3 IGs & CG: 9)	High-Intensity Resistance IG: 21.1 ± 1.6, Moderate Intensity Combination IG: 20.4 ± 1.5, High-Intensity Aerobic: 22.1 ± 1.4, CG: 21.8 ± 1.4 (Range NR), 0%M	Resistance Exercise, Treadmill (Control NR)	High-intensity resistance exercise: 3 sets of 8-10 reps of 7 exercises, Moderate-intensity exercise combining resistance and walking: 30 min of treadmill walking & 12 reps of resistance training, High-intensity aerobic exercise: 30 min of treadmill running	High-intensity resistance exercise (80% 1 repetition maximum), Moderate-intensity exercise combining resistance and walking (resistance exercise performed at 30% 1RM, walking at 50–60% HRR). High-intensity aerobic exercise (80% HRR)	Stroop (Pre/Post, 10 min after session)	**Stroop Neutral Task:** Better accuracy in IGs compared to CG (0.33 ± 2.29). Significant improvements in High-Intensity Resistance (6.44 ± 5.59, $p < .01$) and Moderate Intensity Combination IGs (9.00 ± 3.20, $p < .01$) groups, while the High-Intensity Aerobic IG did not differ significantly from the CG. Pairwise comparison indicated that the Moderate Intensity Combination IG outperformed the High-Intensity Aerobic IG (4.22 ± 2.91, $p < .05$). Improvements in RTs for IGs compared to CG (-1 ± 47 ms), with reductions in the High-Intensity Resistance (-131 ± 90 ms, $p < .01$) and Moderate Intensity Combination IGs (-189 ± 74 ms, $p < .01$). The High-Intensity Aerobic group did not differ significantly from the CG, while RTs in the Moderate Intensity Combination IG were significantly shorter than in the High-Intensity Aerobic IG. **Stroop Incongruent Task:** Better accuracy in IGs compared to CG (1.44 ± 3.71), but only the Moderate Intensity Combination IG demonstrated a statistically significant increase (6.38 ± 3.07, $p < .01$). No difference in RTs in the High-Intensity Resistance or High-Intensity Aerobic IGs compared to CG. Moderate Intensity Combination IG had shorter RT than CG (-162 ± 92 ms, $p < .01$).	Improved IC, particularly for Moderate Intensity	0.83

Crush & Loprinzi (2017), USA	352 (15 IGs, 22 per IG & CG: 22)	15 IGs: 20.9 ± 2.9 – 22.5 ± 4.1, CG: 20.9 ± 1.3, 14%M (18-35), 14%M – 41%M	Treadmill	10, 20, 30, 45, or 60 min	Moderate (40-59% HRR)	TMT A & B, Spatial Span, Stroop, TOL (Pre/Post, 5 or 15 or 30 min after session)	**TMT:** No group x time interactions or group x recovery time interactions **Stroop:** Group x time interaction ($F(3,45) = 5.47$, $p = .003$, $\eta p^2 = 0.15$). Post hoc analyses revealed significant pre- to post-exercise improvements in congruent trials ($p = .01$, $\eta p^2 = 0.09$) and incongruent trials ($p = .02$, $\eta p^2 = 0.10$) in the exercise group, compared to the control group. No significant effects of exercise or recovery duration. **Spatial Span:** 60-min exercise with 5-min recovery IG had better memory scores post-exercise compared to other recovery periods ($F(2,56) = 6.23$, $p = .01$, $\eta p^2 = 0.14$). Post hoc comparisons showed that memory improved significantly from pre- to post-exercise ($p = .004$) in this group. **TOL:** Time × Recovery Period interaction ($F(2,50) = 4.87$, $p = .02$, $\eta p^2 = 0.11$). A 5-minute recovery period after exercise was associated with worse planning performance, compared to longer recovery periods ($p < .05$).	Improved IC, improved WM with 60 min exercise and 5 min recovery, decrement in planning with 5 min recovery	0.87
Douris et al. (2018), USA	40 (3 IGs & CG: 10)	23.7 ± 1.8 (Range NR), 40%M	Stationary Cycling, Video Gaming, Combined Aerobic Exercise and Video Gaming (Resting Control)	30 min	Moderate (60–70% HRmax)	Stroop, Oral Trails B (Pre/Post)	**Stroop:** Main effect of time for Stroop Word, Stroop Color, and Stroop Color-Word. No significant main effect of group or interaction effect. Post hoc paired t-tests with Bonferroni correction indicated significant improvements in Stroop Word ($p = .004$), Stroop Color ($p = .020$), and Stroop Color-Word ($p = .001$) for the Cycling IG. **Oral Trails B Test:** Main effect of time but no main effect of group or interaction. Post hoc comparisons for each group showed no significant changes pre-post.	Improved IC, not CF	0.87

Elkana et al. (2018), Israel	69 (IG: 35, CG: 34)	25.9 ± 3.17 (19-35), 39%M	Stationary Cycling (Resting Control)	15 min	Moderate (60% HRmax)	Non-Verbal Memory test and POMS (Pre/Post)	Interaction between conscientiousness and group (β = −0.22, b = −3.42, *t* = 2.13, *p* = .037), indicating group moderated the relationship between conscientiousness and improvement in working memory. The overall model was significant (*F*(3,65) = 9.36, *p* < .001), explaining 30.2% of variance in working memory change pre-post. Simple slope analysis showed a significant positive association between conscientiousness and working memory change in IG (β = 0.70, *b* = 11.12, *t* = 4.83, *p* < .001), but no effect for the Resting CG.	Improved WM	0.83
Elkana et al. (2022), Israel	116 (Physical Exercise IG: 30, Cognitive IG: 30, Physical-Cognitive Combined IG: 28, CG: 28)	25.50 ± 3.27 (19-35), 28%M	Physical Exercise: Stationary Cycling, Cognitive Exercise, Physical-Cognitive Exercises Combined (Resting Control)	15 min	Moderate (6.21 ±1.53 RPE and 60% HRR)	Phonemic Fluency and Semantic Fluency of Verbal Fluency (Pre/Post, 5 minutes after session)	**Phonemic Fluency:** Main effect of time, with improvements pre-post. Significant group × time × level of activity interaction (*F*(3,106) = 3.517, *p* = .018, ηp² = 0.091). Post-hoc tests indicated significant improvements in the physical, cognitive, and combined groups (*p* < .05); no change in CG. **Semantic Fluency:** Main effect of time, with improvements pre-post. Post-hoc analysis showed significant improvement only for cognitive activity group (*p* < .05).	Improved CF (Phonemic only)	0.87
Gentile et al. (2020), Italy & Serbia	81 (Wingate Aerobic IG: 22, Maximal Aerobic IG: 20, Submaximal Constant IG: 23, CG: 16)	24.6 ± 4.08 (19-39), 54%M	Stationary Cycling (Resting Control)	Wingate: 30 seconds at maximal velocity, Maximal Aerobic: time needed varied, Submaximal Constant: 20 min	High: Wingate (HRmax), Maximal Aerobic (incremental intensity) Moderate: Submaximal Constant (60% HRmax)	Stroop, TOL, Corsi block test (Pre/Post, 3 min after session)	**Stroop:** Main effect of time for congruent RT, with improvement pre-post, no effect of group. Main effect of time for incongruent RT with improvement pre-post, no effect of group. No effects of time or group for Inhibitory score (the logarithmic difference between incongruent and color RTs). Main effect of time for colour RT, with improvement pre-post, no effect of group. **TOL:** Main effects of time, with improvement pre-post. No effect of group. **Corsi Block:** Main effect of time with improvement pre-post, no effect of group.	No effects for IC, CF, WM, planning	0.83

Hung et al. (2013), Taiwan	40 (IG: 20, CG: 20)	M: 22.57 ± 1.88, F: 23.53 ± 2.00 (18-25), 58%M	Stationary Cycling (Reading an exercise-related book)	20 min	Moderate (60–70% HRR)	TOL (Pre/Post, immediately, 30 min, and 60 min after session)	**Move Performance:** Main effect of time for total move score and a time × group interaction (F(3, 114) = 5.74, p < .001, η^2 = .13), but no main effect of group. Post hoc analysis indicated IG had better scores immediately post-session but not at other time points. Main effect of time for total correct score, with improvement over time. No effect of group or group x time interaction. **Time Efficacy:** No main effects of time or group on total initiation time. Time × Group interaction (F(3, 114) = 7.24, p < .001, η^2 = .16) and post hoc tests indicated IG had better scores at 60 min and 30 min post-session, but not other time points. Main effect of time for total execution time with improvement over time. No effect of group or group x time interaction. Main effect of time for total problem-solving time and a group x time interaction (F(3, 114) = 4.70, p < .001, η^2 = .11), with no main effect of group. Post hoc tests showed no significant differences between IG and CG for total problem-solving time.	Improved planning accuracy at post-0 and improved RT at post-30 and post-60	0.87
Hwang & Lu (2018), USA	100 (IG: 50, CG: 50)	21.33 ± 2.16 (18-25), 55%M	Active Video Gaming (Sedentary Video Gaming)	30 min	Moderate-High (accelerometry)	Psychomotor vigilance task, delayed match-to-sample memory task (Pre/Post when HR returned to 10% above baseline heart rate)	**Psychomotor Vigilance Task:** No main effects or interactions **Memory Task:** Time × group interaction for encoding time (F(3,99) = 4.97, η^2 = 0.13, p = .003), with a shorter encoding time for IG compared to CG (p = .019). Main effect of time for retrieval latency time (F(3,99) = 4.37, η^2 = 0.04, p = .039), with decreased retrieval latency over time in all groups. Time × group interaction for correct trial response accuracy (F(3,99) = 3.23, η^2 = 0.09, p = .026); IG improved in response accuracy compared to CG (p = 0.012).	Improved WM	0.87

Hwang et al. (2016), USA	58 (IG: 29, CG: 29)	IG: 22.84 ± 3.13 CG: 24.34 ± 3.00 (18-29), 50%M	Treadmill running (Resting Control)	20 min	High (85 to 90% VO2max)	Stroop, TMT (Pre/Post, approx. 10 min. after session)	**Stroop:** Time × group interaction in Word, Color-Word, and Interference scores, with IG showing higher scores in Word (p = .02) and Color-Word (p < 0.01), and a greater Interference ratio score (p < .01) compared to CG. **TMT:** Time × group interaction for TMT Part B, with IG having faster completion times than CG (p < 0.01).	Improved IC and CF	0.87
Jaffrey et al. (2018), USA	88 (IGs & CGs: 22)	IG1: 21.5 ± 0.5 CG1: 21.3 ± 0.4 IG2: 22.0 ± 0.3 CG2: 21.6 ± 0.4 (Range NR), %M NR	Treadmill walking (Resting Control)	5 min	Self-selected intensity	TMT (IG1: Pre/Post 5 min after session, CG1: Pre/Post 5 & 10 min after session, IG2: Post only 5 min after session, CG2: Post only 5 min after session)	**TMT:** IG1 had improved TMT-B response times pre-post (56.3 s vs. 35.7 s, p = .01). No effects in other groups.	Improved CF	0.83
Khandekar et al. (2022), India	49 (IG: 26, CG: 23)	IG: 23.58 ± 1.62 CG: 24.20 ± 2.07 (18-30), 35%M	Stationary Cycling (Resting Control)	4 bouts of 4 min with 3 min active recovery (28 min)	High (85-90% HRmax)	Stroop, TMT (Pre/Post, approx. 10 min. after session)	**Stroop:** Main effect of group and time, and group x time interaction (F(1, 48) = 7.35, p = .008, ηp^2 = 0.76) for interference scores, with IG showing better post-session performance compared to the CG. Main effect of group and group × time interaction (F(1, 48) = 10.79, p = .001, ηp^2 = 0.107) for average RT, indicating quicker responses in IG compared to CG. **TMT:** Main effect of group and time, and a group × time interaction (F(1, 48) = 4.37, p = .039, ηp^2 = 0.046) for TMT-A. Main effects of group and time, and group × time interaction (F(1, 48) = 60.10, p < .001, ηp^2 = 0.400) for TMT-B. IG performed better than CG post-session on TMT-A and B. Main effect of time for error interference scores, with no interaction, indicating similar error rates between groups.	Improved IC and CF	0.83
Larson et al. (2015), Location Country NR	69 (IG: 34, CG: 35)	IG: 20.91 ± 2.43 CG: 20.74 ± 2.12 (18-35), 52%M	Treadmill walking (Resting Control)	60 min	Low (1.5 MPH walking speed)	Flanker, Go/No-Go (During)	**Flanker:** No significant difference between groups for RT, accuracy, or post-error slowing. **Go/No-Go:** No significant difference between groups for Go accuracy or No-Go inhibition accuracy.	No effects for IC	0.87

Legrand et al. (2018), France	90 (IG: 40, CG: 50)	20.76 ± 1.22 (Range NR), 80%M	Trail Jogging (Resting Control)	15 min	Moderate (6mph average pace)	TMT (Pre/Post 2 minutes after session)	**TMT:** No between group differences at baseline for TMT A or B but TMT B-A index was lower for IG ($t(88) = -2.86$, $p = .005$). Group x time interaction for TMT-A completion time ($F(1, 88) = 5.69$, $p = .019$, $\eta^2 = 0.06$) with improvement in IG pre-post ($M = -7.54$ s, $SD = 16.21$, $t(39) = -2.94$, $p = .005$, $d = -0.67$), CG performance was unchanged. No group × time interaction for TMT-B completion time or TMT B-A index.	No effects for CF	0.87
Loprinzi & Kane (2015), USA	87 (Low Intensity IG: 24, Moderate Intensity IG: 22, High Intensity IG: 22, CG: 19)	21.4 SD NR (20-22), 59%M	Treadmill (Resting Control)	30 min	Low (40%-50% HRmax), Moderate (51%-70% HRmax), High (71%-85% HRmax)	TMT A & B, Spatial Span, Paired Associates, Grammatical Reasoning, Odd One Out, Feature Match, Polygon, Spatial Search, Spatial Slider (Pre/Post, immediately after session)	**Feature Match:** $M \pm SD$ Feature Match test scores were significantly higher after moderate-intensity exercise (145.1 ± 26.9) compared to CG (121.3 ± 19.2; $p = .004$). **All Other Tasks:** No main effects of time or group, no interaction effects across cognitive parameters.	Improved WM for Moderate Intensity, no effects for IC/CF	0.87
Moore et al. (2012), USA	28 (IG: 13, CG: 15)	22 SD NR (18-28), 46%M	Stationary Cycling (Resting Control)	60 min	High (90% VT)	Visual discrimination test (Pre/Post approx. 15 min and 70 min after session) and working memory vigilance test (Post, after first Visual Discrimination post-session)	**Visual Discrimination**: Main effect of test type, with poorer performance on the complex version of the test. group x time x test type (simple or complex) interaction ($F(1,28) = 4.56$, $p = .04$, $\eta p^2 = 0.14$). Subsequent analysis indicated a Group x Time interaction on complex version ($F(1,28) = 4.68$, $p = .04$, $\eta p^2 = 0.11$) only. IG had decline in perceptual sensitivity pre-post, CG did not ($F(2,56) = 4.69$, $p = 0.04$, $\eta p^2 = 0.14$). No difference between 15 min and 70 min post-test scores. **Working Memory Vigilance:** Main effect of group, IG had longer RTs than CG ($F(1, 28) = 5.17$, $p = .03$, $\eta p^2 = 0.16$). No main effect of time or group x time interaction.	Decrement in WM	0.80

Murray & Russoniello (2012), USA	120 (NR)	M: 20.67 ± 2.80, F: 20.05 ± 2.87 (18-25), 50%M	Stationary Cycling (Monitoring IG participants' HR)	30 min	High (Self-selected intensity at a high, but comfortable intensity, mean HR = 75.46% HRmax)	TMT-B (Pre/Post, immediately following session)	**TMT:** Main effects of group and time, and a group × time interaction ($F(1,116) = 35.76$, $p < .001$, $\eta^2 = .24$). Post hoc analysis indicated no between-group differences at baseline, but IG had faster completion times compared to CG at post-test. Completion time improved from baseline (M = 69.92 s, SD = 10.64) to post-test (M = 60.38 s, SD = 11.82).	Improved CF	0.83
Oberste et al. (2016), Germany	121 (3 IGs; 30, CG: 31)	Low Intensity: 24.00 ± 3.71, Moderate Intensity: 23.37 ± 3.89, High Intensity: 23.90 ± 3.73, CG: 23.97 ± 3.37 (18-35), 69%M	Stationary Cycling (Self-myofascial release training)	35 min	Low (45-50% HRmax), Moderate (65-70% HRmax), High (65-70% HRmax)	Stroop, TMT, Free Recall Test (Pre/Post 10 min after session)	**Stroop:** Main effect of time for Word Reading with improvement pre-post. Group x Time interaction ($F(3, 117) = 3.075$, $p = .03$, $\eta p^2 = .073$). Post hoc comparisons revealed that the High-Intensity IG had faster RTs for Word Reading at post-test compared to the Low-Intensity IG ($p = .034$, $d = .784$), while no other between-group differences were found. Main effect of time for Colour Naming and Stroop Effect with improvement pre-post. No main effect of group or group x time interaction for Colour Naming or Stroop Effect. **TMT:** Main effect of time for TMT-A and TMT-B with improvement pre-post. No main effect of group or group x time interaction. **Free Recall:** Main effect of time with improvement pre-post. No main effect of group or group x time interaction.	No effects for IC, CF, or WM	0.87
Razon et al. (2019) Study 1, Country NR	60 (IG: 30, CG: 30)	27.63 ± 9.00 (18-37), 50%M	Handgrip Squeezing (Stepping)	45 min	Moderate and High (30% MVC, Moderate: RPE = 6, High: RPE = 9)	TMT (Pre/Post, immediately after session)	**TMT:** Main effect of intensity (Wilk's $\lambda = .708$, $F(2,57) = 11.76$, $p < .001$, $\eta 2 = .292$). Post hoc analysis revealed TMT A & B completion time improved after high intensity exercise compared to baseline (M = 14.25s, SD = 7.17, $p < .001$), but not after moderate intensity exercise. No main effect of group or group x time interaction.	Improved CF for High Intensity	0.87

Razon et al. (2019) Study 2, Country NR	83 (Handgrip RPE 6: 17, Handgrip RPE 9: 19, Stepping RPE 6: 15, Stepping RPE 9: 16, CG: 15)	22.71 ± 4.13 (18-30), 51%M	Handgrip Squeezing, Stepping (Resting Control)	45 min	Moderate (RPE = 6) and High (RPE = 9), 30% MVC for all Handgrip exercise	TMT and Dynavision working memory task - solving math equations while doing RT task (Pre/Post, immediately after session and after 15 min delay)	**TMT:** Main effect of time. Post hoc analysis indicated improvement in TMT A & B completion time from baseline to immediately post-session and scores remained stable 15 min after session which was significantly different from baseline but not statically different from immediately after exercise. No main effect of group or group x time interaction. **Working Memory:** Main effect of time. Post hoc analysis indicated no significant change in computation errors from baseline to immediately post-test, but errors decreased 15 min post-test, which was significantly different from baseline and immediately after exercise. No main effect of group or group x time interaction.	No effects for CF or WM	0.87
Sanderson & Loprinzi (2019), USA	60 (Moderate Intensity: **, Vigorous Intensity: **, CG: 20)	Moderate Intensity: 20.8 ± 0.8, Vigorous Intensity: 20.9 ± 1.2, CG: 21.1 ± 1.1 (18-40), %M NR	Treadmill (Sudoku)	15 min	Moderate (50% HRR), High (80% HRR)	Iowa Gambling Task (Post, 5 min after session completion)	**Iowa Gambling Task:** Main effect of task block. Post-hoc analyses indicated improved learning from block 1 to block 3, 4, and 5, and improved learning from block 2 to block 4. No main effect of group or group x time interaction.	No effects for IC/CF	0.87

							ANT: Main effect of time for no-cue, center-cue, spatial-cue, incongruent, and congruent, with improvement pre-post. Main effect of group for spatial cue, not for others. No main effect for time or group or group x time interactions for alerting effect (RT no cue - RT center cue) or orienting effect (RT center cue RT spatial cue). Group x time interaction for executive control effect (RT incongruent - RT congruent) (F(3, 103) = 2.736, p = .047, η2 = 0.074). Post hoc analyses indicated no difference between CG and IGs at baseline and all 3 IGs had improved executive control pre-post; CG did not. High Intensity IG had better post-test executive control than CG (p = 0.006) and Low Intensity IG (p = .034). Moderate Intensity IG had better post-test executive control than CG (p = .018).		
Su et al. (2022), China	107 (Low Intensity: 32, Moderate Intensity: 33, High Intensity: 21, CG: 21)	Low Intensity: 21.40 ± 1.20, Moderate Intensity: 21.30 ± 1.00, High Intensity: 20.70 ± 1.20, CG: 20.80 ± 1.00 (18-24), 100%M	Treadmill (Documentary Watching)	20 min	Low: 0.3 (HRmax - HRresting) + HRresting, 0.39 (HRmax - HRresting) + HRresting, Moderate: 0.4 (HRmax – HRresting) + HRresting, 0.59 (HRmax – HRresting) + HRresting, High: 0.6 (HRmax - HRresting) + HRresting, 0.89 (HRmax - HRresting) + HRresting	ANT, Stroop (Pre/Post, within 5 minutes after session)	**Stroop:** Main effect of time for Reactive Control (incongruent – congruent on mostly congruent block) RT and Proactive Control (incongruent – congruent on the mostly incongruent block) accuracy with improvement pre-post. No main effect of group or group x time interaction. Main effect of group for Proactive Control RT, no main effect of time or group x time interaction. Group x time interaction for Reactive Control Accuracy (F(3, 103) = 3.005, p = .034, η2 = 0.080). Post hoc analyses indicated no difference between groups at baseline, Moderate and High Intensity IGs had better accuracy post-test compared to baseline (p = < .001, p = .006), but no difference between groups at post-test.	Improved IC and CF, particularly for Moderate and High Intensity	0.87

Sudo et al. (2017), Japan	32 (IG: 18, CG: 14)	IG: 23.2 ± 2.1, CG: 22.3 ± 2 (Range NR), 100%M	Stationary Cycling (Resting Control)	Average time: 16 min 1 s	High (exercise until exhaustion; the maximal exercise test was stopped when the participants were no longer able to maintain a pedaling rate of 50 rpm)	Delayed Response Task, Go/No-Go (Pre/Post 2 min after session)	**Go/No-Go:** No main effect of time, group or group x time interaction for RT. Group x Time interaction for errors ($F(1,30) = 7.43$, $p = 0.01$, $\eta p^2 = 0.20$). However, post hoc analyses revealed no changes in error trials for the IG or CG. **Delayed Response Errors:** No main effect of time, group or group x time interaction.	No effects for IC or WM.	0.80
Tsai et al. (2014), Taiwan	60 (IGs & CG: 20)	High Intensity: 22.40 ± 2.44, Moderate Intensity: 23.15 ± 2.52, CG: 23.20 ± 2.12 (20-29), 100%M	Resistance Exercise (Reading Magazines)	40 min	High (80% 1RM), Moderate (50% 1RM)	Go/No-Go combined with Flanker (Pre/Post; once the participants' body temperature and HR had returned to within 10% of pre-exercise levels - approx. 5 min after session)	**GNG/Flanker RT:** Main effect of time and task condition, RTs improved pre-post, RTs were faster on congruent-go than incongruent-go. Time x group interaction ($F(2, 57) = 3.78$, $p = .029$, $\eta p^2 = 0.12$), faster RTs pre-post in both High Intensity IG (pre- vs. post-exercise = 299.49 ± 47.90 vs. 275.02 ± 47.56 ms, $p < .001$) and Moderate Intensity IG (pre- vs. post-exercise = 309.57 ± 69.15 vs. 287.21 ± 68.91 ms, $p < .001$) for the Go condition, not for the CG. **GNG/Flanker Accuracy:** Main effect of task condition, better accuracy on No-Go in the congruent condition. Time × group interaction ($F(2, 57) = 3.61$, $p = .033$, $\eta p^2 = 0.11$) and time× group × task condition interaction ($F(2, 57) = 3.22$, $p = 0.048$, $\eta p^2 = .10$). Accuracy on incongruent-no-go condition improved pre-post for the High Intensity IG (pre- vs. post-exercise = 98.00 ± 2.03% vs. 98.75 ± 1.21%, $p = .024$) and Moderate Intensity IG (pre- vs. post-exercise = 98.10 ± 2.10% vs. 98.85 ± 1.27%, $p = .015$), not the CG.	Improved CF for both Moderate and High Intensity	0.87

Wang et al. (2013), Taiwan	80 (IGs & CG: 20)	20.51 ± 1.99 (19-26), 61%M	Stationary Cycling (Resting Control)	30 min	Low (30% HRR), Moderate (50% HRR), High (80% HRR)	WCST (During)	**WCST:** Main effect of group. Post hoc analyses indicated High Intensity IG had more perseverative responses compared to other groups ($F(3, 76) = 6.34$, $p < .001$, $\eta p^2 = .20$), no difference between the 3 other groups. High Intensity IG had lower conceptual-level responses ($F(3, 76) = 4.78$, $p < .004$, $\eta p^2 = .16$) and number of categories completed ($F(3, 76) = 7.89$, $p < .001$, $\eta p^2 = .24$), compared with the other three groups. No exercise-induced effects were observed for failure to maintain set at any exercise intensities.	Decrement in CF for High Intensity	0.87
Wang et al. (2015), Taiwan	27 (IG: 14, CG: 13)	IG: 22.57 ± 2.77, CG: 22.77 ± 2.39 (19-24), 30%M	Stationary Cycling (Reading about exercise and mental health)	30 min	Moderate (65% HRR)	WCST (Pre/Post, immediately after session)	**WCST:** Main effect for time for perseverative responses, perseverative errors, non-perseverative errors , and categories completed, with improvement on all measures pre-post. No main effect of group or group x time interaction.	No effects for CF	0.87
Wilke (2020), Germany	35 (High Intensity Functional Training: 12, Treadmill Walking: 11, CG: 12)	26.7 ± 3.6 (Range NR), 49%M	High Intensity Functional Training, Treadmill Walking (Reading)	15 min	High Intensity Functional Training (NR), Moderate Intensity Walking (60% HRR)	Stroop, TMT, Digit Span (Pre/Post; 30s after session completion)	**Stroop:** Main effect of time for interference condition. Improvement in RT pre-post found only in the High Intensity Functional Training IG. However, no significant group x time interaction. **TMT:** No main effect of time or group x time interaction. **Digit Span:** Group x time interaction ($F(2,32) = 3.36$, $p = .047$, $\eta^2 = 0.17$) for Digit Span Backwards. High Intensity Functional Training IG improved pre-post and the other groups did not. No main effect of time for Digit Span Backwards. Main effect of time for sum score with improvement pre-post and increases found only in the High Intensity Functional Training IG. However, no significant group x time interaction.	Improved IC and WM for High Intensity Functional Training, no effect for CF	0.80

Wilke et al. (2020), Germany	46 (2 IGs: 23)	27.2 ± 4.3 (20-34), 57%M	Free-Weight Resistance Training, Machine-Based Resistance Training	45 min	Moderate-High (individual 6-repetition maximums)	Stroop, TMT, Digit Span (Pre/Post; immediately after session)	**Stroop:** No differences between groups for Stroop Colour or Stroop Word. Analysis of confidence intervals revealed that Free-Weight Resistance Training IG had improved Stroop Word (+2.9%) and Stroop Colour (+4.2%) performance pre-post and Free-Weight Resistance Training IG had greater Stroop Colour-Word improvement (+9.6%) than Machine-Based Resistance Training (+6.3%, p = .02, R = .35). **TMT:** No differences between groups. Analysis of confidence intervals revealed that Free-Weight Resistance Training had improved TMT-A (+34.6%) and TMT-B (+24.3%) performance pre-post. Machine-Based Resistance Training had improved TMT-A (+23.5%) performance post. **Digit Span:** No differences between groups.	Improved IC and CF, particularly for free-weight, no effect for WM	0.80
Zhou & Qin (2019), China	72 (IG & CG: 36)	20.07 ± 0.15 (18-26), 50%M	Stationary Cycling (Reading & Resting)	25 min	Moderate (60-70% HRmax)	Stroop (Pre/Post, until HR returned to 110% HRR, ~15 min)	**Stroop Accuracy:** Main effect of time, with improvement pre-post. Main effect of trial type, with higher accuracy on congruent trials compared to incongruent trials. Time x trial type interaction with improvement pre-post for both congruent and incongruent trials. Accuracy of congruent trials was higher than incongruent trials. No other main effects or interactions. **Stroop RT:** Main effect for time with improvement pre-post. Main effect of trial type, with shorter RT on congruent trials compared to incongruent trials. Group x time x trial type Interaction (F(1, 70) = 4.40, p = 0.04, ηp^2 = 0.06). Follow-up analyses revealed that the RT at baseline was longer than post-test for both tasks and groups. No difference between groups for trial type. No other main effects or interactions.	No effects for IC	0.87

Note. y: years; %M: percentage of males/men; EF: Executive Function; IG: Intervention Group; CG: Control Group; RPE: Ratings of Perceived Exertion; RPM: Revolutions per Minute; HRmax: Maximum Heart Rate; HRresting: Heart Rate at Rest; HRR: Heart Rate Reserve; VO_2Max: Maximum Oxygen Uptake; RT: Response Time; ANT: Attention Network Test; HVLT-R: Hopkins Verbal Learning Test-Revised; PASAT: Paced Auditory Serial Addition Test; TOL: Tower of London; TMT: Trail Making Test; WCST: Wisconsin Card Sorting Test; POMS: Profile of Mood States; IC: Inhibitory Control; CF: Cognitive Flexibility; WM: Working Memory. Study Quality scores range from 0.00 to 1.00, with higher scores indicating better methodological quality.

Table 2.3

Summary of Results for Multi-Session Exercise Interventions

	Participant Characteristics			Intervention Components			Results		
Authors, Country	**Overall sample size *(n)* (IG: *n*, CG: *n*)**	***Mage ± SD* (y) (range), Sex/Gender (%M)**	**Exercise type (control)**	**Frequency**	**Exercise duration (min) (total min of intervention)**	**Intensity (intensity measure)**	**EF outcome measures (when they were measured)**	**Summary of relevant results**	**EF skillset affected by exercise**	**Study quality**
Eather et al. (2019), Australia	53 (IG: 27, CG: 26)	20.38 ± 1.88 (18-25), 34%M	High Intensity Interval Training (Waitlist Control)	3 sessions/ week, 8 weeks	8 min in weeks 1-4, 10 min in weeks 5-6, 12 min in weeks 7-8 (228 min)	High (85% or above HRmax)	TMT A & B (Pre/Post 8-week intervention)	**Trail B:** Improved pre-post for the IG (-5.9 (95% CI [-11.8, 0.1], p = .052, d = 0.63), not for the CG. **Trail Score 1 & 2:** No sig. differences were observed for Trail Score 1 (B-A) or Trail Score 2 (B/A).	Improved CF	0.87
Kim (2015), Republic of Korea	14 (IG: 7, CG: 7)	IG: 20.57 ± 0.53 CG: 20.71 ± 1.49 (Range NR), 100%M	Taekwondo training: aerobic and dynamic exercises (Resting Control)	5 sessions/ week, 8 weeks	85 min (3,400 min)	Moderate-High (RPE 11-15)	Stroop (Pre/Post 8-week intervention)	**Stroop Word**: Main effect of time and group, and group x time interaction (F = 13.682, p < .05). IG had improved scores pre-post (p < .05). **Stroop Colour:** Main effect of time (F = 30.259, p < .05) and group x time interaction (F = 7.282, p < .05). IG had improved scores pre-post (p < .05). **Colour-Word:** No main effects or interactions.	No effects for EFs	0.80
Liu et al. (2023), China	67 (High Intensity Interval Training: 26, Moderate Intensity Continuous Training: 21, CG: 20)	25.23 ± 2.18 (Range NR), 50%M	High Intensity Interval Training, Moderate Intensity Continuous Training (Health Education Lessons)	3 sessions/ week, 12 weeks	40 min (1,440 min)	High (100% of VO2max), Moderate (70–75% of VO_2 max)	TMT (Pre/Post 12-week intervention)	**TMT Completion Time:** Moderate Intensity Continuous Training IG improved compared to the CG (β=−10.175, 95% CI [−20.320, −0.031]). No differences in completion time between High Intensity Interval Training IG and Moderate Intensity Continuous Training IG or CG. **TMT RT**: Moderate Intensity Continuous Training IG (estimated value=−17.34, p < .01) and High Intensity Interval Training IG (estimated value = −10.77, p < 0.01) improved pre-post. **TMT Accuracy:** Moderate Intensity Continuous Training IG improved (estimated value = 0.04, p < 0.05) pre-post.	Improved CF, particularly moderate intensity	1.00

May et al. (2017), USA	60 (IG: 30, CG: 30)	18.55 ± 0.99 (18-30), 18%M	High Intensity Interval Training (Resting Control)	3 sessions/ week, 4 weeks	25 min (300 min)	High (90% HRmax)	Working memory span measures - automated computerized versions of the common reading and mathematics (operation) working memory span tasks (Pre/Post 4-week intervention)	**Span Tasks:** Group x time interaction ($p < .05$). Follow-up univariate contrasts indicated that IG, but not CG, improved significantly pre-post ($p < 0.01$) for operation span (Δ4.30 ± 0.10) and reading span (Δ1.30 ± 0.10).	Improved WM	0.87
Shen et al. (2021), China	36 (Tai Chi: 12, Brisk Walking: 12, CG: 12)	Tai Chi: 21.83 ± 2.48, Walking: 21.92 ± 2.28, CG: 21.75 ± 2.45 (Range NR), 17%M	Tai Chi, Brisk Walking (Resting Control)	3 sessions/week, 8 weeks	60 min (1,440 min)	Moderate (64-76% HRmax)	Flanker (Pre/Post 8-week intervention)	**Flanker Accuracy:** No main effect of time or group and no interaction. **Flanker Inhibitory Control (mean RT on incongruent trials - mean RT on congruent trials):** Group x time interaction ($F(1,33) = 3.903$, $p = .03$, $\eta p^2 = 0.191$). Follow-up analyses indicated that Thai Chi IG had improved performance pre-post, Walking IG and CG did not. There was a difference between groups at post-test ($F(1,33) = 3.46$, $p = .043$, $\eta p^2 = 0.173$), not baseline and the difference was between Thai Chi IG and CG post-test ($p = .009$, $d = 1.014$). No main effect of time or group.	Improved IC	0.80
Thomas & D (2017), India	40 (IG: 20, CG: 20)	IG: 18.95 ± 0.08, CG: 19.40 ± 0.754 (18-21), 100%M	Superbrain Yoga (Simple Squats)	5 sessions/week, 4 weeks	NR, 21 reps, 3 sets/session	NR	N-back (Pre/During/Post, after each week of intervention)	**N-back:** Significant differences between groups and across sessions. **2-back**: Groups differed significantly in sessions 2, 3, and 4. 3-back task: Groups differed significantly in sessions 1, 2, 3, and 4. **4-back task**: Groups differed significantly in sessions 1, 2, 3, and 4. IG performed better than CG in all comparisons ($p < .05$). Improvement in n-back scores (2-back, 3-back, and 4-back) from baseline to session-4 in both groups ($p < .05$).	Improved WM	0.80

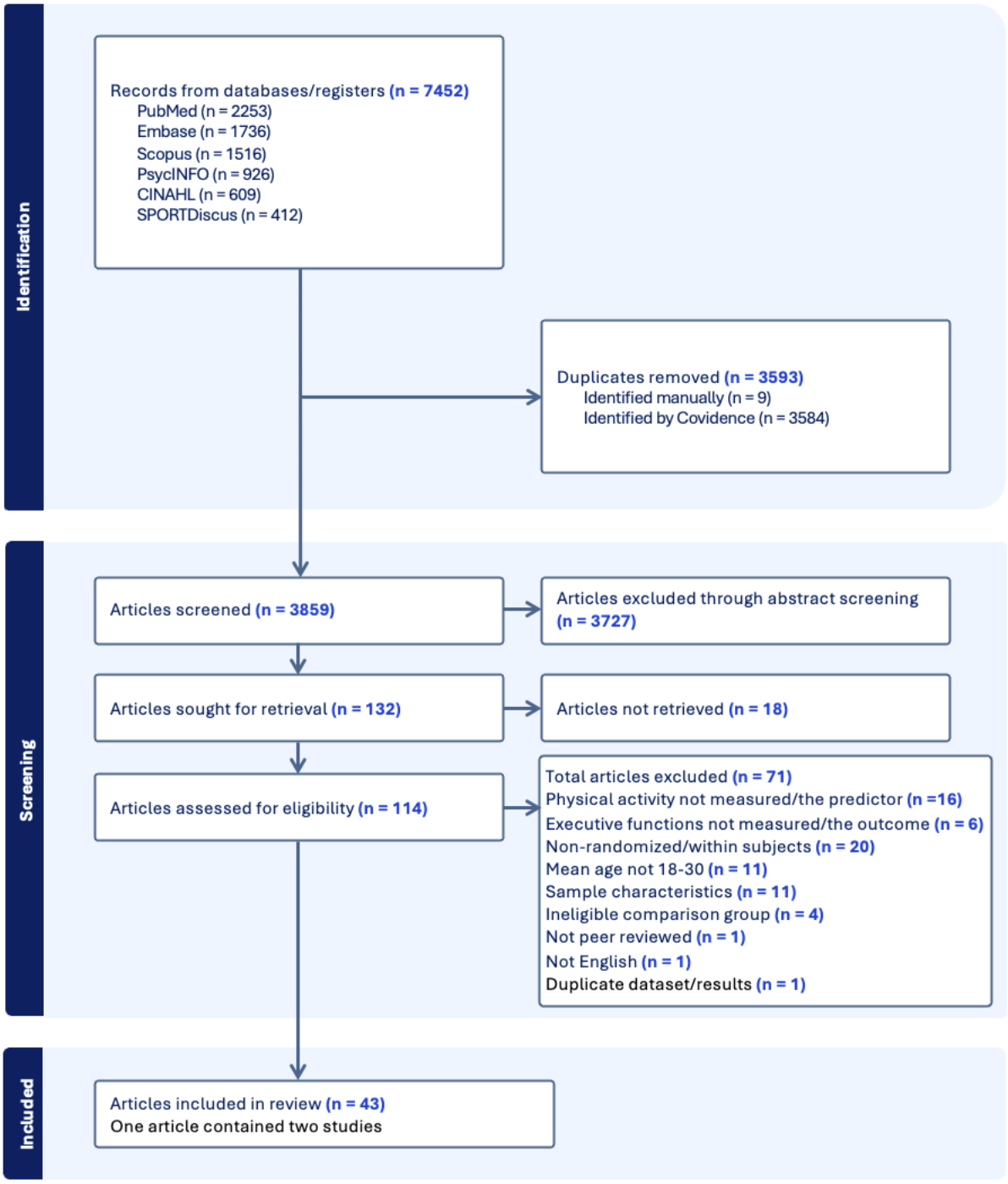
Wang et al. (2023), China	55 (IG: 28, CG: 27)	IG: 20.17 ± 1.66, CG: 19.93 ± 1.74 (Range NR), 45%M	Tai Chi (Sports)	up to 3 sessions/week, 12 weeks	60 min (up to 2,160 min)	Moderate (60-69% HRmax)	Visual 2-back (Pre/Post)	**Visual 2-back Accuracy:** Difference between the Tai Chi group and the control group (F = 54.89, $p \leq .001$) and RT (F = 99.45, $p \leq .001$). Main effects of time, group, and group x time interaction (F(1,53)=50.815, $p \leq .001$, ηp^2 =0.489) for Accuracy. **Visual 2-back RT:** Main effects of time, group, and group x time interaction (F(1,53) = 79.526, $p \leq .001$, ηp^2 =.600) for RT. Post-hoc analysis showed that the IG had better Accuracy (F(1,53) = 54.899, $p \leq .001$) and RT (F(1,53) = 99.454, $p \leq 0.001$) than the CG.	Improved WM	0.87
Zhu et al. (2021a), China	121 (IG: 48, CG: 73)	IG: 18.67 ± 0.56, CG: 18.50 ± 0.69 (18-20), 50%M	Mixed Exercise Including Sports, Games, and Running (Waitlist)	4 sessions/week, 9 weeks	60, 60, 60, 45 min (2,025 min)	Moderate (64–77% HRmax)	Flanker (Pre/Post 9-week intervention)	**Flanker RT:** No main effects of group or time or group x time interaction for congruent or incongruent accuracy. Main effect of group, main effect of time, and group x time interaction (F(1, 118) = 47.689, $p < .001$, $\eta p^2 = 0.288$) for congruent RT with improvement pre-post in the IG. Main effect of group for incongruent RT (F(1,118) = 16.672, $p < .001$, $\eta p^2 = 0.125$) indicating faster RTs in IG.	Improved IC	0.87
Zhu et al. (2021b), China	59 (IG: 35, CG: 24)	IG: 18.66 ± 0.48, CG: 18.5 ± 0.78 (18-20), 41%M	Stationary Cycling (Maintained typical activity)	4 sessions/week, 9 weeks	60 min (2,160 min)	Moderate (60-69% HRmax)	Flanker (Pre/Post 9-week intervention)	**Flanker RT:** Group x time interaction for incongruent RT (F(1,56) = 25.63, $p < .05$, $\eta p^2 = 0.314$), but not congruent RT. Simple effect analyses revealed that RT decreased pre-post in the IG ($p < .05$) and increased pre-post the CG ($p < .05$). **Flanker Accuracy:** No group x time interaction for accuracy in either the incongruent or congruent trials.	Improved IC	0.87

Note. *y*: years; %M: percentage of males/men; EF: Executive Function; IG: Intervention Group; CG: Control Group; RPE: Ratings of Perceived Exertion; HRmax: Maximum Heart Rate; VO_2Max: Maximum Oxygen Uptake; RT: Response Time; TMT: Trail Making Test; IC: Inhibitory Control; CF: Cognitive Flexibility; WM: Working Memory. Study Quality scores range from 0.00 to 1.00, with higher scores indicating better methodological quality.

2.8 Figures

Figure 2.1

PRISMA Diagram Summarizing the Study Selection Process



2.9 References

Aguirre-Loaiza, H., Arias, I., Bonilla, S., Ramírez, R., Ramírez-Herrera, S., Nanez, J., Barbosa-Granados, S., & Arenas-Granada, J. (2022). Effect of acute physical exercise on inhibitory control in young adults: High-intensity indoor cycling session. *Physiology & Behavior*, *254*, 113902. https://doi.org/10.1016/j.physbeh.2022.113902

Allan, J. L., McMinn, D., & Daly, M. (2016). A bidirectional relationship between executive function and health behavior: Evidence, implications, and future directions. *Frontiers in Neuroscience, 10*, 386. https://doi.org/10.3389/fnins.2016.00386

Aly, M., & Kojima, H. (2020). Acute moderate-intensity exercise generally enhances neural resources related to perceptual and cognitive processes: A randomized controlled ERP study. *Mental Health and Physical Activity*, *19*, 100363. https://doi.org/10.1016/j.mhpa.2020.100363

Basso, J. C., Shang, A., Elman, M., Karmouta, R., & Suzuki, W. A. (2015). Acute exercise improves prefrontal cortex but not hippocampal function in healthy adults. *Journal of the International Neuropsychological Society*, *21*(10), 791–801. https://doi.org/10.1017/s135561771500106x

Blomstrand, P., & Engvall, J. (2021). Effects of a single exercise workout on memory and learning functions in young adults—A systematic review. *Translational Sports Medicine*, *4*(1), 115–127. https://doi.org/10.1002/tsm2.190

Brown, D. M. Y., & Bray, S. R. (2015). Isometric exercise and cognitive function: an investigation of acute dose–response effects during submaximal fatiguing contractions. *Journal of Sports Sciences*, *33*(5), 487–497. https://doi.org/10.1080/02640414.2014.947524

Brown, D. M. Y., & Bray, S. R. (2018). Acute effects of continuous and high-intensity interval exercise on executive function. *Journal of Applied Biobehavioral Research*, *23*(3). https://doi.org/10.1111/jabr.12121

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports, 100*(2), 126–131.

Cleary, M., Walter, G., & Jackson, D. (2011). "Not always smooth sailing": Mental health issues associated with the transition from high school to college. *Issues in Mental Health Nursing, 32*(4), 250–254. https://doi.org/10.3109/01612840.2010.548906

Chang, H., Kim, K., Jung, Y., & Kato, M. (2017). Effects of acute high-intensity resistance exercise on cognitive function and oxygenation in prefrontal cortex. *Physical Activity and Nutrition*, *21*(2), 1–8. https://doi.org/10.20463/jenb.2017.0012

Chang, Y., & Etnier, J. L. (2009). Exploring the dose-response relationship between resistance exercise intensity and cognitive function. *Journal of Sport and Exercise Psychology*, *31*(5), 640–656. https://doi.org/10.1123/jsep.31.5.640

Chang, Y., Tsai, C., Hung, T., So, E. C., Chen, F., & Etnier, J. L. (2011). Effects of acute exercise on executive function: a study with a Tower of London Task. *Journal of Sport and Exercise Psychology*, *33*(6), 847–865. https://doi.org/10.1123/jsep.33.6.847

Cox, E. P., O'Dwyer, N., Cook, R., Vetter, M., Cheng, H. L., Rooney, K., & O'Connor, H. (2016). Relationship between physical activity and cognitive function in apparently healthy young to middle-aged adults: A systematic review. *Journal of Science and Medicine in Sport*, *19*(8), 616–628. https://doi.org/10.1016/j.jsams.2015.09.003

Crush, E. A., & Loprinzi, P. D. (2017). Dose-response effects of exercise duration and recovery on cognitive functioning. *Perceptual and Motor Skills*, *124*(6), 1164–1193. https://doi.org/10.1177/0031512517726920

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*(1), 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Diamond, A., & Ling, D. S. (2016). Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience*, *18*, 34–48. https://doi.org/10.1016/j.dcn.2015.11.005

Diamond, A., & Ling, D. S. (2019). Aerobic-exercise and resistance-training interventions have been among the least effective ways to improve executive functions of any method tried thus far. *Developmental Cognitive Neuroscience*, *37*, 100572.

Douris, P. C., Handrakis, J. P., Apergis, D., Mangus, R. B., Patel, R., Limtao, J., Platonova, S., Gregorio, A., & Luty, E. (2018). The effects of aerobic exercise and gaming on cognitive performance. *Journal of Human Kinetics*, *61*(1), 73–83. https://doi.org/10.1515/hukin-2017-0134

Dube, S. L., Sigmon, S., Althoff, R. R., Dittus, K., Gaalema, D. E., Ogden, D. E., Phillips, J., Ades, P., & Potter, A. S. (2022). Association of self-reported executive function and mood with executive function task performance across adult populations. *Applied Neuropsychology: Adult*, *29*(4), 605–616. https://doi.org/10.1080/23279095.2020.1794869

Duckworth, A. L., Taxer, J. L., Eskreis-Winkler, L., Galla, B. M., & Gross, J. J. (2019). Self-control and academic achievement. *Annual Review of Psychology*, *70*(1), 373–399. https://doi.org/10.1146/annurev-psych-010418-103230

Eather, N., Riley, N., Miller, A., Smith, V., Poole, A., Vincze, L., Morgan, P. J., & Lubans, D. R. (2019). Efficacy and feasibility of HIIT training for university students: The Uni-HIIT RCT. *Journal of Science and Medicine in Sport*, *22*(5), 596–601. https://doi.org/10.1016/j.jsams.2018.11.016

Elkana, O., Bustanai, N. Y. K., Louzia-Timen, R., Kodesh, E., Franco, M., & Doniger, G. M. (2018). Conscientiousness is associated with improvement in visuospatial working memory and mood following acute physical exercise: A randomized controlled trial. *Personality and Individual Differences*, *132*, 126–132. https://doi.org/10.1016/j.paid.2018.05.018

Elkana, O., Louzia-Timen, R., Kodesh, E., Levy, S., & Netz, Y. (2020). The effect of a single training session on cognition and mood in young adults – is there added value of a dual-task over a single-task paradigm? *International Journal of Sport and Exercise Psychology*, *20*(1), 36–56. https://doi.org/10.1080/1612197x.2020.1854821

Ferguson, H. J., Brunsdon, V. E. A., & Bradford, E. E. F. (2021). The developmental trajectories of executive function from adolescence to old age. *Scientific Reports*, *11*(1), 1382. https://doi.org/10.1038/s41598-020-80866-1

Festa, F., Medori, S., & Macrì, M. (2023). Move your body, boost your brain: The positive impact of physical activity on cognition across all age groups. *Biomedicines, 11*(6), Article 1765. https://doi.org/10.3390/biomedicines11061765

Flexon, J. L., Meldrum, R. C., Young, J. T. N., & Lehmann, P. S. (2016). Low self-control and the Dark Triad: Disentangling the predictive power of personality traits on young adult substance use, offending and victimization. *Journal of Criminal Justice*, *46*, 159–169. https://doi.org/10.1016/j.jcrimjus.2016.05.006

Friedman, N. P., & Gustavson, D. E. (2022). Do rating and task measures of control abilities assess the same thing? *Current Directions in Psychological Science*, *31*(3), 262–271. https://doi.org/10.1177/09637214221091824

Gentile, A., Thomas, E., Feka, K., Di Vincenzo, A., Restifo, M., Amata, V., Alesi, M., Drid, P., Maksimovic, N., Bianco, A., & Boca, S. (2020). A single bout of physical exercise does not affect young adults' executive functions. *Biomedical Human Kinetics*, *12*(1), 226–235. https://doi.org/10.2478/bhk-2020-0029

Gutierrez-Colina, A. M., Davis, M., & Eaton, C. K. (2020). The role of executive functioning in health self-management and the transition to adult health care among college students. *Journal of American College Health, 68*(8), 845–852. https://doi.org/10.1080/07448481.2020.1775605

Hall, P. A., Fong, G. T., Epp, L. J., & Elias, L. J. (2008). Executive function moderates the intention-behavior link for physical activity and dietary behavior. *Psychology & Health, 23*(3), 309–326. https://doi.org/10.1080/14768320701212099

Hartman, S. J., Nelson, S. H., Myers, E., Natarajan, L., Sears, D. D., Palmer, B. W., Weiner, L. S., Parker, B. A., & Patterson, R. E. (2018). Randomized controlled trial of increasing physical activity on objectively measured and self-reported cognitive functioning among breast

cancer survivors: The memory & motion study. *Cancer*, *124*(1), 192–202. https://doi.org/10.1002/cncr.30987

Haverkamp, B. F., Wiersma, R., Vertessen, K., van Ewijk, H., Oosterlaan, J., & Hartman, E. (2020). Effects of physical activity interventions on cognitive outcomes and academic performance in adolescents and young adults: A meta-analysis. *Journal of Sports Sciences*, *38*(23), 2637–2660. https://doi.org/10.1080/02640414.2020.1794763

Higgins, J. P. T., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M. J., & Welch, V. A. (Eds.). (2022). *Cochrane handbook for systematic reviews of interventions* (Version 6.3). Cochrane. https://training.cochrane.org/handbook

Hillman, C. H., McAuley, E., Erickson, K. I., Liu-Ambrose, T., & Kramer, A. F. (2018). On mindful and mindless physical activity and executive function: A response to Diamond and Ling (2016). *Developmental Cognitive Neuroscience*, *37*. https://doi.org/10.1016/j.dcn.2018.01.006

Huang, T.-Y., Chen, F.-T., Li, R.-H., Hillman, C. H., Cline, T. L., Chu, C.-H., Hung, T.-M., & Chang, Y.-K. (2022). Effects of acute resistance exercise on executive function: A systematic review of the moderating role of intensity and executive function domain. *Sports Medicine - Open*, *8*(1), 141. https://doi.org/10.1186/s40798-022-00527-7

Hung, T., Tsai, C., Chen, F., Wang, C., & Chang, Y. (2013). The immediate and sustained effects of acute exercise on planning aspect of executive function. *Psychology of Sport and Exercise*, *14*(5), 728–736. https://doi.org/10.1016/j.psychsport.2013.05.004

Hwang, J., & Lu, A. S. (2018). Narrative and active video game in separate and additive effects of physical activity and cognitive function among young adults. *Scientific Reports*, *8*(1). https://doi.org/10.1038/s41598-018-29274-0

Hwang, J., Brothers, R. M., Castelli, D. M., Glowacki, E. M., Chen, Y. T., Salinas, M. M., Kim, J., Jung, Y., & Calvert, H. G. (2016). Acute high-intensity exercise-induced cognitive enhancement and brain-derived neurotrophic factor in young, healthy adults. *Neuroscience Letters*, *630*, 247–253. https://doi.org/10.1016/j.neulet.2016.07.033

Jaffery, A., Edwards, M. K., & Loprinzi, P. D. (2018). The effects of acute exercise on cognitive Function: Solomon Experimental Design. *The Journal of Primary Prevention*, *39*(1), 37–46. https://doi.org/10.1007/s10935-017-0498-z

Karbach, J., & Kray, J. (2020). Executive function training. In T. Strobach & J. Karbach (Eds.), *Cognitive Training: An Overview of Features and Applications* (pp. 199–212). Springer International Publishing. https://doi.org/10.1007/978-3-030-39292-5_14

Khandekar, P., Shenoy, S., & Sathe, A. (2022). Prefrontal cortex hemodynamic response to acute high intensity intermittent exercise during executive function processing. *The Journal of General Psychology*, *150*(3), 295–322. https://doi.org/10.1080/00221309.2022.2048785

Kim, Y. (2015). The effect of regular Taekwondo exercise on Brain-derived neurotrophic factor and Stroop test in undergraduate student. *Physical Activity and Nutrition*, *19*(2), 73–79. https://doi.org/10.5717/jenb.2015.15060904

Kmet, L. M., Lee, R. C., & Cook, L. S. (2004). *Standard quality assessment criteria for evaluating primary research papers from a variety of fields*. Alberta Heritage Foundation for Medical Research (AHFMR). https://doi.org/10.7939/R37M04F16

Lambourne, K., & Tomporowski, P. (2010). The effect of exercise-induced arousal on cognitive task performance: A meta-regression analysis. *Brain Research*, *1341*, 12–24. https://doi.org/10.1016/j.brainres.2010.03.091

Larson, M. J., LeCheminant, J. D., Carbine, K., Hill, K. R., Christenson, E., Masterson, T., & LeCheminant, R. (2015). Slow walking on a treadmill desk does not negatively affect executive abilities: an examination of cognitive control, conflict adaptation, response inhibition, and post-error slowing. *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.00723

Legrand, F., Albinet, C., Canivet, A., Gierski, F., Morrone, I., & Besche-Richard, C. (2018). Brief aerobic exercise immediately enhances visual attentional control and perceptual speed. Testing the mediating role of feelings of energy. *Acta Psychologica*, *191*, 25–31. https://doi.org/10.1016/j.actpsy.2018.08.020

Liguori, G., & American College of Sports Medicine. (2020). *American College of Sports Medicine's Guidelines for Exercise Testing and Prescription*. Lippincott Williams & Wilkins.

Liu, J., Min, L., Liu, R., Zhang, X., Wu, M., Di, Q., & Ma, X. (2023). The effect of exercise on cerebral blood flow and executive function among young adults: a double-blinded randomized controlled trial. *Scientific Reports*, *13*(1). https://doi.org/10.1038/s41598-023-33063-9

Loprinzi, P. D., & Kane, C. J. (2015). Exercise and cognitive function: a randomized controlled trial examining acute exercise and free-living physical activity and sedentary effects. *In Mayo Clinic Proceedings* (Vol. 90, No. 4, pp. 450-460). Elsevier. https://doi.org/10.1016/j.mayocp.2014.12.023

Ludyga, S., Gerber, M., Pühse, U., Looser, V. N., & Kamijo, K. (2020). Systematic review and meta-analysis investigating moderators of long-term effects of exercise on cognition in healthy individuals. *Nature Human Behaviour*, *4*(6), 603–612. https://doi.org/10.1038/s41562-020-0851-8

Ludyga, S., Held, S., Rappelt, L., Donath, L., & Klatt, S. (2023). A network meta-analysis comparing the effects of exercise and cognitive training on executive function in young and middle-aged adults. *European Journal of Sport Science*, *23*(7), 1415–1425. https://doi.org/10.1080/17461391.2022.2099765

May, R. W., Hutchinson, M., Seibert, G. S., Fincham, F., & Sanchez-Gonzalez, M. A. (2017). Improving cognitive performance via high intensity interval aerobic exercise: A randomized controlled trial. *Journal Exercise Physiology Online, 20,* 141-147.

McGrath, A. B., Weinstock, J., Cloutier, R., Christensen, M., Taylor, D. J., & Henderson, C. E. (2021). Examination of college student health behaviors and self-reported executive functions. *Journal of American College Health*, *71*(2), 1–11. https://doi.org/10.1080/07448481.2021.1904951

McHugh, M. L. (2012). Interrater reliability: The kappa statistic. *Biochemia Medica*, 276–282. https://doi.org/10.11613/BM.2012.031

McMorris, T., Sproule, J., Turner, A., & Hale, B. J. (2011). Acute, intermediate intensity exercise, and speed and accuracy in working memory tasks: A meta-analytical comparison of effects. *Physiology & Behavior*, *102*(3–4), 421–428. psyh. https://doi.org/10.1016/j.physbeh.2010.12.007

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734

Microsoft Corporation. (2024). *Microsoft Excel* (Version 16.91). Microsoft Corporation. https://www.microsoft.com

Moore, R. D., Romine, M. W., O'connor, P. J., & Tomporowski, P. D. (2012). The influence of exercise-induced fatigue on cognitive function. *Journal of Sports Sciences*, *30*(9), 841–850. https://doi.org/10.1080/02640414.2012.675083

Moreau, D., & Chou, E. (2019). The acute effect of high-intensity exercise on executive function: A meta-analysis. *Perspectives on Psychological Science*, *14*(5), 734–764. https://doi.org/10.1177/1745691619850568

Murray, N. P., & Russoniello, C. (2012). Acute physical activity on cognitive function: A heart rate variability examination. *Applied Psychophysiology and Biofeedback*, *37*(4), 219–227. https://doi.org/10.1007/s10484-012-9196-z

Oberste, M., Bloch, W., Hübner, S. T., & Zimmer, P. (2016). Do reported effects of acute aerobic exercise on subsequent higher cognitive performances remain if tested against an instructed self-myofascial release training control group? A randomized controlled trial. *PLoS ONE*, *11*(12), e0167818. https://doi.org/10.1371/journal.pone.0167818

Othman, N., Ahmad, F., El Morr, C., & Ritvo, P. (2019). Perceived impact of contextual determinants on depression, anxiety and stress: A survey with university students.

International Journal of Mental Health Systems, *13*(1), 17. https://doi.org/10.1186/s13033-019-0275-x

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ, 372*, n71. https://doi.org/10.1136/bmj.n71

Piercy, K. L., Troiano, R. P., Ballard, R. M., Carlson, S. A., Fulton, J. E., Galuska, D. A., George, S. M., & Olson, R. D. (2018). The physical activity guidelines for Americans. *JAMA*, *320*(19), 2020–2028. https://doi.org/10.1001/jama.2018.14854

Razon, S., Lebeau, J., Basevitch, I., Foster, B., Akpan, A., Mason, J., Boiangin, N., & Tenenbaum, G. (2017). Effects of acute exercise on executive functioning: Testing the moderators. *International Journal of Sport and Exercise Psychology*, *17*(4), 303–320. https://doi.org/10.1080/1612197x.2017.1349821

Sanderson, C., & Loprinzi, P. D. (2019). Acute exercise on reversal learning. *OBM Neurobiology*, *3*(4), 1. https://doi.org/10.21926/obm.neurobiol.1904043

Shen, Q., Yin, H., Cui, L., Zhang, J., Wang, D., Zhu, L., Wang, Y., & Li, X. (2021). The potential advantages of Tai Chi Chuan in promoting inhibitory control and spontaneous neural activity in young adults. *Frontiers in Behavioral Neuroscience*, *15*. https://doi.org/10.3389/fnbeh.2021.747733

Su, R., Wang, C., Liu, W., Han, C., Fan, J., Ma, H., Li, H., & Zhang, D. (2022). Intensity-dependent acute aerobic exercise: Effect on reactive control of attentional functions in acclimatized

lowlanders at high altitude. *Physiology & Behavior*, *250*, 113785. https://doi.org/10.1016/j.physbeh.2022.113785

Sudo, M., Komiyama, T., Aoyagi, R., Nagamatsu, T., Higaki, Y., & Ando, S. (2017). Executive function after exhaustive exercise. *European Journal of Applied Physiology*, *117*(10), 2029–2038. https://doi.org/10.1007/s00421-017-3692-z

Thomas, J., & D, V. (2017). A comparative study of the effects of Superbrain yoga and aerobic exercise on cognitive functions. *National Journal of Physiology Pharmacy and Pharmacology*, 1. https://doi.org/10.5455/njppp.2017.7.0309126062017

Tomporowski, P. D., Davis, C. L., Miller, P. H., & Naglieri, J. A. (2008). Exercise and children's intelligence, cognition, and academic achievement. *Educational Psychology Review, 20*(2), 111–131. https://doi.org/10.1007/s10648-007-9057-0

Toplak, M. E., West, R. F., & Stanovich, K. E. (2013). Practitioner review: do performance-based measures and ratings of executive function assess the same construct? *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *54*(2), 131–143. https://doi-org.ezproxy.library.dal.ca/10.1111/jcpp.12001

Tsai, C., Wang, C., Pan, C., Chen, F., Huang, T., & Chou, F. (2014). Executive function and endocrinological responses to acute resistance exercise. *Frontiers in Behavioral Neuroscience*, *8*. https://doi.org/10.3389/fnbeh.2014.00262

Tremblay, M. S., Carson, V., Chaput, J.-P., Connor Gorber, S., Dinh, T., Duggan, M., Faulkner, G., Gray, C. E., Gruber, R., Janson, K., Janssen, I., Katzmarzyk, P. T., Kho, M. E., Latimer-Cheung, A. E., LeBlanc, C., Okely, A. D., Olds, T., Pate, R. R., Phillips, A., … Zehr, L. (2016). Canadian 24-hour movement guidelines for children and youth: An integration of

physical activity, sedentary behaviour, and sleep. *Applied Physiology, Nutrition, and Metabolism*, *41*(6 (Suppl. 3)), S311–S327. https://doi.org/10.1139/apnm-2016-0151

Umegaki, H., Sakurai, T., & Arai, H. (2021). Active life for brain health: A narrative review of the mechanism underlying the protective effects of physical activity on the brain. *Frontiers in Aging Neuroscience*, *13*. https://doi.org/10.3389/fnagi.2021.761674

Veritas Health Innovation. (2022). *Covidence systematic review software*. Melbourne, Australia. Available at https://www.covidence.org

Wang, C., Chu, C., Chu, I., Chan, K., & Chang, Y. (2013). Executive function during acute exercise: the role of exercise intensity. *Journal of Sport and Exercise Psychology*, *35*(4), 358–367. https://doi.org/10.1123/jsep.35.4.358

Wang, C., Shih, C., Pesce, C., Song, T., Hung, T., & Chang, Y. (2015). Failure to identify an acute exercise effect on executive function assessed by the Wisconsin Card Sorting Test. *Journal of Sport and Health Science/Journal of Sport and Health Science*, *4*(1), 64–72. https://doi.org/10.1016/j.jshs.2014.10.003

Wang, Y., Tian, J., & Yang, Q. (2023). Tai Chi exercise improves working memory capacity and emotion regulation ability. *Frontiers in Psychology*, *14*. https://doi.org/10.3389/fpsyg.2023.1047544

Wilke, J. (2020). Functional high-intensity exercise is more effective in acutely increasing working memory than aerobic walking: an exploratory randomized, controlled trial. *Scientific Reports*, *10*(1). https://doi.org/10.1038/s41598-020-69139-z

Wilke, J., Stricker, V., & Usedly, S. (2020). Free-weight resistance exercise is more effective in enhancing inhibitory control than machine-based training: a randomized, controlled trial. *Brain Sciences*, *10*(10), 702. https://doi.org/10.3390/brainsci10100702

Zhang, M., Jia, J., Yang, Y., Zhang, L., & Wang, X. (2023). Effects of exercise interventions on cognitive functions in healthy populations: A systematic review and meta-analysis. *Ageing Research Reviews*, *92*, 102116. https://doi.org/10.1016/j.arr.2023.102116

Zhou, F., & Qin, C. (2019). Acute moderate-intensity exercise generally enhances attentional resources related to perceptual processing. *Frontiers in Psychology*, *10*. https://doi.org/10.3389/fpsyg.2019.02547

Zhu, H., Zhu, L., Xiong, X., Dong, X., Chen, D., Wang, J., Cai, K., Wang, W., & Chen, A. (2021). Influence of aerobic fitness on white matter integrity and inhibitory control in early adulthood: A 9-week exercise intervention. *Brain Sciences*, *11*(8), 1080. https://doi.org/10.3390/brainsci11081080

Zhu, L., Yu, Q., Herold, F., Cheval, B., Dong, X., Cui, L., Xiong, X., Chen, A., Yin, H., Kong, Z., Mueller, N., Kramer, A. F., & Zou, L. (2021). Brain structure, cardiorespiratory fitness, and executive control changes after a 9-week exercise intervention in young adults: A randomized controlled trial. *Life*, *11*(4), 292. https://doi.org/10.3390/life11040292

CHAPTER 3: LONG-TERM PHYSICAL ACTIVITY PATTERNS AND EXECUTIVE FUNCTIONS IN YOUNG ADULTS

The manuscript prepared for this study is presented below. Jenn Leckey, under the supervision of Dr. Sophie Jacques and Dr. Shannon Johnson, developed the research questions and methodology, led data collection, performed data analyses, interpreted results, and wrote a substantial amount of the manuscript.

Jenn Leckey, Cory A. Munroe, Shannon A. Johnson, Sophie Jacques. Long-term physical activity patterns and executive functions in young adults. [Manuscript in Submission Process]. Department of Psychology, Dalhousie University.

3.1 Abstract

The positive relationship between physical activity (PA) and executive functions (EFs) has been well-documented in children and older adults. However, this relationship among young adults, particularly regarding longer-term PA patterns, remains poorly understood. Our objective was to examine relationships between self-reported recent and lifetime PA patterns and EFs with a comprehensive battery of self-reported and performance-based EF measures, while accounting for potential covariates. We also aimed to group participants in terms of EF "profiles" and explore their relationship with PA. Undergraduate students (*N* = 212) completed a questionnaire assessing physical activity, EFs, and other related constructs (e.g., musical training, sleep, affect, perceived stress) prior to completing nine performance-based EF tasks online. The importance of PA in predicting EFs was mixed. In contrast, musical training, positive affect, and sleep quality exhibited stronger positive associations with EF outcomes. Two distinct EF profiles (Higher and Lower EFs) were identified, and PA did not predict profile membership. However, participants with musical training were more likely to belong to the Higher EFs profile. These findings emphasize the importance of adopting a multifaceted perspective of EFs that incorporates various lifestyle factors, which could facilitate the development of more effective strategies for promoting cognitive health in young adults.

3.2 Introduction

Physical activity (PA) has long been recognized for its positive effects on physical and mental health, including cardiovascular fitness, weight management, and overall well-being (Warburton et al., 2006). Recently, there has been a growing interest in the potential cognitive benefits of PA, particularly in relation to executive functions (EFs), the higher-order cognitive processes involved in goal-directed behaviour (Diamond, 2013). Young adulthood is a critical stage for optimizing EFs as the demands of transitioning to adulthood rely heavily on these skills (Othman et al., 2019). However, the relationships between PA, especially long-term PA patterns, and EFs in young adults is poorly understood given that previous research has typically focused on children and older adults, or the effects of short-term PA on a limited number of performance-based EFs measures (Haverkamp et al., 2020; Ho et al., 2018; Pachava & Shenoy, 2023; Salas-Gomez et al., 2020; Verburgh et al., 2014). Thus, in the current study, we investigated relationships between self-reported short- and long-term PA patterns and EFs with a comprehensive battery of self-reported and performance-based EF measures.

3.2.1 Executive Functions

Executive functions refer to the ability to regulate one's thoughts, feelings and actions to achieve desired outcomes (Duckworth et al., 2019). EFs encompass multiple interrelated skills (Diamond, 2013; Miyake et al., 2000) including working memory (the ability to retain and manipulate information in the mind), inhibitory control (the ability to resist temptation and impulsive reactions), and cognitive flexibility (the ability to change perspectives and approaches to adjust to new demands). Better EFs predict of a range of favourable outcomes, including health, well-being, resilience, academic and employment success, prosperity, and quality of life

(Cobb-Clark et al., 2022).

Despite the crucial role of EFs in helping young adults navigate the transition to adulthood (Othman et al., 2019), research with this age group remains limited compared to the extensive studies conducted with children and older adults (Cox et al., 2016; Salas-Gomez et al., 2020). Young adults with poor EFs are more likely to engage in risky and unhealthy behaviours (e.g., unhealthy diet; Allan et al., 2016; harmful substance use; Reynolds et al., 2019); whereas those with more advanced EFs are more likely to engage in health-promoting behaviours (Hall et al., 2008; McGrath et al., 2021). The prefrontal cortex continues to develop structurally and functionally well into the mid-twenties, with maturing neuronal pathways and strengthening synapses that enhance EFs (Tomporowski et al., 2008). There is evidence to suggest that EFs can be ameliorated at different ages through targeted intervention and training (Abdalkareem Jasim et al., 2024; Friese et al., 2017). Thus, identifying interventions that promote brain development and enhance EFs in young adulthood is especially important.

3.2.2 Intervention Effects of Physical Activity on Executive Functions

There is a growing interest in the potential cognitive benefits of exercise, particularly in relation to EFs (Pachava & Shenoy, 2023; Salas-Gomez et al., 2020). A review of the neurobiological effects of PA indicated that PA promotes increased cerebral blood flow, brain-derived neurotrophic factor levels, and neurogenesis, while reducing oxidative stress and inflammation, collectively supporting cognitive functioning (Umegaki et al., 2021). Indeed, intervention studies report that increasing PA over the short-term generally benefits EFs in individuals of different ages (see Abdalkareem Jasim et al., 2024, for a review).

In general, meta-analyses with children (Alvarez-Bueno et al., 2017; de Greeff et al.,

2018; Li et al., 2020; Song et al., 2023; Xue et al., 2019) and older adults (Contreras-Osorio et al., 2022; Xiong et al., 2021, Zhang et al., 2023) suggest that longer-term, repeated PA (also referred to as chronic PA) positively affects performance-based EFs. However, its impact on specific performance-based EFs is less clear. For example, in children, chronic PA has been linked to improvements in working memory and cognitive flexibility (de Greeff et al., 2018; Li et al., 2020), though some studies report mixed findings for inhibitory control (Alvarez-Bueno et al., 2017; Rathore & Lom, 2017; Song et al., 2023). In older adults, sport-based interventions enhanced working memory but not other EFs (Contreras-Osorio et al., 2022), while aerobic interventions lasting 13–26 weeks improved working memory, cognitive flexibility, and inhibitory control (Xiong et al., 2021). In their meta-analysis with adult populations, Zhang and colleagues (2023) found the greatest benefits of exercise over 3–6 months for EFs, though these findings primarily included older adults. Results of Haverkamp and colleagues' (2020) meta-analyses indicated a positive impact of chronic PA on adolescents' and young adults' attention, cognitive flexibility, and working memory performance but no effect for inhibitory control. There were no significant age-related differences in outcomes (Haverkamp et al., 2020).

Compared to the knowledge about children and older adults, research on relationships between chronic PA and EFs among young adults remains limited, warranting further investigation to clarify these associations and to understand the potential differential effects on specific EF components. To our knowledge, no studies have investigated the impact of PA over the lifetime on EFs, leaving a gap in understanding regarding the relationship between long-term activity patterns and cognition in young adults.

3.2.3 Associations Between Self-Reported Physical Activity and Executive Functions

Some correlational studies have indicated that self-reported PA over the past 7 days (Pachava & Shenoy, 2023; Salas-Gomez et al., 2020) and past 3 months (Lambourne et al., 2006) is positively associated with performance on neurocognitive measures of EFs among young adults. Salas-Gomez et al. (2020) and Pachava and Shenoy (2023) assessed self-reported PA over the past 7 days and found that PA was positively associated with performance on tasks measuring inhibitory control, cognitive flexibility, and working memory. Specifically, Salas-Gomez et al. (2020) reported that total self-reported PA was linked to better performance on the Stroop and Trail-Making Tests, while Pachava and Shenoy (2023) found that moderate levels of PA were associated with better performance on the Spatial Working Memory task of the Cambridge Neuropsychological Automated Testing Battery, but not attention or visual memory tasks. Extending the assessment period, Lambourne et al. (2006) found that self-reported PA over the past 3 months was positively associated with reading span, a measure of working memory. In contrast, Ho and colleagues (2018) found no significant relationship between young adults' self-reported PA and performance on the Flanker task, a measure of attention and inhibitory control.

Previous studies that investigated relationships between self-reported PA and EFs among young adults, including those described above (Ho et al., 2018; Pachava & Shenoy, 2023; Salas-Gomez et al., 2020), have typically utilized the International Physical Activity Questionnaire (IPAQ) or the IPAQ – Short Form (IPAQ-SF; Craig et al., 2003) to assess participants' PA levels. The IPAQ (27 items) and IPAQ-SF (7 items) measure "vigorous" PA, "moderate" PA, and "walking" over the previous 7 days. Similarly, Lambourne et al. (2006)

assessed PA by asking participants to report moderate and vigorous activities (i.e., “strenuous sports”, cycling, swimming) performed regularly over the past three months (see Kohl et al., 1988 for the measure).

While these measures provide valuable insights into recent PA levels, they share limitations. Both emphasize moderate-to-vigorous PA, which may not capture the full spectrum of PA habits, particularly when compared to a comprehensive list such as those from the Canada Fitness Survey (CFS; Statistics Canada, 1983). Consequently, most studies using the IPAQ or similar measures have focused on overall PA levels without investigating the relationship between participation in different PAs and EFs. Longitudinal research suggests that greater activity diversity (i.e., breadth of daily activities) is associated with greater performance-based EFs (Lee et al., 2021), highlighting the importance of gathering more detailed information about activities. Further, self-reported PA measured over the past week or few months does not capture long-term patterns. Gathering information about PA at different time points using a more detailed list of activities, as in the CFS, may provide a more nuanced understanding of young adults' PA patterns of the short and long term and their relationships with EFs.

3.2.4 Measuring Executive Functions

Previous investigations into the relationships between PA and EFs have predominantly utilized performance-based EF measures (Hall et al., 2008; Haverkamp et al., 2020; Ho et al., 2018; Pachava & Shenoy, 2023; Salas-Gomez et al., 2020), while largely neglecting self-report EF measures. Performance-based EF measures refer to performance on standardized and experimental tests that evaluate cognitive processes such as working memory, cognitive

flexibility, and inhibitory control (Best, 2010). These tasks provide concrete data on how well an individual can perform specific neurocognitive tasks under controlled conditions (Best, 2010). In contrast, self-reports involve individuals' subjective evaluations of their own applied EFs in daily life (Buchanan, 2016). Measuring EFs using both types of measures is crucial because performance-based tasks may not fully capture how EFs are employed in real-world settings (Friedman & Gustavson, 2022), and self-reported measures can offer insights into personal and contextual factors influencing cognitive functioning (Chaku et al., 2021).

In fact, a growing body of literature suggests that results on self-report and performance-based EFs measures are, at most, weakly correlated, and each has strengths and drawbacks (Dube et al., 2022; Friedman & Gustavson, 2022; Toplak et al., 2013). On one hand, although performance-based EF measures display good within-subject variability, they do suffer from poor test-retest reliability and predictive validity (Eisenberg et al., 2019; Enkavi et al., 2019). On the other hand, despite potential biases resulting from self-reports, self-reported EF measures display good between-subjects variability (Eisenberg et al., 2019; Enkavi et al., 2019) and within-subject correlations (Duckworth & Kern, 2011). Hence, incorporating a comprehensive battery of both performance-based and self-reported EFs measures offers a more comprehensive understanding of the relationships between PA and EFs across different contexts (Burgess et al., 1998).

3.2.5 Other Predictors of Executive Functions

Both PA and EFs are correlated with other variables (e.g., stress, sleep) that could account for their shared variance (Diamond, 2013). Unfortunately, previous research has generally not included co-variates aside from age and gender (Haverkamp et al., 2020; Pachava

& Shenoy, 2023; Salas-Gomez et al., 2020; Verburgh et al., 2014). Age is a well-known predictor of EFs, given that EFs improve throughout early development and peak in mid-adulthood (Diamond, 2013). There is ongoing debate with respect to the link between gender and EFs, such that some researchers report gender differences in EFs performance (Reilly, 2012; Vuontela et al., 2013), whereas others indicate minimal or no significant gender differences (Grissom & Reyes, 2019).

Other known predictors of EFs, such as multilingualism (Vassiliu et al., 2024), musical training (D'Souza et al., 2018), affect, stress, sleep quality (Diamond, 2013), and nature connectedness (Kasap et al., 2021) have not generally been accounted for when examining relationships between PA and EFs. Specifically, multilingual young adults tend to perform better than unilingual individuals across a range of EFs tasks (Vassiliu et al., 2024). Likewise, musical training experience has been associated with greater EFs abilities, particularly working memory (D'Souza et al., 2018). Increased connectedness with nature has been consistently associated with greater EFs abilities and well-being (Kasap et al., 2021). Generally, those with higher positive affect, better sleep quality, lower stress, and lower negative affect demonstrate better EFs (Diamond, 2013). Moreover, PA is known to fluctuate with affect, stress, and sleep quality (Chennaoui et al., 2015; Schöndube et al., 2016). Thus, to determine the true relationships between PA and EFs it is important to account for these potential covariates.

3.2.6 Executive Function Profiles

Most research on EFs is variable-centered, focusing on how measures of EFs relate to each other and emphasizing variability between individuals (Beltz, 2018). When multiple EFs are measured, they are frequently analyzed in competition to determine which accounts for the

most variance in specific outcomes. Consequently, variable-centered approaches may oversimplify the complexity of EF by not accounting for the interrelatedness of EF skills within individuals (Chaku et al., 2021). In contrast, person-centered methods, such as latent profile analyses (LPA), have garnered recent interest as they offer a data-driven method of identifying unique "profiles" of skills within individuals (Chaku et al., 2021; Spurk et al., 2020). For example, Chaku and colleagues (2021) and Malagoli and colleagues (2022) used LPAs to identify distinct EF profiles among adolescents. Chaku and colleagues (2021) found that these profiles were uniquely associated with outcomes such as academic performance, mental health, risk-taking behaviours, and the quality of social relationships, whereas Malagoli and colleagues (2022) did not observe associations between EF profiles and socio-demographic characteristics or psychological variables.

To our knowledge, only one study has investigated EF profiles among young adults. Rau et al. (2015) used two tasks measuring cognitive flexibility and attentional control to identify three distinct EFs profiles (i.e., average EF performance, set maintenance weakness, and cognitive flexibility and verbal weaknesses). Despite their use of this important person-centered approach, the limited number of EF measures may have restricted their ability to capture the full complexity of EF profiles. Moreover, they did not examine whether EF profiles are uniquely associated with lifestyle variables, such as PA or musical training, or with current state variables, such as stress or sleep, underscoring the need for further research using a person-centered approach in young adults.

3.2.7 Current Study

The first objective of the current study was to examine the relationships between PA

measured over different time periods (i.e., over the past month and lifetime) and various components of both self-reported and performance-based EFs in young adults, while accounting for other known covariates of PA and EFs. We hypothesized that participating in a greater number of PAs over the past month and throughout the lifetime would predict performance-based and self-reported EFs even after controlling for other known correlates. Identifying how young adults' engagement in PA over the short and long terms relate to different EFs components may provide insight into the potential benefits of recent and lifetime PA on specific EFs that could help inform both theory and interventions aimed at enhancing cognitive health during this important stage of life.

The second objective was to explore EF profiles in young adults and examine whether PA and other factors (mood, stress, sleep) predict membership in each profile. We hypothesized that young adults would cluster into EF profiles, but did not predict the specific composition of these profiles or their relationship to other factors given limited prior research. Exploring EF profiles and understanding the potential reciprocal relationship between PA and EF will further refine our understanding of how these factors interact to influence both cognitive and physical health outcomes in young adults.

3.3 Method

3.3.1 Participants

Students (*N* = 233) at a Canadian university were recruited through an online undergraduate student recruitment pool. Participants were required to be between the ages of 18 to 30, attending university at the time of participation, and capable of understanding, reading, and speaking English fluently based on self-report. They were also required to have

access to a computer with a microphone and webcam that connected to the internet. All participants received bonus points to be used towards an undergraduate course and were entered to win one of ten Amazon e-gift cards.

Of the 233 participants recruited, three participants were excluded for self-reporting that they were over the age of 30 and 18 participants were excluded for not completing the second part of the study, resulting in a final sample of 212. Participants were on average 20.7 years of age (*SD* = 2.5) and 76.4% identified as women (*n* = 162), 21.2% identified as men (*n* = 45), and 2.4% identified as non-binary (*n* = 5). Given the limited number of non-binary individuals in our sample, their gender information was categorized as 'missing' for the analyses. This decision ensured both statistical reliability and confidentiality, as including such a small subgroup could potentially compromise the anonymity of participants and affect the robustness of the statistical analyses.

The sample was relatively evenly distributed across years of undergraduate schooling, with 25.9% being in their first year (*n* = 55), 18.9% in their second year (*n* = 40), 25.5% in their third year (*n* = 54), 25.5% in their fourth year (*n* = 54), and 4.3% in their fifth or sixth year (*n* = 9). Most participants reported English as their first language (86.8%, *n* = 184) and 71.2% reported being multilingual (*n* = 151). Those who did not report English as their first language reported it as their second language. Many participants reported having engaged in musical training (65.1%, *n* = 138), which began around the age of 8 on average (*SD* = 3.7).

3.3.2 Study Design

Participants completed the study in two parts: 1) a questionnaire, and 2) an EFs testing session. The questionnaire was completed on Opinio (ObjectPlanet, 1998-2025), an online

survey management platform and included the Barratt Impulsiveness Scale – 11 (BIS; Patton et al., 1995) and the Learning, Executive, and Attention Functioning scale (LEAF; Castellanos et al., 2018) as measures of self-reported impulsivity and EFs, respectively, lifetime PA, and other variables known to covary with EFs (i.e., demographic information, multilingualism, musical training, perceived sleep quality, perceived stress, positive and negative affect, and nature connectedness). On average, participants took 55 min (*Mdn* = 28.5 min, *SD* = 202.9) to complete the questionnaire. The large variation in completion time is because participants could save and return to the questionnaire later, and Opinio does not account for periods of inactivity. Within one week following the completion of the questionnaire, participants completed a testing session including nine performance-based EFs measures. Five tasks (Digit Span, Wechsler, 2008; Verbal Fluency, Delis et al., 2001; Colour-Word Interference Test, Delis et al., 2001; Paced Auditory Serial Addition Task, McInerney et al., 2003; Flexible Item Selection Task, Jacques & Zelazo, 2001), requiring verbal responses from participants, were administered and videorecorded by a researcher via Zoom. Immediately following the completion of the Zoom tasks, participants were provided a link to complete the remaining four tasks independently online using the Dalhousie Cognitive Assessment Battery (DalCAB; Flanker, Choice Response Time, Dual Task, Go/No-Go; Jones et al., 2016). These required keyboard responses and measured both accuracy and response time. The researcher remained available for any questions that arose during the completion of the DalCAB tasks and participants returned to the Zoom session afterward to check in. All participants provided electronic informed consent immediately prior to completing the online questionnaire and verbal consent prior to beginning the testing session.

3.3.3 Measures

Background and Demographic Questionnaire

Demographic Information. Participants provided their gender, age, year of schooling, and general health information. This information was used to characterize our sample, and age and gender were used in the analyses.

Language. The Language Background Section of the Language and Social Background Questionnaire (LSBQ, Anderson et al., 2018) includes questions about languages known, when they were learned, the contexts of usage, and proficiency in each language. Participants were coded as unilingual, if the only language known was English, or multilingual, if they reported knowing more than one language.

Musical Training. The Music USE questionnaire (MUSE; Chin & Rickard, 2012) assesses music engagement. Participants completed a subset of four questions from the Index of Music Instrument Playing of the MUSE. Participants were coded as having formal musical training experience or not based on their yes/no response to “Have you ever taken music lessons?”.

Current State Questionnaire Measures

Mood. The Positive and Negative Affect Schedule-Short Form (PANAS-SF; Watson et al., 1988) consists of two 10-item scales – one measuring positive affect and one measuring negative affect over the past few weeks. Each item is rated on a 5-point Likert scale and higher scores represent higher levels of positive and negative affect, respectively. Participants’ mean scores on both scales were included in the analyses.

Stress. The Perceived Stress Scale (PSS-10; Cohen et al., 1983) consists of 10 items rated with a 5-point Likert scale. Higher scores are indicative of greater perceived stress. Due to

experimenter error, a portion of our participants (n = 76) only received eight of the ten PSS items on the questionnaire. Once this error was discovered, the remaining participants (n = 136) completed the full 10-item scale. For consistency, we used the mean rating of the eight items that were completed by all participants as the measure of perceived stress. For the participants with all 10 items available, the correlation between the mean of the 10 and 8 items was strong (r = .98, p < .001).

Sleep Quality. The Medical Outcomes Study (MOS) Sleep Scale Survey Instrument (Hays & Stewart, 1992) surveys sleep length, disturbance, and quality during the previous four weeks. It consists of two written response questions and 10 items rated on a 6-point Likert Scale. The Sleep Problems Index II, which includes nine of the 10 Likert Scale items, was used for our analyses. These items were reverse scored so that higher scores represented better sleep quality, rather than sleep disturbance.

Lifestyle Measures

Nature Connectedness. The Nature Connectedness Index (NCI; Richardson et al., 2019) is a measurement of the extent to which a person feels emotionally connected to the natural world. It involves rating six items on a 7-point Likert scale and each rating corresponds to weighted points. Participants' mean scores across the six items were used for the analyses and higher scores reflect a greater connection to nature.

Physical Activity. Participants reported their PA using questions based on the PA section of the CFS (Statistics Canada, 1983). These questions surveyed what PAs participants engaged in during an average week in the month prior as well as in the last year, in the last 5 years, and at any point during their life. The list of PAs provided to participants is shown in Appendix B and

there were additional fillable spaces for activities that were not listed. For the activities participated in during the past month, participants reported the average duration (in min) and frequency (in number of times per week) of the activity. Participants received a score for total number of activities participated in in their lifetime (Lifetime PA), total number participated in in the past month (Past Month PA), and total Metabolic Equivalent of Tasks (METs) exerted in the past month (Past Month METs). The Past Month METs score was calculated based on the MET values identified for each activity in the Compendium of Physical Activities (Ainsworth et al., 2011), multiplied by the average duration and frequency of the activity participants reported in the past month. The METs for each activity were then summed to obtain a total METs score for the month.

Self-reported EF Measures

LEAF Scale. The LEAF (Castellanos et al., 2018) was originally developed to assess learning- and EF-related abilities in children and adolescents between the ages of six to 17. It comprises 11, 5-item subscales that fall into one of three content areas: academic, cognitive learning, and cognitive EFs. Each item is rated on a 4-point Likert scale based on experiences in the past week. Munroe and colleagues (2025) validated the LEAF scale with the participants in the current study and 343 additional undergraduate students. Factor analyses revealed that the EFs content area for undergraduates encompassed both the cognitive learning and cognitive EFs content areas initially identified with children and adolescents (Castellanos et al., 2018; Munroe et al., 2025). Therefore, the overall mean of the 39 items included in the EFs subscales from Munroe and colleagues' (2025) study was utilized in the current study. These included the following subscales: Attention, Planning and Organization, Memory, Comprehension and

Conceptual Learning, Novel Problem Solving, and Processing Speed. Higher scores reflect greater difficulty with EFs.

BIS-11. The BIS-11 (Patton et al., 1995) is a 30-item measure of self-reported impulsivity. Items related to Attentional Impulsiveness, Motor Impulsiveness, and Nonplanning Impulsiveness are rated on a 4-point Likert scale and some items are reverse-scored. The overall mean of all 30-items was used, with higher scores reflecting greater self-reported impulsivity.

Performance-Based Measures of EFs

Measures Administered by Researcher via Zoom (Listed in Order of Administration).

Digit Span. The Digit Span subtest of the Wechsler Adult Intelligence Scale-Fourth Edition (WAIS-IV; Wechsler, 2008) is a widely used measure of working memory capacity and attention. Participants are presented with progressively longer sequences of digits orally and asked to say the digits back in the same order (Digit Span Forward), in reverse order (Digit Span Backward), or in numerical order (Digit Span Sequencing). The total number of correct items was summed across the three subtests and used in the current study with higher scores indicating greater working memory ability.

Verbal Fluency. The Verbal Fluency Test, a subtest of the Delis-Kaplan Executive Function System (D-KEFS; Delis et al., 2001; Baron, 2004), assesses verbal fluency, word retrieval, and cognitive flexibility. Participants generate words according to specific criteria within a limited time frame. Phonemic fluency involves generating words that begin with a particular letter, semantic fluency involves generating words within a particular category, and switching involves alternating naming words from two different categories. A verbal fluency score of correct words summed across the three conditions was used.

Colour-Word Naming. The Colour-Word Interference Test of the D-KEFS (Delis et al., 2001; Baron, 2004)—a version of the Stroop test (Stroop, 1935)—assesses inhibitory control and cognitive flexibility. The four conditions are completed in order: 1) name the colours of the series of squares presented on the screen (Colour Naming), 2) read the colour words presented in black ink on the screen (Word Reading), 3) name the ink colours of colour words printed in incongruent ink colour (e.g., the word "red" printed in blue ink; Colour-Word Interference), and 4) name the ink colours of colour words printed in incongruent ink colours unless words are surrounded by a box, in which case, the colour word is named (Switching). The time taken to complete the Colour-Word Interference condition was used as a measure of inhibitory control. Longer times indicate poorer inhibitory control.

Paced Auditory Serial Addition Task. The Victoria Computerized Adaptation of the Paced Auditory Serial Addition Task (PASAT; McInerney et al., 2003) was selected as a measure of working memory due to its challenging nature, which makes it well-suited for assessing undergraduate students' cognition (Brooks et al., 2011). A series of single-digit numbers are presented auditorily at a fixed pace and participants are asked to add each new number to the one immediately preceding it and verbally report the sum. Two blocks of trials are administered using the identical sequence of numbers. In the first block, numbers are presented every 1.6 sec and in the second, numbers are presented every 1.2 sec. The total number of correct answers is summed across the two blocks, with a higher score indicating better working memory ability.

Flexible Item Selection Task (FIST). The 4-item FIST (Jacques & Zelazo, 2001) is a cognitive flexibility measure. Participants are presented with four items on their screen (e.g., large red circle, large blue circle, small yellow circle, medium yellow circle) and asked to name

two pairs of matching items; one pair matches on one attribute (e.g., size; the two large circles), and the second pair matches on a different attribute (e.g., colour; the two yellow circles). For nine trials, items consist of pairs of items with no overlapping attributes. In the other nine trials, one item is included in both pairs, necessitating cognitive flexibility to navigate the overlap. Scores were derived based on the sum of correct pairs identified on only the trials that required cognitive flexibility, with a higher score indicating better cognitive flexibility.

DalCAB Measures (Listed in Order of Administration).

Flanker. The Flanker subtest of the DalCAB (Jones et al., 2016) is a measure of multiple EFs abilities. A central stimulus is presented on the screen, which is flanked above or below with other stimuli (flankers) that are either the same as (congruent) or different than (incongruent) the central stimulus. Participants indicate on their keyboard whether the central stimulus is red or black while ignoring the flankers. Reduced accuracy and longer response times are expected on incongruent trials compared to congruent trials. The interference effect, the incongruent trial response times compared to the congruent trial response times, is a measure of selective attention and filtering (Jones et al., 2016) and was used for our analyses. A greater interference effect indicates poorer EFs.

Dual Task. The Dual Task subtest of the DalCAB (Jones et al., 2016) is a measure of cognitive flexibility. First, participants completed the 2-Choice Reaction Time subtest, which involves indicating the colour of the stimulus presented on the screen with the left and right arrow keys (e.g., left arrow for red stimuli, right arrow for black stimuli). The Dual Task subtest involves the same task as 2-Choice Reaction Time while participants simultaneously keep a mental tally of the frequency of each stimulus colour. The difference between response time on

2-Choice Reaction Time and Dual Task was used for our analyses. A greater difference score indicates poorer cognitive flexibility.

Go/No-Go. The Go/No-Go subtest of the DalCAB (Jones et al., 2016) is a measure of inhibitory control. A continuous series of two stimuli is presented one at a time, and participants are instructed to respond to one type of stimuli (Go), while withholding their response to the other type of stimuli (No-Go). For one half of the task, Go stimuli are presented for 80% of trials and for the other half of the task, No-Go trials are presented for 80% of trials. The number of "false alarm" presses (go responses on no-go trials) in the 80% Go condition was included in the analyses. A greater number of false alarm responses indicates worse inhibitory control.

3.3.4 Data Analytic Plan

Descriptive statistics, including means, standard deviations, skewness, and kurtosis were computed for all variables of interest and distributions were explored with histograms. The raw data were cleaned using SPSS Statistics, Version 28.0.1.1 (IBM, Armonk, NY, USA). We examined participants' completion time for the online questionnaire, missing values, and univariate outliers. Univariate outliers were screened by identifying scores that were > 3 *SD*s from the mean. If outlier data seemed valid upon examination, outlier scores were adjusted to one unit above/below the next highest/lowest score as recommended by Tabachnick and Fidell (2014). Outliers that appeared to be invalid were coded as missing values. Pairwise deletion was used for all analyses.

Physical Activity Predicting Executive Functions

Zero-order correlational analyses were completed for all variables of interest. Multiple linear regression analyses were conducted to predict each of the EFs outcome variables. Multiple regression assumptions were checked, which included examining correlation coefficients and VIF values for multicollinearity, residual scatterplots for homoscedasticity and normality, and Mahalanobis distances for multivariate outliers. Regression coefficients, model fit statistics, and *p*-values were examined to evaluate the strength and significance of the relationships. Additionally, relative importance analyses were conducted to determine the relative contribution of each predictor variable to the overall models. For effect sizes, we relied on semi-partial squared correlations (sR^2) and measures of relative importance using the Lindeman, Merenda and Gold (lmg) method in Grömping's (2006) relaimpo package in R Statistical Software, Version 4.3.1 (Foundation for Statistical Computing). An alpha level of .05 was set for all inferential statistics.

Executive Function Profiles

LPA was utilized to identify profiles among young adults who share similar EF characteristics. Five models (i.e., 1-profile to 5-profile models) with the nine EF scores were tested iteratively in MPlus Version 8.10 (Muthen & Muthen, 2017). Maximum likelihood estimation was used to account for missing data and each model was run with 500 random starts. Model fit statistics and model interpretability (e.g., profile content and parsimony) were considered when evaluating the number of classes to retain. The following fit statistics were considered in the selection of the best fitting model: i) the log-likelihood parameter, with values closer to zero indicating better model fit; ii) the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and adjusted BIC (aBIC), with lower values reflecting better fit; iii)

the Lo-Mendell-Rubin adjusted and Vuong-Lo-Mendell-Rubin likelihood ratio tests (LMR-A-LRT; VLMR-LRT), where a significant *p*-value indicates that the model provides a better fit compared to a model with one fewer profile; iv) entropy value, with higher values representing better classification accuracy.

Physical Activity Predicting Executive Function Profiles

After selecting the best-fitting profile solution, logistic regression analyses were conducted to predict EFs profiles. Outliers were identified by inspecting standardized residuals, and the linearity of the logit assumption was tested using the Box-Tidwell procedure. Additionally, to ensure the stability and reliability of the models, an adequate number of events per variable (EPV) was maintained, adhering to the recommendation of at least 10 EPV as outlined by Peduzzi et al. (1996). These analyses were completed with SPSS Statistics, Version 28.0.1.1 (IBM). An alpha level of .05 was set for all inferential statistics.

3.4 Results

Data processing was completed prior to conducting analyses. Some participants (*n* = 11) reported duration and frequency for PAs that they did not endorse participating in within the past month. The duration and frequency values for these activities were coded as missing to avoid over-estimating activity. Participants indicated participating in an average of 36 activities (*SD* = 23.13) in their lifetime and expending an average of 429.88 METs (*SD* = 483.59) in the month prior to completing the study questionnaire.

In terms of EFs task data, one participant did not complete the Colour-Word Interference Test and one did not complete Verbal Fluency. Due to software error, two participants did not complete any DalCAB tasks, Flanker data did not save for two participants, Flanker and Dual Task

data did not save for one participant, and Dual Task and Go/No-Go data did not save for one participant. Of the 16 univariate outlier datapoints that were identified across all variables (Sleep Quality (*n* = 1); Past Month PA (*n* = 1); Past Month METs (*n* = 2); BIS (*n* = 2); Digit Span (*n* = 3); Go/No-Go (*n* = 4); Dual Task (*n* = 2)), most (*n* = 13) appeared to be valid upon inspection and were changed to one unit above/below the next highest/lowest score. The few (*n* = 3), all from the Go/No-Go task, that appeared to be invalid data were also extreme outliers (e.g., > 7 *SD*s from the mean), and were coded as missing values.

While we initially planned to use accuracy contrast scores for the Flanker and Dual Task subtests, the negative skewness and kurtosis of these scores indicated ceiling effects. Thus, we opted to use response time contrast scores for the analyses instead. Square root transformations were done for the past month METs and Go/No-Go false alarm scores as they were positively skewed (Tabachnick & Fidell, 2014). An inverse square root transformation was completed for FIST scores, which were negatively skewed (Tabachnick & Fidell, 2014), and the transformed FIST score was again inversed by multiplying by -1 so that higher scores indicated better cognitive flexibility.

Correlation coefficients among variables were all <.70 (except for the self-reported LEAF and BIS scores, see below) and VIF values were < 3, so were not indicative of multicollinearity. Residual scatterplots indicated homoscedasticity and normality. Three multivariate outliers were identified with Mahalanobis distances, and these participants were excluded from the regression and relative importance analyses. Descriptive statistics for all variables included in the analyses are presented in Table 3.1.

3.4.1 Correlational Analyses

Bivariate correlations for all variables included in the analyses are also displayed in Table 3.1. Gender was weakly negatively correlated with multilingualism and sleep quality, indicating that men were more likely to be multilingual and have poorer sleep quality than women. The weak positive correlation between gender and Verbal Fluency indicates that women tended to perform slightly better on Verbal Fluency. Self-reported history of musical training was correlated with self-reported engagement in a greater number of lifetime PAs, and better performance on Colour Word Interference and Verbal Fluency.

Greater levels of positive affect were correlated with lower negative affect, lower stress, better sleep quality, greater connectedness to nature, greater number of lifetime PAs, more METs exerted in the past month, and better (lower scores) self-reported EFs. Conversely, greater levels of negative affect were correlated with higher stress levels, poorer sleep quality, and poorer self-reported EFs. Greater stress levels were correlated with poorer sleep quality, fewer lifetime PAs, fewer past month METs, and poorer self-reported EFs. Higher nature connectedness was correlated with greater past month METs.

Participants who reported a greater number of PAs over their lifetime also reported greater past month METs. Lifetime PA was positively correlated with Verbal Fluency performance. Past month METs was correlated with better self-reported EFs, but poorer performance on Digit Span and the PASAT.

In terms of correlations among EFs measures, better self-reported EFs was correlated with better performance on Colour Word Interference. Better performance on Colour Word Interference was correlated with better performance on the four other Zoom tasks (i.e., Verbal

Fluency, Digit Span, the PASAT, FIST). Verbal Fluency was also positively correlated with all other Zoom tasks. In addition to relationships with Colour Word Interference and Verbal Fluency, better performance on Digit Span was associated with better performance on the PASAT and with Dual Task. The DalCAB tasks were not significantly correlated with one another.

3.4.2 Multiple Regression and Relative Importance Analyses

Given the strong correlation ($r = .71$, $p < .001$) between the LEAF and BIS scores, a composite mean score for these was created. This composite self-reported EFs score (LEAF BIS) and each of the eight performance-based EF scores (i.e., Colour Word Interference Time, Verbal Fluency Total, Digit Span Total, PASAT Total, FIST Flexible Total, Flanker Interference Response Time, Dual Task Two-Task Cost Response Time, Go/No-Go False Alarm Presses) were predicted in a series of regression analyses. Given that PA variables were our primary interest, lifetime number of PAs and Past Month METs[1] were entered in separate regression models along with nine other predictors (i.e., age, gender, multilingualism, musical training, positive affect, negative affect, stress, sleep quality, and nature connectedness). This totalled 18 multiple regression models, each with 10 predictors. Results of the 18 multiple regression models with relative importance are presented in Tables 3.2–3.10.

Collectively, for the composite self-reported EFs score (LEAF BIS), the model with lifetime PA and the model with past month METs accounted for 35% and 36% of the variance, respectively, mainly due to the relative importance of sleep quality, stress, positive affect, and

[1] Exploratory analyses revealed that results for regression models including past month number of PAs and past month METS were nearly identical, which is unsurprising given that they are both measures of past month PA. Therefore, we opted to use past month METS as it incorporates number of activities, in addition to duration, frequency, and energy expenditure.

negative affect. When lifetime PA was used as a predictor, the variance in self-reported EFs was primarily accounted for by the importance of four variables (R^2 = .34): sleep quality (*RI* = .13), stress (*RI* = .09), positive affect (*RI* = .08), and negative affect (*RI* = .04). Similarly, with Past Month METs as a predictor, the variance was also primarily accounted for by the importance of four variables (R^2 = .34): sleep quality (*RI* = .13), stress (*RI* = .08), positive affect (*RI* = .08), and negative affect (*RI* = .04). Only sleep quality and positive affect emerged as significant predictors in both models.

The 10 predictors in both Colour Word Interference Time models accounted for 7% of the variance, mainly due to the relative importance of musical training (R^2 = .05; *RI* = .05). For Verbal Fluency, the model with lifetime PA and the model with past month METs accounted for 12% and 9% of the variance, respectively. With lifetime PA as a predictor, the variance was primarily accounted for by the importance of two variables (R^2 = .07): musical training (*RI* = .05) and lifetime PA (*RI* = .04) and both emerged as significant predictors. With past month METs as a predictor, the variance was largely accounted for only by the importance of musical training (R^2 = .05, *RI* = .06), which was also a significant predictor.

For Digit Span, the model with lifetime PA and the model with past month METs accounted for 4% and 6% of the variance, respectively. For the PASAT, the model with lifetime PA and the model with past month METs accounted for 6% and 10% of the variance, respectively. The variance in the models with past month METs as a predictor for both working memory tasks was primarily accounted for by the importance of past month METs (R^2 = .04, *RI* = .02 for Digit Span; R^2 = .06, *RI* = .04 for the PASAT). Past month METs also emerged as a significant negative predictor in these two models, contrary to expectations.

For the FIST and Go/No-Go False Alarm presses, both models explained 2% of the variance and for Dual Task Two-Task Cost Response Time, both models explained 3% of the variance. For the Flanker Interference Response Time, the model with lifetime PA and the model with past month METs accounted for 5% and 4% of the variance, respectively. However, no predictors emerged as particularly important or significant in the FIST, Go/No-Go, Flanker, or Dual Task models. A summary of the significant predictors and the direction of the relationships for each model is presented in Table 3.11.

3.4.3 Latent Profile Analyses

The nine EF measures were included in the LPA to create EF "profiles". Fit indices for number of profiles tested (1 – 5) are presented in Table 3.12. There was a substantial decrease in the fit indices for a 2-profile solution compared to a 1-profile solution. When estimating more than two profiles, however, the decrease in values related to model fit was comparatively small. The statistically significant likelihood ratio tests for the 2-profile solution further indicated best fit. While the entropy value increased with each added profile, all other indices indicated that a 2-profile solution was best fit. Upon visual inspection of the meaningfulness of 2-, 3- , and 4-profile models, the 2-profile solution was retained. The 2-profile solution represented the best combination of fit indices, profile composition, and interpretability. The two profiles are described in detail below and illustrated in Figure 3.1.

Descriptive labels for each profile were based on scores on EF measures. Profile 1 (Lower EFs) constituted 58% of the sample and Profile 2 (Higher EFs) constituted 42% of the sample. A summary of differences between EF skills by profile is provided in Table 3.13. Significant differences favoring Profile 2 (Higher EFs) were observed between the two profiles for all EFs

tasks, except for the Flanker. Those in Profile 2 also self-reported significantly lower EF difficulties on the LEAF BIS composite. While it appears that young adults in Profile 1 (Lower EFs) performed better on the Flanker measure than those in Profile 2 (Higher EFs), the difference was not statistically significant.

3.4.4 Logistic Regression Analyses

To examine whether participants with the two EF profiles differed significantly from each other in terms of PA and the other predictors, two logistic regression analyses were conducted—one including lifetime PA and the other, past month METs. Preliminary results indicated that negative affect was not linearly related to the log-odds of the EFs Profile variable. A follow-up analysis incorporating a quadratic term for negative affect did not impact significance of the logistic regression results. Consequently, the untransformed negative affect variable was retained in the final analyses.

The logistic regression analysis including lifetime PA and nine additional predictors conducted to predict EF profile membership was statistically significant, $\chi 2$ (1, 10) = 18.70, p = .044, and correctly classified 67.1% of cases. Musical training emerged as the only significant predictor, with an odds ratio of 2.40 (95% CI [1.24, 4.66]). This indicates that participants with musical training were 2.40 times more likely to belong to Profile 2 (Higher EFs) compared to those without musical training. However, the logistic regression analysis including past month METs and nine additional predictors, was not statistically significant $\chi 2$ (1, 10) = 17.78, p = .059.

3.5 Discussion

In the current study, we examined relationships between PA, both over the past month and lifetime, and EFs, measured through both self-reported and performance-based measures,

among young adults. Research on the relationship between longer-term, or chronic PA, on EFs among young adults is relatively limited and existing findings are mixed. Previous studies (Ho et al., 2018; Pachava & Shenoy, 2023; Salas-Gomez et al., 2020) have often relied on broad measures of PA, assessed one or few components of EFs, and have not incorporated important covariates. To address these limitations, we administered a detailed assessment of PA, a comprehensive battery of 10 EFs measures (both self-reported and performance-based), and included a range of additional variables that could influence the PA-EFs relationship to young adults. We first examined whether past month METs and lifetime number of PAs predicted self-reported and performance-based EFs tasks, while accounting for the role of other predictors of EFs, namely, age, gender, multilingualism, musical training, perceived sleep quality, perceived stress, positive and negative affect, and nature connectedness. Secondly, we investigated if and how young adults could be grouped into distinct EF "profiles" and whether these profiles were associated with PA and the other measures.

Broadly, our results indicate that although PA related to some aspects of EFs, other variables including musical training, positive affect, and perceived sleep quality better predicted EFs. Additionally, two distinct EFs profiles were identified: one representing a group with higher EFs and another with lower EFs. No differences in PA were observed between the two profiles, although those with musical training were more likely to be in the higher EF profile.

3.5.1 Predicting Executive Functions

Overall, the multiple regression models explained a relatively small proportion of variance in EF performance but a larger proportion of variance in self-reported EF. This could be partially due to measurement approach; measures that share modality (e.g., self-report) tend to

correlate more strongly with each other because they are influenced by common factors, such as subjective perception of one's abilities (Podsakoff et al., 2003). Further, the variables in the models may have been more relevant to predicting self-reported EFs, compared to performance-based EFs. That is, self-reported EF measures capture applied EFs in real-world contexts, which may be more influenced by lifestyle factors such as PA, sleep, and affect (Diamond, 2013). In contrast, performance-based EF tasks are designed to measure specific EFs in controlled conditions, which may be less influenced by these broader lifestyle variables (Duckworth & Kern, 2011). Indeed, we found only one significant correlation between the LEAF BIS score and a performance-based EF measure, namely, Colour-Word Interference RT. These findings align with the literature demonstrating that self-reported and performance-based EFs measures are, at most, weakly correlated with some studies suggesting they represent different constructs entirely (Duckworth & Kern, 2011; Friedman & Gustavson, 2022). Thus, the applied EFs that individuals perceive and report in daily life may not necessarily correspond to their performance on standardized cognitive tasks.

The DalCAB and FIST performance-based EF measures were not significantly predicted by any of the measures included in our models. The ceiling effect observed on these measures could have limited the ability to detect meaningful variations in EFs performance, potentially obscuring relationships with other factors.

3.5.2 The Role of Physical Activity in Predicting Executive Functions

We hypothesized that greater past month and lifetime PA would predict better self-reported and performance-based EFs. However, our results indicate that a greater number of lifetime PAs only predicted better Verbal Fluency performance but explained only a small

amount of variance. This suggests that while lifetime number of PAs may relate to specific cognitive functions, such as Verbal Fluency, the overall impact on broader EF abilities may be limited. Although previous intervention (Haverkamp et al., 2020) and correlational (Salas-Gomez et al., 2020) studies have identified positive relationships between PA and young adults' cognitive flexibility, measures of cognitive flexibility (e.g., Colour-Word Interference, the FIST, Dual Task) in our study were not predicted by past month or lifetime PA. Verbal Fluency may differ from the other tasks in that it involves language production and retrieval skills in addition to cognitive flexibility (Shao et al., 2014). The combination of cognitive abilities required for Verbal Fluency suggests that it may have a stronger reliance on crystallized intelligence, whereas tasks like Colour-Word Interference, the FIST, and Dual Task may draw more heavily on fluid intelligence (Cattell, 1987; Horn & Cattell, 1967). Therefore, while lifetime PA may enhance Verbal Fluency, possibly by supporting language-based neural pathways, its associations with tasks that depend more on fluid, adaptive thinking may be less robust.

Unexpectedly, greater past month METs predicted poorer working memory performance on both the PASAT and Digit Span. Although the regression coefficient for Digit Span was small (near zero), it achieved statistical significance, potentially due to reduced variability from the other variables in the model, suggesting a subtle but measurable relationship between past month METs and Digit Span performance. This finding conflicts with most prior research, which generally supports a positive effect of PA on adults' working memory (Lambourne et al., 2006; Loprinzi et al., 2018; Pachava & Shenoy, 2023). For instance, self-reported METs in the past 3 months (Lambourne et al., 2006) and past week (Pachava & Shenoy, 2023) correlated positively with working memory performance. In their intervention study, Thomas & D (2017) also

reported a positive association between chronic PA and working memory performance among young adults.

One potential explanation for this discrepancy is suggested from single-session (acute) exercise intervention studies, which have noted curvilinear dose-response relationship between PA and EF (Chang & Etnier, 2009; Chang et al., 2015). Moderate levels of PA tend to optimize young adults' EF performance, whereas prolonged or vigorous PA has a lesser positive effect and may not significantly differ from resting control conditions (Chang & Etnier, 2009; Chang et al., 2015). Chang and colleagues (2015) propose that overtraining may result in central fatigue associated with challenges such as heat stress, dehydration, or hypoglycemia that could impair EF performance. Therefore, it is possible that participants who engaged in higher levels of PA in the past month experienced cognitive fatigue, which may have contributed to the observed decline in working memory performance. However, if fatigue were a primary factor, we would have expected to see worse performance across other EFs measures, as well as elevated reports of stress and/or reduced sleep quality but these patterns were not observed. These findings suggest that other factors that were not captured could be influencing the observed relationships between recent PA and working memory. Future research should examine these complex interactions more closely, including the role of PA intensity, recovery, and subjective experiences of fatigue, to better understand the nuanced effects of PA on cognitive performance.

3.5.3 Sleep Quality, Positive Affect, and Self-reported Executive Functions

Self-reported sleep quality and positive affect emerged as the strongest predictors of self-reported EFs. This suggests that young adults' perception of their sleep and positive affect is

linked to how they assess their own EFs, which aligns with previous research (Dube et al., 2020; Liu et al., 2020). However, these factors did not predict performance-based EF measures, likely due to the fundamental differences between self-reported and performance-based EFs measures discussed above. For example, individuals may perceive themselves as being better able to organize, focus, or shift attention in daily life when they experience greater sleep quality and positive affect, but these perceptions may not necessarily translate into improved performance on standardized EF tasks.

Additionally, the context of the undergraduate academic experience may contribute to these findings. Undergraduate students are regularly required to complete structured exams (e.g., tests, quizzes, finals) and are expected to perform well regardless of their mental or physical state (Cleary et al., 2011; Gardani et al., 2021). Our results imply that their ability to complete performance-based EFs measures in a structed test-like setting may be relatively unaffected by their reported sleep, stress, or affect. Indeed, prior research has similarly found that undergraduate students' performance-based EFs are not significantly affected by factors like sleep (Zavecz et al., 2020) and stress (VonDras et al., 2005) compared to other populations, suggesting that students may have developed coping mechanisms or strategies that enable them to maintain performance in structured testing environments despite temporary fluctuations in their mental or physical well-being.

3.5.4 The Importance of Musical Training

While it was not the primary focus of our research, our results demonstrated that musical training emerged as the most important predictor of performance on Colour-Word Interference and Verbal Fluency tasks. Young adults with a self-reported history of musical

training performed better on these measures, which assess inhibitory control and cognitive flexibility, respectively. These findings are consistent with previous research indicating that adult musicians outperform their peers without a history of musical training on measures of inhibitory control, including Colour-Word Interference (Travis et al., 2011) and cognitive flexibility, including Verbal Fluency (Zuk et al., 2014). Musical training is thought to enhance EFs due to the cognitive demands it imposes, such as inhibiting automatic responses, sustaining attention amidst distractions, and switching between different musical structures or rules (Moreno et al., 2011; Travis et al., 2011; Zuk et al., 2014). These processes mirror the cognitive demands of tasks like Colour-Word Interference and Verbal Fluency (Travis et al., 2011; Zuk et al., 2014).

Other researchers have also found a positive relationship between adults' musical training and working memory performance (D'Souza et al., 2018; Zuk et al., 2014). The lack of this association in the current study was potentially the result of comparing those with any history of musical training to those without, whereas prior studies compared musicians with extensive musical training to those without (D'Souza et al., 2018; Zuk et al., 2014). This suggests that while musical training may contribute to certain aspects of EFs, its impact may depend on the depth and intensity of that training. A review of musical training intervention studies with children indicated a positive effect on EFs (Degé & Frischen, 2022). Thus, future research with young adults should consider the extent of musical engagement when examining its relationship with EFs to better understand these relationships.

3.5.5 Young Adult Executive Function Profiles

The LPA revealed two distinct EFs profiles among our sample: Higher and Lower EFs. There is minimal prior research on how individuals may be grouped into EFs profiles (Chaku et al., 2021; Spurk et al., 2020) and only one prior study to our knowledge has done so with young adults. Rau and colleagues (2015) identified three profiles with LPA using only two tasks: average EF performance, set maintenance weakness, and cognitive flexibility/verbal weaknesses. While their profiles captured specific EF weaknesses, our study incorporated a broader set of tasks, allowing for a more comprehensive profile differentiation of overall EFs in young adults.

Logistic regression analyses revealed that participants with musical training were more likely to belong to the Higher EFs profile compared to those without musical training. This relationship, in combination with the finding that musical training predicted better performance on Verbal Fluency and Colour-Word Interference, implies a positive relationship between musical training and EFs, although the direction is unclear: based on our findings, musical training may help enhance EFs, more advanced EFs abilities may facilitate musical training engagement, or a third variable (e.g., socio-economic status) could predict increased EFs and increased likelihood of obtaining musical training. Nevertheless, prior research suggests that musical training interventions are a promising avenue for improving EFs across various age groups. For example, a recent systematic review of 29 musical training interventions with children (Rodriguez-Gomez & Talero-Gutierrez, 2022) found a beneficial effect of musical training on EF performance, primarily on inhibitory control, and to a lesser degree, working memory and cognitive flexibility. Likewise, Rogers and Metzler-Baddeley (2024) reported a

similar positive effect of musical training interventions on EFs in older adults. However, to our knowledge, there is no existing research examining the impact of musical training on EFs in young adults.

Although the identified profiles were not related to other measures as we had hypothesized, the distinction between individuals with Higher and Lower EF profiles offers a meaningful framework for further understanding cognitive functioning among young adults. These profiles may hold greater predictive power in other contexts or with different outcomes, given established relationships between EFs and other measures such as musical training, academic achievement (Chaku et al., 2021), risk-taking behaviour (Reynolds et al., 2019), and health (Shields et al., 2017). Future research should attempt to replicate the LPA findings and explore how EFs profiles interact with other psychological, behavioural, or environmental factors to better understand their relevance. By refining methods for identifying and analyzing EF profiles, future research could utilize this framework to develop targeted interventions tailored to individuals' cognitive strengths and specific weaknesses.

3.5.6 Limitations and Future Directions

Interpreting our findings highlighted the limitations of this study and potential directions for future research. Firstly, self-report measures are inherently prone to biases such as social desirability or recall errors, which could attenuate true relationships between PA and performance-based EFs. While measuring PA with an updated list from the CFS (Statistics Canada, 1983) allowed us to examine specific PAs participants engaged in throughout their lifetime along with duration, intensity, and frequency of recent PAs, this comprehensive approach likely increased susceptibility to recall inaccuracies. We expect that any reporting

inaccuracies would underestimate PA levels, rather than inflate them, as participants may have underreported less frequent or less memorable activities. Thus, it is possible that the identified relationships between PA and other variables may be stronger than our results indicated. Despite the limitations of retrospective self-reports, they remain the most practical method for capturing long-term PA patterns in a cross-sectional study. However, future longitudinal studies that incorporate objective measures, such as wearable activity trackers, would be optimal for assessing PA trends over time with greater accuracy. In fact, recent advances in technology, and the increasing use of wearable devices in the general population makes their use in PA-related studies increasingly feasible.

The self-report measures of affect, stress, and sleep included in our models did not predict much variance in participants' performance-based EFs, suggesting that important variables predictive of EF in young adults may not have been captured. The omission of potentially influential factors, such as participants' nutrition (Cohen et al., 2016) and substance use (Luciana, 2020) may have limited our ability to explain additional variability in EF performance. To reduce the burden on participants, they could complete the testing session up to one week following the completion of the questionnaire. This design may have been adequate for assessing associations between relatively stable variables like Lifetime PA and musical background with EF, but it may have underestimated potential short-term effects of acute PA on EF performance (Aguirre-Loaiza et al., 2022; Basso et al., 2015), or other influential short-term factors, such as acute stress (Shields et al., 2017). Self-report and performance-based data should be collected in the same study session in the future.

Another notable limitation stems from remote data collection due to COVID-19 restrictions. Participants did not complete any part of the study in a controlled laboratory environment, which likely introduced some variability in performance. While participants were asked to minimize distraction during the testing session, differing home environments and unavoidable distractions were inevitable at times. With COVID-19 restrictions now lifted, a return to controlled laboratory environments allowing for more standardized testing conditions would be beneficial. This could improve the reliability of performance-based EFs measures, providing more accurate assessments of EFs. Additionally, exploring whether performance differs between home-based and lab-based settings could offer insights into the influence of current environmental factors on cognitive test outcomes.

Participants were undergraduate students, which may limit generalizability to other populations of young adults, such as those with varying educational or socio-economic backgrounds. Higher education levels have been associated with improvements in cognitive abilities, including aspects of EFs (Baars et al., 2015; Guerra-Carrillo et al., 2017). As a result, variations in EFs may be more limited in an undergraduate sample, potentially limiting the relationships between EFs and other variables or the findings of the EFs profile analyses. It would be beneficial for future research to include a more diverse sample of young adults, incorporating those who are not in university.

By addressing these limitations and refining methodologies, future research can enhance our understanding of the complex interactions between PA, EF, and other related factors. This could facilitate the development of interventions that are tailored to individuals'

specific cognitive profiles and environmental contexts, leading to more effective strategies for promoting cognitive health in young adults.

3.6 Conclusions

In conclusion, this study provides further insight into the relationships between longer-term PA patterns and EFs among young adults, while also considering the contributions of other factors such as musical training, sleep quality, and positive affect. Although PA predicted specific aspects of EFs, its associations with overall EF abilities was limited. Notably, musical training, positive affect, and sleep quality were more strongly associated with EF outcomes. The identification of two distinct EF profiles offers a new perspective on cognitive functioning in this population. This more personalized approach may be instrumental for tailoring interventions that address individual cognitive strengths and weaknesses. Our findings underscore the importance of incorporating a multifaceted view of EFs that accounts for various lifestyle influences. By recognizing the interplay between PA and other factors, such as musical training, practitioners and educators may develop more effective strategies to enhance cognitive health in young adults. Future research should continue to explore these interactions among young adults to inform methods of optimizing EFs at this critical life stage.

3.7 Tables

Table 3.1

Descriptive Statistics and Bivariate Correlations for all Variables in Analyses

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. Age																				
2. Gender	-.04																			
3. Multilingualism	-.08	**-.16***																		
4. Musical Training	.03	.05	-.05																	
5. Positive Affect	.02	-.11	.07	-.08																
6. Negative Affect	-.06	.04	-.05	-.07	**-.23****															
7. Stress	-.09	.11	-.01	-.10	**-.56****	**.68****														
8. Sleep Quality	.06	**-.22****	.11	-.10	**.38****	**-.35****	**-.46****													
9. Nature Connectedness	.02	.03	.03	.11	**.26****	.03	-.12	.08												
10. Lifetime PA	.06	-.05	-.01	**.15***	**.19****	-.06	**-.20****	.08	.13											
11. Past Month METs	-.04	-.06	.13	.12	**.19****	-.06	**-.19****	.03	**.16***	**.30****										
12. LEAF BIS Mean	.05	.04	-.06	.00	**-.41****	**.35****	**.46****	**-.48****	-.05	-.07	**-.16***									
13. Colour Word Int. RT	.05	-.11	.03	**-.22****	.02	.08	.02	-.04	-.06	.02	.01	**.20****								
14. Verbal Fluency Total	-.05	**.15***	-.02	**.24****	.02	-.04	-.04	-.09	.10	**.15***	.03	-.10	**-.44****							
15. Digit Span Total	.04	.03	.06	-.02	.04	.00	-.06	.11	-.02	.06	**-.17***	-.03	**-.26****	**.29****						
16. PASAT Total	-.11	-.06	.08	.07	.09	-.07	-.04	.12	.00	.07	**-.19****	-.12	**-.33****	**.42****	**.36****					
17. FIST Flexible Total	.01	.08	.02	.05	-.09	-.06	.01	-.03	-.04	.03	-.02	.03	**-.29****	**.19****	.08	.05				
18. Flanker Int. RT	.04	.02	-.06	.10	-.10	-.06	-.04	-.06	.07	-.04	.01	.03	-.11	.05	-.03	-.01	.02			
19. Dual Task Cost RT	.04	.05	-.01	.07	.10	.03	-.04	.05	.05	.07	.03	-.02	.09	-.01	**-.18****	-.04	.06	.06		
20. Go/No-Go False Alarm	-.13	.03	.04	-.04	-.02	.04	.05	.01	-.01	-.06	.05	.07	.07	-.06	.00	-.09	-.01	.06	-.01	
N	212	207	212	212	212	212	212	212	212	212	212	212	211	211	212	212	212	207	208	207
Mean	20.72	0.78	0.71	0.65	3.09	2.34	2.03	-36.53	10.23	35.55	17.88	0.00	45.22	94.63	29.10	43.24	1.59	62.48	133.37	0.16
SD	2.50	0.41	0.45	0.48	0.71	0.76	0.66	17.04	4.53	23.13	10.51	0.92	9.24	17.87	4.84	12.66	0.58	39.98	88.80	0.19
Skewness	1.64	-1.38	-0.94	-0.64	-0.09	0.58	0.03	-0.72	-0.07	1.31	0.69	0.61	0.71	-0.29	0.48	0.46	0.81	0.29	0.38	0.59
Kurtosis	3.12	-0.10	-1.12	-1.61	-0.49	-0.28	-0.49	0.10	-1.26	2.21	1.02	0.16	0.38	0.13	0.62	0.68	0.09	0.22	0.25	-1.18

Range	18-30	0-1	0-1	0-1	1.3-4.7	1.1-4.6	0.38–3.63	-87.00–-4.44	0.67–16.67	3-109	0.00–50.32	-1.73–2.69	25.96–74.94	44-138	17-44	9.0–84.5	1.00–3.16	-39.32–181.00	-132.81-380.00	0.00–0.63

Note. Bolded values are significant; Age is in years. Gender: 0= man, 1= woman; Multilingualism: 0= unilingual, 1= multilingual; Musical Training: 0= no history of musical training, 1= history of musical training; PA= physical activity; METs= metabolic equivalent of tasks; LEAF= Learning, Executive and Attention Functioning scale; BIS= Barrett Impulsiveness Scale; Int.= Interference; PASAT= Paced Auditory Serial Addition Task; FIST= Flexible Item Selection Task; RT = Response Time; Past month METs, FIST, and Go/No-Go statistics were calculated with the square root transformation of the scores. Higher scores on the LEAF BIS Mean, Colour Word Int. Time, Flanker Int. RT, Dual Task Cost RT, and Go/No-Go False Alarm indicate poorer EFs.

* $p < .05$ (2-tailed); ** $p < .01$ (2-tailed).

Table 3.2

Multiple Regression Models Predicting Self-Reported EFs (LEAF and BIS Combined)

Model	Predictor	*B*	95 CI *B*	*p*	sR^2	Relative Importance
Self-reported EFs with Lifetime PA	(Intercept)	-1.02	-2.40 – 0.37	0.150		
	Sleep Quality	-0.02	-0.03 – -0.01	**<0.001**	0.11	0.13
	Stress	0.24	-0.05 – 0.52	0.105	0.01	0.09
	Positive Affect	-0.29	-0.49 – -0.09	**0.004**	0.04	0.08
	Negative Affect	0.09	-0.12 – 0.29	0.403	0.00	0.04
	Age	0.03	-0.01 – 0.08	0.176	0.01	0.00
	Gender	-0.17	-0.45 – 0.10	0.209	0.01	0.00
	Nature Connectedness	0.01	-0.02 – 0.03	0.448	0.00	0.00
	Lifetime PA	0.00	0.00 – 0.01	0.551	0.02	0.00
	Musical Training	-0.10	-0.33 – 0.13	0.402	0.00	0.00
	Multilingualism	-0.03	-0.26 – 0.21	0.832	0.00	0.00
Self-reported EFs with Past Month METs	(Intercept)	-0.95	-2.33 – 0.42	0.174		
	Sleep Quality	-0.02	-0.03 – -0.01	**<0.001**	0.11	0.13
	Stress	0.22	-0.07 – 0.50	0.131	0.01	0.08
	Positive Affect	-0.28	-0.47 – -0.08	**0.006**	0.04	0.08
	Negative Affect	0.09	-0.11 – 0.30	0.380	0.00	0.04
	Past Month METs	0.00	0.00 – 0.00	0.298	0.01	0.01
	Age	0.03	-0.02 – 0.07	0.196	0.01	0.00
	Gender	-0.18	-0.45 – 0.09	0.193	0.01	0.00
	Nature Connectedness	0.01	-0.01 – 0.04	0.348	0.00	0.00
	Multilingualism	-0.01	-0.25 – 0.23	0.960	0.00	0.00
	Musical Training	-0.08	-0.31 – 0.15	0.501	0.00	0.00

Note. B = unstandardized coefficient. 95 CI *B* = 95% confidence interval beta. sR^2= semi-partial *R*-squared. 95% confidence intervals and *p*-values are presented for *B*. Significant *p*-values are bolded. Predictor variables are presented in order of relative importance (largest to smallest). Relative Importance is the Lindeman, Merenda and Gold (lmg) statistic. Age is in years. Gender: 0= man, 1= woman; Multilingualism: 0= unilingual, 1= multilingual; Musical Training: 0= no history of musical training, 1= history of musical training; PA= physical activity; METs= metabolic equivalent of tasks; LEAF= Learning, Executive and Attention Functioning scale; BIS= Barrett

Impulsiveness Scale. Past month METs is the square root transformation of the original score. Higher scores on the BIS and LEAF indicate poorer EFs.

Table 3.3

Multiple Regression Models Predicting Colour Word Interference Condition Time

Model	Predictor	*B*	95 CI *B*	*p*	sR^2	Relative Importance
Colour Word with Lifetime PA	(Intercept)	44.35	28.17 – 60.53	**<0.001**		
	Musical Training	-4.35	-7.07 – -1.62	**0.002**	**0.05**	0.05
	Gender	-1.50	-4.68 – 1.69	0.355	0.00	0.00
	Sleep Quality	-0.05	-0.13 – 0.04	0.272	0.01	0.00
	Negative Affect	0.94	-1.48 – 3.35	0.444	0.00	0.00
	Age	0.22	-0.30 – 0.74	0.404	0.00	0.00
	Multilingualism	0.82	-1.96 – 3.61	0.560	0.00	0.00
	Lifetime PA	-0.01	-0.07 – 0.05	0.798	0.00	0.00
	Stress	-1.21	-4.55 – 2.12	0.473	0.00	0.00
	Nature Connectedness	-0.04	-0.33 – 0.25	0.789	0.00	0.00
	Positive Affect	-0.37	-2.67 – 1.92	0.750	0.00	0.00
Colour Word with Past Month METs	(Intercept)	44.04	27.96 – 60.11	**<0.001**		
	Musical Training	-4.45	-7.17 – -1.74	**0.001**	0.05	0.05
	Gender	-1.47	-4.66 – 1.72	0.364	0.00	0.00
	Sleep Quality	-0.05	-0.13 – 0.04	0.288	0.01	0.00
	Negative Affect	0.93	-1.49 – 3.34	0.450	0.00	0.00
	Age	0.23	-0.29 – 0.75	0.388	0.00	0.00
	Multilingualism	0.72	-2.10 – 3.54	0.614	0.00	0.00
	Nature Connectedness	-0.05	-0.34 – 0.24	0.728	0.00	0.00
	Stress	-1.13	-4.44 – 2.19	0.503	0.00	0.00
	Past month METs	0.00	0.00 – 0.00	0.653	0.00	0.00
	Positive Affect	-0.45	-2.76 – 1.86	0.702	0.00	0.00

Note. B = unstandardized coefficient. 95 CI *B* = 95% confidence interval beta. sR^2= semi-partial *R*-squared. 95% confidence intervals and *p*-values are presented for *B*. Significant *p*-values are bolded. Predictor variables are presented in order of relative importance (largest to smallest). Relative Importance is the Lindeman, Merenda and Gold (lmg) statistic. Age is in years. Gender: 0= man, 1= woman; Multilingualism: 0= unilingual, 1= multilingual; Musical Training: 0= no history of musical training, 1= history of musical training; PA= physical activity; METs= metabolic equivalent of tasks. Past month METs is the square root transformation of the original score. Higher scores on Colour Word Interference Condition Time indicate poorer EFs.

Table 3.4

Multiple Regression Models Predicting Verbal Fluency Total Correct

Model	Predictor	*B*	95 CI *B*	p	sR^2	Relative Importance
Verbal Fluency with Lifetime PA	(Intercept)	82.43	51.42 – 113.45	**<0.001**		
	Musical Training	7.80	2.55 – 13.05	**0.004**	0.04	0.05
	Lifetime PA	0.14	0.02 – 0.25	**0.018**	0.03	0.04
	Gender	4.11	-1.99 – 10.22	0.185	0.01	0.01
	Sleep Quality	-0.08	-0.25 – 0.08	0.317	0.00	0.01
	Age	-0.37	-1.37 – 0.63	0.464	0.00	0.00
	Positive Affect	1.34	-3.05 – 5.74	0.547	0.00	0.00
	Nature Connectedness	0.10	-0.47 – 0.66	0.733	0.00	0.00
	Multilingualism	-0.15	-5.49 – 5.19	0.956	0.00	0.00
	Stress	-0.76	-7.17 – 5.65	0.815	0.00	0.00
	Negative Affect	0.14	-4.48 – 4.76	0.952	0.00	0.00
Verbal Fluency with Past Month METs	(Intercept)	86.98	55.74 – 118.21	**<0.001**		
	Musical Training	8.79	3.50 – 14.08	**0.001**	0.05	0.06
	Gender	4.33	-1.86 – 10.53	0.169	0.01	0.01
	Sleep Quality	-0.08	-0.25 – 0.08	0.316	0.01	0.01
	Nature Connectedness	0.21	-0.36 – 0.78	0.464	0.00	0.01
	Stress	-1.80	-8.26 – 4.66	0.583	0.00	0.00
	Positive Affect	1.71	-2.76 – 6.19	0.451	0.00	0.00
	Age	-0.43	-1.44 – 0.59	0.409	0.00	0.00
	Past Month METs	0.00	-0.01 – 0.00	0.480	0.00	0.00
	Negative Affect	0.47	-4.20 – 5.15	0.842	0.00	0.00
	Multilingualism	0.15	-5.32 – 5.63	0.956	0.00	0.00

Note. B = unstandardized coefficient. 95 CI *B* = 95% confidence interval beta. sR^2= semi-partial *R*-squared. 95% confidence intervals and *p*-values are presented for *B*. Significant *p*-values are bolded. Predictor variables are presented in order of relative importance (largest to smallest). Relative Importance is the Lindeman, Merenda and Gold (lmg) statistic. Age is in years. Gender: 0= man, 1= woman; Multilingualism: 0= unilingual, 1= multilingual; Musical Training: 0= no history of musical training, 1= history of musical training; PA= physical activity; METs= metabolic equivalent of tasks. Past month METs is the square root transformation of the original score.

Table 3.5

Multiple Regression Models Predicting Digit Span Total Correct

Model	Predictor	*B*	95 CI *B*	*p*	sR^2	Relative Importance
Digit Span with Lifetime PA	(Intercept)	26.71	17.90 – 35.51	**<0.001**		
	Lifetime PA	0.02	-0.01 – 0.06	0.148	0.01	0.01
	Sleep Quality	0.03	-0.02 – 0.08	0.193	0.01	0.01
	Negative Affect	0.83	-0.48 – 2.14	0.212	0.01	0.00
	Stress	-0.70	-2.51 – 1.12	0.451	0.00	0.00
	Multilingualism	0.65	-0.87 – 2.16	0.401	0.00	0.00
	Age	0.11	-0.17 – 0.40	0.428	0.00	0.00
	Nature Connectedness	-0.08	-0.24 – 0.08	0.310	0.01	0.00
	Positive Affect	-0.01	-1.25 – 1.24	0.992	0.00	0.00
	Musical Training	-0.25	-1.73 – 1.24	0.744	0.00	0.00
	Gender	0.47	-1.26 – 2.20	0.593	0.00	0.00
Digit Span with Past Month METs						
	(Intercept)	27.69	19.01 – 36.37	**<0.001**		
	Past Month METs	-0.00	-0.00 – -0.00	**0.023**	0.03	0.02
	Sleep Quality	0.03	-0.02 – 0.07	0.255	0.01	0.01
	Stress	-0.96	-2.75 – 0.83	0.290	0.01	0.00
	Multilingualism	0.92	-0.60 – 2.44	0.236	0.01	0.00
	Negative Affect	0.89	-0.41 – 2.19	0.176	0.01	0.00
	Age	0.09	-0.19 – 0.37	0.514	0.00	0.00
	Positive Affect	0.19	-1.05 – 1.43	0.763	0.00	0.00
	Nature Connectedness	-0.05	-0.21 – 0.11	0.528	0.00	0.00
	Gender	0.39	-1.33 – 2.11	0.655	0.00	0.00

Note. B = unstandardized coefficient. 95 CI *B* = 95% confidence interval beta. sR^2= semi-partial *R*-squared. 95% confidence intervals and *p*-values are presented for *B*. Significant *p*-values are bolded. Predictor variables are presented in order of relative importance (largest to smallest). Relative Importance is the Lindeman, Merenda and Gold (lmg) statistic. Age is in years. Gender: 0= man, 1= woman; Multilingualism: 0= unilingual, 1= multilingual; Musical Training: 0= no history of musical training, 1= history of musical training; PA= physical activity; METs= metabolic equivalent of tasks. Past month METs is the square root transformation of the original score.

Table 3.6

Multiple Regression Models Predicting the PASAT Total Correct

Model	Predictor	*B*	95 CI *B*	*p*	sR^2	Relative Importance
PASAT with Lifetime PA	(Intercept)	47.00	24.06 – 69.94	**<0.001**		
	Age	-0.55	-1.29 – 0.19	0.144	0.01	0.01
	Sleep Quality	0.08	-0.04 – 0.20	0.182	0.01	0.01
	Positive Affect	2.18	-1.06 – 5.43	0.186	0.01	0.01
	Musical Training	2.70	-1.16 – 6.56	0.169	0.01	0.01
	Lifetime PA	0.05	-0.04 – 0.13	0.283	0.01	0.01
	Negative Affect	-1.49	-4.90 – 1.93	0.392	0.00	0.00
	Gender	-1.39	-5.90 – 3.12	0.544	0.00	0.00
	Stress	2.71	-2.02 – 7.44	0.260	0.01	0.00
	Multilingualism	0.99	-2.95 – 4.94	0.620	0.00	0.00
	Nature Connectedness	-0.12	-0.54 – 0.29	0.564	0.00	0.00
PASAT with Past Month METs	(Intercept)	49.34	27.12 – 71.57	**<0.001**		
	Past Month METs	-0.01	-0.01 – 0.00	**0.001**	0.06	0.04
	Age	-0.62	-1.33 – 0.10	0.093	0.02	0.01
	Positive Affect	2.86	-0.32 – 6.04	0.078	0.02	0.01
	Musical Training	3.55	-0.20 – 7.29	0.063	0.01	0.01
	Sleep Quality	0.07	-0.05 – 0.18	0.273	0.01	0.01
	Multilingualism	2.01	-1.88 – 5.90	0.310	0.01	0.00
	Gender	-1.81	-6.21 – 2.59	0.418	0.00	0.00
	Negative Affect	-1.36	-4.69 – 1.96	0.420	0.00	0.00
	Stress	1.99	-2.60 – 6.57	0.394	0.00	0.00
	Nature Connectedness	-0.03	-0.44 – 0.37	0.876	0.00	0.00

Note. B = unstandardized coefficient. 95 CI *B* = 95% confidence interval beta. sR^2= semi-partial *R*-squared. 95% confidence intervals and *p*-values are presented for *B*. Significant *p*-values are bolded. Predictor variables are presented in order of relative importance (largest to smallest). Relative Importance is the Lindeman, Merenda and Gold (lmg) statistic. Age is in years. Gender: 0= man, 1= woman; Multilingualism: 0= unilingual, 1= multilingual; Musical Training: 0= no history of musical training, 1= history of musical training; PA= physical activity; METs= metabolic equivalent of tasks. Past month METs is the square root transformation of the original score. PASAT= Paced Auditory Serial Addition Task.

Table 3.7

Multiple Regression Models Predicting the FIST Flexible Total Correct

Model	Predictor	*B*	95 CI *B*	*p*	sR^2	Relative Importance
FIST with Lifetime PA	(Intercept)	-1.50	-2.55 – -0.46	**0.005**		
	Age	0.00	0.00 – 0.01	0.382	0.00	0.00
	Sleep Quality	0.00	-0.01 – 0.01	0.914	0.00	0.00
	Positive Affect	0.00	-0.02 – 0.02	0.759	0.00	0.00
	Musical Training	0.04	-0.17 – 0.26	0.683	0.00	0.00
	Lifetime PA	0.05	-0.13 – 0.23	0.551	0.00	0.00
	Negative Affect	0.00	-0.01 – 0.01	0.914	0.00	0.00
	Gender	0.00	0.00 – 0.01	0.382	0.00	0.00
	Stress	0.09	-0.12 – 0.29	0.404	0.00	0.00
	Multilingualism	-0.07	-0.23 – 0.08	0.353	0.00	0.00
	Nature Connectedness	0.00	-0.02 – 0.02	0.759	0.00	0.01
FIST with Past Month METs	(Intercept)	-1.45	-2.49 – -0.41	**0.006**		
	Past Month METs	0.00	-0.03 – 0.03	0.942	0.00	0.00
	Age	0.00	0.00 – 0.00	0.815	0.00	0.00
	Positive Affect	0.00	-0.01 – 0.01	0.943	0.00	0.00
	Musical Training	0.00	-0.02 – 0.02	0.840	0.00	0.00
	Sleep Quality	0.03	-0.18 – 0.25	0.750	0.00	0.00
	Multilingualism	0.05	-0.13 – 0.23	0.581	0.00	0.00
	Gender	0.07	-0.11 – 0.24	0.459	0.00	0.00
	Negative Affect	-0.07	-0.23 – 0.09	0.380	0.00	0.00
	Stress	0.09	-0.11 – 0.30	0.371	0.00	0.00
	Nature Connectedness	-0.06	-0.20 – 0.09	0.462	0.00	0.01

Note. B = unstandardized coefficient. 95 CI *B* = 95% confidence interval beta. sR^2= semi-partial *R*-squared. 95% confidence intervals and *p*-values are presented for *B*. Significant *p*-values are bolded. Predictor variables are presented in order of relative importance (largest to smallest). Relative Importance is the Lindeman, Merenda and Gold (lmg) statistic. Age is in years. Gender: 0= man, 1= woman; Multilingualism: 0= unilingual, 1= multilingual; Musical Training: 0= no history of musical training, 1= history of musical training; PA= physical activity; METs= metabolic equivalent of tasks. Past month METs is the square root transformation of the original score. FIST= Flexible Item Selection Task.

Table 3.8

Multiple Regression Models Predicting Go/No-Go False Alarm Presses

Model	Predictor	*B*	95 CI *B*	*p*	sR^2	Relative Importance
Go/No-Go with Lifetime PA	(Intercept)	0.31	-0.05 – 0.67	0.092		
	Positive Affect	0.00	-0.05 – 0.05	0.952	0.00	0.00
	Nature Connectedness	0.00	-0.01 – 0.01	0.960	0.00	0.00
	Gender	0.01	-0.06 – 0.09	0.694	0.00	0.00
	Musical Training	0.00	-0.07 – 0.06	0.876	0.00	0.00
	Sleep Quality	0.00	0.00 – 0.00	0.672	0.00	0.00
	Negative Affect	0.01	-0.05 – 0.06	0.822	0.00	0.00
	Stress	0.01	-0.07 – 0.08	0.818	0.00	0.00
	Lifetime PA	0.00	0.00 – 0.00	0.622	0.00	0.00
	Multilingualism	0.01	-0.05 – 0.08	0.641	0.00	0.00
	Age	-0.01	-0.02 – 0.00	0.150	0.01	0.01
Go/No-Go with Past Month METs	(Intercept)	0.30	-0.06 – 0.66	0.098		
	Positive Affect	0.00	-0.05 – 0.05	0.933	0.00	0.00
	Nature Connectedness	0.00	-0.01 – 0.01	0.868	0.00	0.00
	Gender	0.01	-0.06 – 0.09	0.698	0.00	0.00
	Sleep Quality	0.00	0.00 – 0.00	0.614	0.00	0.00
	Musical Training	-0.01	-0.07 – 0.05	0.781	0.00	0.00
	Negative Affect	0.01	-0.05 – 0.06	0.835	0.00	0.00
	Multilingualism	0.01	-0.05 – 0.07	0.725	0.00	0.00
	Stress	0.01	-0.06 – 0.09	0.742	0.00	0.00
	Past Month METs	0.00	0.00 – 0.00	0.466	0.00	0.00
	Age	-0.01	-0.02 – 0.00	0.157	0.01	0.01

Note. B = unstandardized coefficient. 95 CI *B* = 95% confidence interval beta. sR^2= semi-partial *R*-squared. 95% confidence intervals and *p*-values are presented for *B*. Significant *p*-values are bolded. Predictor variables are presented in order of relative importance (largest to smallest). Relative Importance is the Lindeman, Merenda and Gold (lmg) statistic. Age is in years. Gender: 0= man, 1= woman; Multilingualism: 0= unilingual, 1= multilingual; Musical Training: 0= no history of musical training, 1= history of musical training; PA= physical activity; METs=

metabolic equivalent of tasks. Past month METs is the square root transformation of the original score. Higher scores on Go/No-Go False Alarm Presses indicate poorer EFs.

Table 3.9

Multiple Regression Models Predicting Flanker Interference Response Time

Model	Predictor	*B*	95 CI *B*	*p*	sR^2	Relative Importance
Flanker with Lifetime PA	(Intercept)	91.33	18.02 – 164.64	**0.015**		
	Positive Affect	-8.94	-19.36 – 1.47	0.092	0.01	0.01
	Stress	-10.44	-25.51 – 4.62	0.173	0.01	0.01
	Nature Connectedness	0.94	-0.41 – 2.29	0.173	0.01	0.01
	Musical Training	4.69	-7.70 – 17.07	0.456	0.00	0.01
	Multilingualism	-5.17	-17.72 – 7.37	0.417	0.00	0.00
	Sleep Quality	-0.15	-0.54 – 0.23	0.434	0.00	0.00
	Negative Affect	-0.11	-11.02 – 10.79	0.984	0.00	0.00
	Lifetime PA	-0.13	-0.40 – 0.15	0.367	0.00	0.00
	Age	0.55	-1.80 – 2.90	0.646	0.00	0.00
	Gender	-1.80	-16.42 – 12.82	0.808	0.00	0.00
Flanker with Past Month METs	(Intercept)	88.26	15.10 – 161.43	**0.018**		
	Positive Affect	-9.16	-19.71 – 1.39	0.088	0.02	0.01
	Stress	-9.53	-24.51 – 5.45	0.211	0.01	0.01
	Nature Connectedness	0.82	-0.52 – 2.16	0.228	0.01	0.01
	Musical Training	3.87	-8.45 – 16.19	0.536	0.00	0.01
	Multilingualism	-5.12	-17.84 – 7.59	0.428	0.00	0.00
	Sleep Quality	-0.15	-0.54 – 0.24	0.446	0.00	0.00
	Negative Affect	-0.36	-11.28 – 10.56	0.948	0.00	0.00
	Age	0.55	-1.80 – 2.91	0.644	0.00	0.00
	Gender	-2.09	-16.74 – 12.55	0.778	0.00	0.00
	Past Month METs	0.00	-0.01 – 0.01	0.975	0.00	0.00

Note. B = unstandardized coefficient. 95 CI *B* = 95% confidence interval beta. sR^2= semi-partial *R*-squared. 95% confidence intervals and *p*-values are presented for *B*. Significant *p*-values are bolded. Predictor variables are presented in order of relative importance (largest to smallest). Relative Importance is the Lindeman, Merenda and Gold (lmg) statistic. Age is in years. Gender: 0= man, 1= woman; Multilingualism: 0= unilingual, 1= multilingual; Musical Training: 0= no history of musical training, 1= history of musical training; PA= physical activity; METs= metabolic equivalent of tasks. Past month METs is the square root transformation of the original score. Higher scores on the Flanker Interference Reaction Time indicate poorer EFs.

Table 3.10

Multiple Regression Models Predicting Dual Task Two-Task Cost Response Time

Model	Predictor	*B*	95 CI *B*	*p*	sR^2	Relative Importance
Dual Task with Lifetime PA	(Intercept)	6.19	-157.66 – 170.04	0.941		
	Musical Training	21.68	-5.95 – 49.30	0.123	0.01	0.01
	Positive Affect	15.89	-7.35 – 39.13	0.179	0.01	0.01
	Gender	16.03	-16.66 – 48.72	0.335	0.00	0.00
	Sleep Quality	0.28	-0.58 – 1.14	0.521	0.00	0.00
	Nature Connectedness	0.16	-2.84 – 3.16	0.916	0.00	0.00
	Age	1.46	-3.79 – 6.71	0.584	0.00	0.00
	Negative Affect	3.67	-20.70 – 28.04	0.767	0.00	0.00
	Stress	8.22	-25.45 – 41.88	0.631	0.00	0.00
	Lifetime PA	0.05	-0.55 – 0.65	0.873	0.00	0.00
	Multilingualism	3.65	-24.40 – 31.70	0.798	0.00	0.00
Dual Task with Past Month METs	(Intercept)	7.79	-155.20 – 170.78	0.925		
	Musical Training	21.77	-5.71 – 49.25	0.120	0.01	0.01
	Positive Affect	15.63	-7.88 – 39.13	0.191	0.01	0.01
	Gender	16.31	-16.34 – 48.95	0.326	0.01	0.00
	Sleep Quality	0.29	-0.57 – 1.15	0.509	0.00	0.00
	Nature Connectedness	0.17	-2.82 – 3.15	0.912	0.00	0.00
	Age	1.46	-3.79 – 6.71	0.584	0.00	0.00
	Negative Affect	3.83	-20.51 – 28.17	0.757	0.00	0.00
	Stress	8.03	-25.42 – 41.48	0.636	0.00	0.00
	Past Month METs	0.00	-0.03 – 0.03	0.851	0.00	0.00
	Multilingualism	3.24	-25.15 – 31.63	0.822	0.00	0.00

Note. B = unstandardized coefficient. 95 CI *B* = 95% confidence interval beta. sR^2= semi-partial *R*-squared. 95% confidence intervals and *p*-values are presented for *B*. Significant *p*-values are bolded. Predictor variables are presented in order of relative importance (largest to smallest). Relative Importance is the Lindeman, Merenda and Gold (lmg) statistic. Age is in years. Gender: 0= man, 1= woman; Multilingualism: 0= unilingual, 1= multilingual; Musical Training: 0= no history of musical training, 1= history of musical training; PA= physical activity; METs= metabolic equivalent of tasks. Past month METs is the square root transformation of the original score. Higher scores on Dual Task Two-Task Cost Reaction Time indicate poorer EFs.

Table 3.11

Summary of Significant Predictors for All Multiple Regression Models

Model	Predictor	LEAF BIS Mean	Colour Word Int. Time	Verbal Fluency Tot.	Digit Span Tot.	PASAT Tot.
Model with Lifetime PA	Age					
	Gender					
	Multilingualism					
	Musical Training		− More musical training, faster completion time	+ More musical training, better fluency		
	Positive Affect	− Higher positive affect, better self-reported EFs				
	Negative Affect					
	Stress					
	Sleep Quality	− Better sleep quality, better self-reported EFs				
	Nature Connectedness					
	Lifetime PA			+ More lifetime PAs, better fluency		
Model with Past Month METs	Age					
	Gender					
	Multilingualism					
	Musical Training		− More musical training, faster completion time	+ More musical training, better fluency		
	Positive Affect	− Higher positive affect, better self-reported EFs				
	Negative Affect					
	Stress					

Sleep Quality	– Better sleep quality, better self-reported EFs		
Nature Connectedness			
Past Month METs		– More past month METs, worse digit span	– More past month METs, worse PASAT

Note. Age is in years. Gender: 0= man, 1= woman; Multilingualism: 0= unilingual, 1= multilingual; Musical Training: 0= no history of musical training, 1= history of musical training; PA= physical activity; METs= metabolic equivalent of tasks; LEAF= Learning, Executive and Attention Functioning scale; BIS= Barrett Impulsiveness Scale; Int.= Interference; Tot. = total correct responses; PASAT= Paced Auditory Serial Addition Task; Past month METs was calculated with the square root transformation of the scores. Higher scores on the LEAF BIS Mean and Colour Word Int. Time indicate poorer EFs. '+' = significant positive relationship; '–' = significant negative relationship. EFs tasks that were not significantly predicted by any predictors in the regression models were omitted from the table for simplicity (i.e., Flexible Item Selection Task; Flanker, Dual Task, and Go/No-Go).

Table 3.12

Model Fit Statistics for 1 – 5 Profiles

Model	Log-Lik.	AIC	BIC	aBIC	Entropy	LMR	VLMR-LRT	LMR-A-LRT	Class Count					Class Probabilities				
1 Profile	-5966.771	11969.541	12029.960	11972.924														
2 Profiles	**-5908.903**	**11873.806**	**11967.790**	**11879.068**	**0.627**	**113.614**	**0.044**	**0.046**	**123**	**89**				**0.903**	**0.874**			
3 Profiles	-5877.360	11830.721	11958.271	11837.862	0.800	61.929	0.316	0.323	147	45	20			0.917	0.914	0.920		
4 Profiles	-5851.112	11798.224	11959.340	11807.244	0.838	51.535	0.206	0.211	18	141	43	10		0.898	0.913	0.921	0.970	
5 Profiles	-5822.538	11761.075	11955.757	11771.975	0.870	56.101	0.158	0.164	16	131	10	42	13	0.873	0.954	0.908	0.849	0.941

Note. The bolded two-class model indicates the selected best-fitting model based on fit indices and interpretability. Log-Lik.= Log-likelihood. AIC= Aikaike Information Criteria. BIC= Bayesian Information Criteria. LMR= Lo, Mendell, Rubin statistic. VLMR-LRT- Vuong-Lo-Mendell-Rubin likelihood-ratio test for k-1 versus k classes. LMR-A-LRT= Lo-Mendell-Rubin adjusted likelihood-ratio test for k-1 versus k classes.

Table 3.13

Executive Functions by Profile

Variable	Profile 1 Lower EFs *Mean (SD)*	Profile 2 Higher EFs *Mean (SD)*	t-test	*p-value*
LEAF BIS Mean	0.15 (.91)	-0.20 (.91)	2.754	**.006**
Colour Word Interference RT	49.58 (8.68)	39.12 (6.02)	10.325	**<.001**
Verbal Fluency Total	85.36 (15.34)	107.33 (12.50)	-11.447	**<.001**
Digit Span Total	27.17 (4.29)	31.76 (4.28)	-7.712	**<.001**
PASAT Total	36.85 (9.31)	52.08 (11.29)	-3.352	**<.001**
FIST Flexible Total	6.74 (2.21)	7.70 (1.91)	-10.421	**<.001**
Flanker Interference RT	57.98 (41.57)	68.57 (37.10)	2.592	.055
Dual Task Cost RT	143.66 (9.13)	119.60 (70.06)	-1.928	**.042**
Go/No-Go False Alarm	0.08 (0.10)	0.05 (0.07)	2.045	**.01**

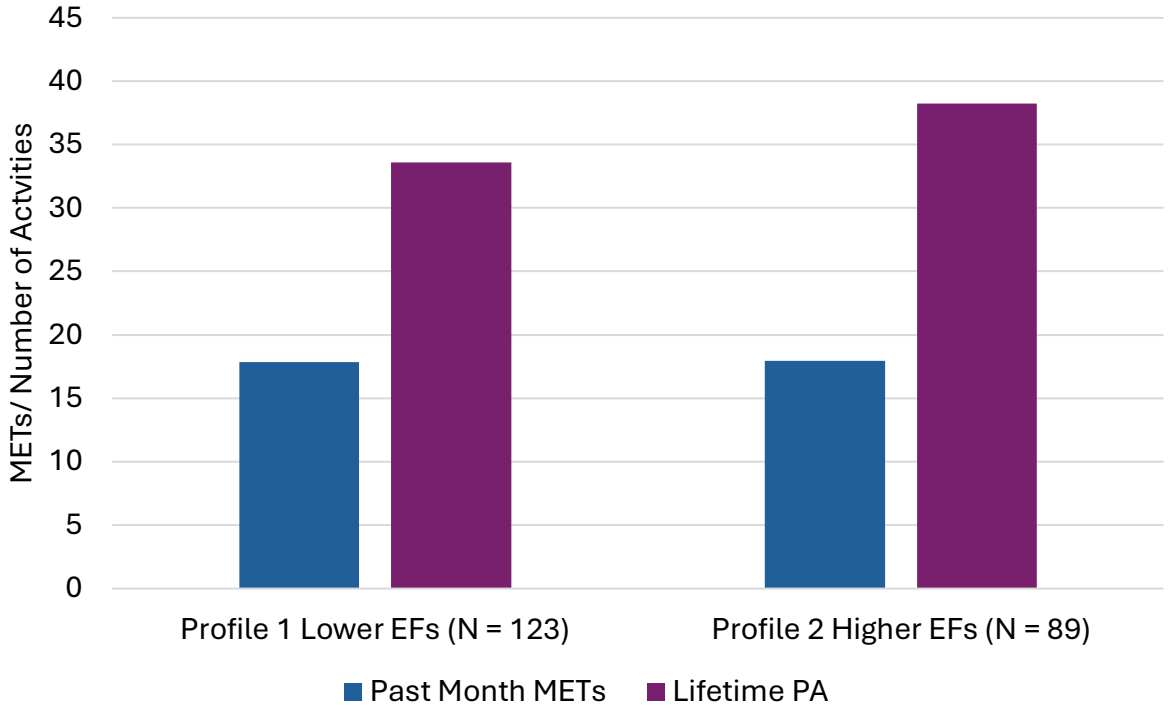
Note. EFs = executive functions; LEAF= Learning, Executive and Attention Functioning scale; BIS= Barrett Impulsiveness Scale;

PASAT= Paced Auditory Serial Addition Task; FIST= Flexible Item Selection Task; RT= Response time.

3.8 Figures

Figure 3.1

Past Month Metabolic Equivalent of Tasks and Lifetime Number of Physical Activities by Executive Functions Profile



Note. METs= metabolic equivalent of tasks; EFs = executive functions; PA = physical activity.

3.9 References

Abdalkareem Jasim, S., Singh, M., Baqir Al-Dhalimy, A. M., Zwamel, A. H., Jawad, I. A., & Shalaby, N. S. (2024). The impact of chronic exercise on cognitive function: An overview of reviews. *Iranian Journal of Psychiatry*. https://doi.org/10.18502/ijps.v19i4.16561

Aguirre-Loaiza, H., Arias, I., Bonilla, S., Ramírez, R., Ramírez-Herrera, S., Nanez, J., Barbosa-Granados, S., & Arenas-Granada, J. (2022). Effect of acute physical exercise on inhibitory control in young adults: High-intensity indoor cycling session. *Physiology & Behavior*, *254*, 113902. https://doi.org/10.1016/j.physbeh.2022.113902

Allan, J. L., McMinn, D., & Daly, M. (2016). A bidirectional relationship between executive function and health behavior: Evidence, implications, and future directions. *Frontiers in Neuroscience, 10*, 386. https://doi.org/10.3389/fnins.2016.00386

Alvarez-Bueno, C., Pesce, C., Cavero-Redondo, I., Sánchez-López, M., Pardo-Guijarro, M. J., & Martínez-Vizcaíno, V. (2017). The effect of physical activity interventions on children's cognition and metacognition: A systematic review and meta-analysis. *Journal of the American Academy of Child & Adolescent Psychiatry, 56*(9), 729–738. https://doi.org/10.1016/j.jaac.2017.06.012

Anderson, J. A. E., Mak, L., Keyvani Chahi, A., & Bialystok, E. (2018). The Language and Social Background Questionnaire: Assessing degree of bilingualism in a diverse population. *Behavior Research Methods*, *50*(1), 250–263. https://doi.org/10.3758/s13428-017-0867-9

Baars, M. A. E., Nije Bijvank, M., Tonnaer, G. H., & Jolles, J. (2015). Self-report measures of executive functioning are a determinant of academic performance in first-year students at

a university of applied sciences. *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.01131

Baron, I. S. (2004). Delis-Kaplan Executive Function System. *Child Neuropsychology, 10*(2), 147–152. https://doi.org/10.1080/09297040490911140

Basso, J. C., Shang, A., Elman, M., Karmouta, R., & Suzuki, W. A. (2015). Acute exercise improves prefrontal cortex but not hippocampal function in healthy adults. *Journal of the International Neuropsychological Society*, *21*(10), 791–801. https://doi.org/10.1017/s135561771500106x

Beltz, A. M. (2018). Connecting theory and methods in adolescent brain research. *Journal of Research on Adolescence*, *28*(1), 10–25. https://doi.org/10.1111/jora.12366

Best, J. R. (2010). Effects of physical activity on children's executive function: Contributions of experimental research on aerobic exercise. *Developmental Review, 30*(4), 331-351. https://doi.org/10.1016/j.dr.2010.08.001

Buchanan, T. (2016). Self-report measures of executive function problems correlate with personality, not performance-based executive function measures, in nonclinical samples. *Psychological Assessment*, *28*(4), 372–385. https://doi.org/10.1037/pas0000192

Burgess, P. W., Alderman, N., Evans, J., Emslie, H., & Wilson, B. A. (1998). The ecological validity of tests of executive function. *Journal of the International Neuropsychological Society, 4*(6), 547–558. https://doi.org/10.1017/S1355617706461073

Castellanos, I., Kronenberger, W. G., & Pisoni, D. B. (2018). Questionnaire-based assessment of executive functioning: psychometrics. *Applied Neuropsychology: Child*, *7*(2), 93–109. https://doi.org/10.1080/21622965.2016.1248557

Cattell, R. B. (1987). *Intelligence: Its structure, growth, and action.* North-Holland.

Chaku, N., Hoyt, L. T., & Barry, K. (2021). Executive functioning profiles in adolescence: Using person-centered approaches to understand heterogeneity. *Cognitive Development*, *60*, 101119. https://doi.org/10.1016/j.cogdev.2021.101119

Chang, Y.-K., Chu, C.-H., Wang, C.-C., Wang, Y.-C., Song, T.-F., Tsai, C.-L., & Etnier, J. L. (2015). Dose-response relation between exercise duration and cognition. *Medicine and Science in Sports and Exercise*, *47*(1), 159–165. https://doi.org/10.1249/MSS.0000000000000383

Chang, Y., & Etnier, J. L. (2009). Exploring the dose-response relationship between resistance exercise intensity and cognitive function. *Journal of Sport and Exercise Psychology*, *31*(5), 640–656. https://doi.org/10.1123/jsep.31.5.640

Chennaoui, M., Arnal, P. J., Sauvet, F., & Léger, D. (2015). Sleep and exercise: A reciprocal issue? *Sleep Medicine Reviews*, *20*, 59–72. https://doi.org/10.1016/j.smrv.2014.06.008

Chin, T. C., & Rickard, N. S. (2012). The music USE (MUSE) questionnaire: An instrument to measure engagement in music. *Music Perception*, *29*(4), 429–446. https://doi.org/10.1525/mp.2012.29.4.429

Cleary, M., Walter, G., & Jackson, D. (2011). "Not always smooth sailing": Mental health issues associated with the transition from high school to college. *Issues in Mental Health Nursing, 32*(4), 250–254. https://doi.org/10.3109/01612840.2010.548906

Cobb-Clark, D. A., Dahmann, S. C., Kamhöfer, D. A., & Schildberg-Hörisch, H. (2022). The predictive power of self-control for life outcomes. *Journal of Economic Behavior & Organization*, *197*, 725–744. https://doi.org/10.1016/j.jebo.2022.02.028

Cohen, J. F. W., Gorski, M. T., Gruber, S. A., Kurdziel, L. B. F., & Rimm, E. B. (2016). The effect of healthy dietary consumption on executive cognitive functioning in children and adolescents: A systematic review. *British Journal of Nutrition*, *116*(6), 989–1000. https://doi.org/10.1017/S0007114516002877

Cohen, S., Kamarck, T., & Mermelstein, R. (1983). A global measure of perceived stress. *Journal of Health and Social Behavior*, *24*(4), 385–396. https://doi.org/10.2307/2136404

Contreras-Osorio, F., Ramirez-Campillo, R., Cerda-Vega, E., Campos-Jara, R., Martínez-Salazar, C., Araneda, R., Ebner-Karestinos, D., Arellano-Roco, C., & Campos-Jara, C. (2022). Effects of sport-based exercise interventions on executive function in older adults: A Systematic Review and Meta-Analysis. *International Journal of Environmental Research and Public Health*, *19*(19). https://doi.org/10.3390/ijerph191912573

Cox, E. P., O'Dwyer, N., Cook, R., Vetter, M., Cheng, H. L., Rooney, K., & O'Connor, H. (2016). Relationship between physical activity and cognitive function in apparently healthy young to middle-aged adults: A systematic review. *Journal of Science and Medicine in Sport*, *19*(8), 616–628. https://doi.org/10.1016/j.jsams.2015.09.003

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J. F., & Oja, P. (2003). International Physical Activity Questionnaire: 12-country reliability and validity. *Medicine & Science in Sports & Exercise*, *35*(8), 1381–1395. https://doi.org/10.1249/01.MSS.0000078924.61453.FB

D'Souza, A. A., Moradzadeh, L., & Wiseheart, M. (2018). Musical training, bilingualism, and executive function: Working memory and inhibitory control. *Cognitive Research: Principles and Implications*, *3*(1), 11. https://doi.org/10.1186/s41235-018-0095-6

de Greeff, J. W., Bosker, R. J., Oosterlaan, J., Visscher, C., & Hartman, E. (2018). Effects of physical activity on executive functions, attention and academic performance in preadolescent children: A meta-analysis. *Journal of Science and Medicine in Sport, 21*(5), 501–507. https://doi.org/10.1016/j.jsams.2017.09.595

Degé, F., & Frischen, U. (2022). The impact of music training on executive functions in childhood—A systematic review. *Zeitschrift Für Erziehungswissenschaft*, *25*(3), 579–602. https://doi.org/10.1007/s11618-022-01102-2

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001). *Delis-Kaplan Executive Function System (D-KEFS)*. The Psychological Corporation.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*(1), 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Dube, S. L., Sigmon, S., Althoff, R. R., Dittus, K., Gaalema, D. E., Ogden, D. E., Phillips, J., Ades, P., & Potter, A. S. (2020). Association of self-reported executive function and mood with executive function task performance across adult populations. *Applied Neuropsychology. Adult*, 1–12. https://doi-org/10.1080/23279095.2020.1794869

Duckworth, A. L., & Kern, M. L. (2011). A meta-analysis of the convergent validity of self-control measures. *Journal of Research in Personality*, *45*(3), 259–268. https://doi.org/10.1016/j.jrp.2011.02.004

Duckworth, A. L., Taxer, J. L., Eskreis-Winkler, L., Galla, B. M., & Gross, J. J. (2019). Self-control and academic achievement. *Annual Review of Psychology*, *70*(1), 373–399. https://doi.org/10.1146/annurev-psych-010418-103230

Eisenberg, D. T., Johnson, M. W., & Barch, D. M. (2019). Cognitive performance and the reliability of self-report measures of executive function. *Journal of Cognitive Enhancement*, 3(1), 44-59. https://doi.org/10.1007/s41465-019-00066-2

Enkavi, A. Z., Verde, J. R., & Falk, E. B. (2019). The reliability and validity of self-reported cognitive abilities in behavioral research. *Psychological Science*, 30(5), 688-697. https://doi.org/10.1177/0956797619849927

Friedman, N. P., & Gustavson, D. E. (2022). Do rating and task measures of control abilities assess the same thing? *Current Directions in Psychological Science*, *31*(3), 262–271. https://doi.org/10.1177/09637214221091824

Friese, M., Frankenbach, J., Job, V., & Loschelder, D. D. (2017). Does self-control training improve self-control? A meta-analysis. *Perspectives on Psychological Science, 12*(6), 1077–1099. https://doi.org/10.1177/1745691617697076

Frye, W. S., & Shapiro, S. K. (2021). The role of executive functioning on the intention-behaviour relationship of health behaviours: A temporal self-regulatory perspective. *Psychology & Health*, *36*(5), 612–627. https://doi.org/10.1080/08870446.2020.1767778

Gardani, M., Bradford, D. R. R., Russell, K., Allan, S., Beattie, L., Ellis, J., & Akram, U. (2021). A systematic review and meta-analysis of poor sleep, insomnia symptoms and stress in undergraduate students. *Sleep Medicine Reviews*, 101565. https://doi.org/10.1016/j.smrv.2021.101565

Grissom, N. M., & Reyes, T. M. (2019). Let's call the whole thing off: Evaluating gender and sex differences in executive function. *Neuropsychopharmacology*, *44*(1), 86–96. https://doi.org/10.1038/s41386-018-0179-5

Grömping, U. (2006). Relative importance for linear regression in R: The *relaimpo* package. *Journal of Statistical Software, 17*(1), 1–27. https://doi.org/10.18637/jss.v017.i01

Guerra-Carrillo, B., Katovich, K., & Bunge, S. A. (2017). Does higher education hone cognitive functioning and learning efficacy? Findings from a large and diverse sample. *PLoS ONE*, *12*(8), e0182276. https://doi.org/10.1371/journal.pone.0182276

Hall, P. A., Fong, G. T., Epp, L. J., & Elias, L. J. (2008). Executive function moderates the intention-behavior link for physical activity and dietary behavior. *Psychology & Health, 23*(3), 309–326. https://doi.org/10.1080/14768320701212099

Haverkamp, B. F., Wiersma, R., Vertessen, K., van Ewijk, H., Oosterlaan, J., & Hartman, E. (2020). Effects of physical activity interventions on cognitive outcomes and academic performance in adolescents and young adults: A meta-analysis. *Journal of Sports Sciences*, *38*(23), 2637–2660. https://doi.org/10.1080/02640414.2020.1794763

Hays, R. D., Martin, S. A., Sesti, A. M., & Spritzer, K. L. (2005). Psychometric properties of the Medical Outcomes Study Sleep measure. *Sleep Medicine*, *6*(1), 41–44. https://doi.org/10.1016/j.sleep.2004.07.006

Ho, S., Gooderham, G. K., & Handy, T. C. (2018). Self-reported free-living physical activity and executive control in young adults. *PLOS ONE*, *13*(12), e0209616. https://doi.org/10.1371/journal.pone.0209616

Horn, J. L., & Cattell, R. B. (1967). Age differences in fluid and crystallized intelligence. *Acta Psychologica, 26*, 107–129. https://doi.org/10.1016/0001-6918(67)90011-X

IBM Corp. (2022). *IBM SPSS Statistics for Windows, Version 28.0.1.1* [Computer software]. IBM Corp.

Jacques, S., & Zelazo, P. D. (2001). The Flexible Item Selection Task (FIST): A measure of executive function in preschoolers. *Developmental Neuropsychology*, *20*(3), 573–591. https://doi.org/10.1207/S15326942DN2003_2

Jones, S. A. H., Butler, B. C., Kintzel, F., Johnson, A., Klein, R. M., & Eskes, G. A. (2016). Measuring the performance of attention networks with the Dalhousie Computerized Attention Battery (DalCAB): Methodology and reliability in healthy adults. *Frontiers in Psychology*, *7*. https://doi.org/10.3389/fpsyg.2016.00823

Kasap, E. Z., Ağzıtemiz, F., & Ünal, G. (2021). Cognitive, mental and social benefits of interacting with nature: A systematic review. *Journal of Happiness and Health*, *1*(1), Article 1.

Kohl, H.W., Blair, S.N., Paffenbarger, R.S., Macera, C.A. and Kronenfeld, J.J. (1988). A mail survey of physical activity habits as related to measured physical fitness. *American Journal of Epidemiology*, 127, 1228-1239.

Lambourne, K. (2006). The relationship between working memory capacity and physical activity rates in young adults. *Journal of Sports Science & Medicine*, *5*(1), 149–153.

Lee, S., Charles, S. T., & Almeida, D. M. (2021). Change is good for the brain: activity diversity and cognitive functioning across adulthood. *The Journals of Gerontology: Series B*, *76*(6), 1036–1048. https://doi.org/10.1093/geronb/gbaa020

Li, L., Zhang, J., Cao, M., Hu, W., Zhou, T., Huang, T., Chen, P., & Quan, M. (2020). The effects of chronic physical activity interventions on executive functions in children aged 3–7 years: A meta-analysis. *Journal of Science and Medicine in Sport*, *23*(10), 949–954. https://doi.org/10.1016/j.jsams.2020.03.007

Liu, J., Zhu, L., & Liu, C. (2020). Sleep quality and self-control: The mediating roles of positive and negative affects. *Frontiers in Psychology*, *11*. https://doi.org/10.3389/fpsyg.2020.607548

Loprinzi, P. D., Frith, E., Edwards, M. K., Sng, E., & Ashpole, N. (2018). The effects of exercise on memory function among young to middle-aged adults: Systematic review and recommendations for future research. *American Journal of Health Promotion*, *32*(3), 691–704. https://doi.org/10.1177/0890117117737409

Luciana, M. (2020). Risks versus consequences of adolescent and young adult substance use: A focus on executive control. *Current Addiction Reports*, *7*(4), 453–463. https://doi.org/10.1007/s40429-020-00341-9

Malagoli, C., Chiorri, C., Traverso, L., & Usai, M. C. (2022). Inhibition and individual differences in behavior and emotional regulation in adolescence. *Psychological Research*, *86*(4), 1132–1144. https://doi.org/10.1007/s00426-021-01565-8

McGrath, A. B., Weinstock, J., Cloutier, R., Christensen, M., Taylor, D. J., & Henderson, C. E. (2021). Examination of college student health behaviors and self-reported executive functions. *Journal of American College Health*, *71*(2), 1–11. https://doi.org/10.1080/07448481.2021.1904951

McInerney, R. (2004). Victoria Computerized Adaptation of the Paced Auditory Serial Addition Task (PASAT). Retrieved from http://www.mcinerney.ca/pasat.html

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal

lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734

Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Cepeda, N. J., & Chau, T. (2011). Short-term music training enhances verbal intelligence and executive function. *Psychological Science*, *22*(11), 1425–1433. https://doi.org/10.1177/0956797611416999

Munroe, C. A., Leckey, J., Johnson, S. A., & Jacques, S. (2025). Factor Structure and Psychometric Properties of the Learning, Executive, and Attention Functioning (LEAF) Scale in Young Adults. *Assessment*. https://doi.org/10.1177/10731911251317788

Muthén, L. K., & Muthén, B. O. (2017). *Mplus User's Guide* (8th ed.). Muthén & Muthén.

ObjectPlanet. (1998-2025). *Opinio 7.26* [Computer software]. https://www.opinio.net

Othman, N., Ahmad, F., El Morr, C., & Ritvo, P. (2019). Perceived impact of contextual determinants on depression, anxiety and stress: A survey with university students. *International Journal of Mental Health Systems*, *13*(1), 17. https://doi.org/10.1186/s13033-019-0275-x

Pachava, S. R., & Shenoy, S. (2023). Association of self-reported physical activity with cognitive function in young adults. *Cognition, Brain, Behavior: An Interdisciplinary Journal*, *27*(1), 49–68. https://doi.org/10.24193/cbb.2023.27.03

Patton, J. H., Stanford, M. S., & Barratt, E. S. (1995). Factor structure of the Barratt Impulsiveness Scale. *Journal of Clinical Psychology*, *51*(6), 768–774. https://doi.org/10.1002/1097-4679(199511)51:6<768::AID-JCLP2270510607>3.0.CO;2-1

Peduzzi, P., Concato, J., Kemper, E., Holford, T. R., & Feinstein, A. R. (1996). A simulation study of the number of events per variable in logistic regression analysis. *Journal of Clinical Epidemiology, 49*(12), 1373–1379. https://doi.org/10.1016/S0895-4356(96)00236-3

Podsakoff, P. M., MacKenzie, S. B., Lee, J.-Y., & Podsakoff, N. P. (2003). Common method biases in behavioral research: A critical review of the literature and recommended remedies. *Journal of Applied Psychology*, *88*(5), 879–903. https://doi.org/10.1037/0021-9010.88.5.879

Rathore, A., & Lom, B. (2017). The effects of chronic and acute physical activity on working memory performance in healthy participants: A systematic review with meta-analysis of randomized controlled trials. *Systematic Reviews*, *6*(1), 124. https://doi.org/10.1186/s13643-017-0514-7

Rau, H. K., Suchy, Y., Butner, J. E., & Williams, P. G. (2016). Latent profiles of executive functioning in healthy young adults: Evidence of individual differences in hemispheric asymmetry. *Psychological Research*, *80*(6), 997–1019. https://doi.org/10.1007/s00426-015-0706-5

Reilly, D. (2012). Gender, culture, and sex-typed cognitive abilities. *PLOS ONE*, *7*(7), e39904. https://doi.org/10.1371/journal.pone.0039904

Reynolds, B. W., Basso, M. R., Miller, A. K., Whiteside, D. M., & Combs, D. (2019). Executive function, impulsivity, and risky behaviors in young adults. *Neuropsychology*, *33*(2), 212–221. https://doi.org/10.1037/neu0000510

Richardson, M., Hunt, A., Hinds, J., Bragg, R., Fido, D., Petronzi, D., Barbett, L., Clitherow, T., & White, M. (2019). A measure of nature connectedness for children and adults:

Validation, performance, and insights. *Sustainability*, *11*(12), Article 12. https://doi.org/10.3390/su11123250

Rodriguez-Gomez, D. A., & Talero-Gutiérrez, C. (2022). Effects of music training in executive function performance in children: A systematic review. *Frontiers in Psychology*, *13*. https://doi.org/10.3389/fpsyg.2022.968144

Rogers, F., & Metzler-Baddeley, C. (2024). The effects of musical instrument training on fluid intelligence and executive functions in healthy older adults: A systematic review and *meta*-analysis. *Brain and Cognition*, *175*, 106137. https://doi.org/10.1016/j.bandc.2024.106137

Salas-Gomez, D., Fernandez-Gorgojo, M., Pozueta, A., Diaz-Ceballos, I., Lamarain, M., Perez, C., Kazimierczak, M., & Sanchez-Juan, P. (2020). Physical activity Is associated with better executive function in university students. *Frontiers in Human Neuroscience*, *14*. https://doi.org/10.3389/fnhum.2020.00011

Schöndube, A., Kanning, M., & Fuchs, R. (2016). The bidirectional effect between momentary affective states and exercise duration on a day level. *Frontiers in Psychology*, *7*. https://doi.org/10.3389/fpsyg.2016.01414

Shao, Z., Janse, E., Visser, K., & Meyer, A. S. (2014). What do verbal fluency tasks measure? Predictors of verbal fluency performance in older adults. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.00772

Shields, G. S., Moons, W. G., & Slavich, G. M. (2017). Better executive function under stress mitigates the effects of recent life stress exposure on health in young adults. *Stress*, *20*(1), 92–102. https://doi.org/10.1080/10253890.2017.1286322

Song, W., Feng, L., Wang, J., Ma, F., Chen, J., Qu, S., & Luo, D. (2022). Play smart, be smart? Effect of cognitively engaging physical activity interventions on executive function among children 4-12 years old: A systematic review and meta-analysis. *Brain Sciences*, *12*(6). https://doi.org/10.3390/brainsci12060762

Spurk, D., Hirschi, A., Wang, M., Valero, D., & Kauffeld, S. (2020). Latent profile analysis: A review and "how to" guide of its application within vocational behavior research. *Journal of Vocational Behavior*, *120*, 103445. https://doi.org/10.1016/j.jvb.2020.103445

Statistics Canada. (1983). *Canada Fitness Survey: A survey of the physical activity patterns of Canadians*. Ottawa: Statistics Canada.

Tabachnick, B. G., & Fidell, L. S. (2014). *Using multivariate statistics* (6th ed.). Pearson.

Thomas, J., & D, V. (2017). A comparative study of the effects of superbrain yoga and aerobic exercise on cognitive functions. *National Journal of Physiology Pharmacy and Pharmacology*, 1. https://doi.org/10.5455/njppp.2017.7.0309126062017

Tomporowski, P. D., Davis, C. L., Miller, P. H., & Naglieri, J. A. (2008). Exercise and children's intelligence, cognition, and academic achievement. *Educational Psychology Review, 20*(2), 111–131. https://doi.org/10.1007/s10648-007-9057-0

Toplak, M. E., West, R. F., & Stanovich, K. E. (2013). Practitioner review: Do performance-based measures and ratings of executive function assess the same construct? *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *54*(2), 131–143. https://doi.org/10.1111/jcpp.12001

Travis, F., Harung, H. S., & Lagrosen, Y. (2011). Moral development, executive functioning, peak experiences and brain patterns in professional and amateur classical musicians:

Interpreted in light of a Unified Theory of Performance. *Consciousness and Cognition*, *20*(4), 1256–1264. https://doi.org/10.1016/j.concog.2011.03.020

Umegaki, H., Sakurai, T., & Arai, H. (2021). Active life for brain health: A narrative review of the mechanism underlying the protective effects of physical activity on the brain. *Frontiers in Aging Neuroscience*, *13*. https://doi.org/10.3389/fnagi.2021.761674

Vassiliu, C., Leong, V., & Hendriks, H. (2024). The influence of multilingual experience on executive function and structure learning: Effects in young adults in the UK and Singapore. *Languages*, *9*(4), Article 4. https://doi.org/10.3390/languages9040136

Verburgh, L., Königs, M., Scherder, E. J. A., & Oosterlaan, J. (2014). Physical exercise and executive functions in preadolescent children, adolescents and young adults: A meta-analysis. *British Journal of Sports Medicine*, *48*(12), 973–979. https://doi.org/10.1136/bjsports-2012-091441

VonDras, Dean & Powless, M & Olson, AK & Wheeler, D & Snudden, AL. (2005). Differential effects of everyday stress on the episodic memory test performances of young, mid-life, and older adults. *Aging & Mental Health 9*, 60-70. 10.1080/13607860412331323782.

Vuontela, V., Carlson, S., Troberg, A.-M., Fontell, T., Simola, P., Saarinen, S., & Aronen, E. T. (2013). Working memory, attention, inhibition, and their relation to adaptive functioning and behavioral/emotional symptoms in school-aged children. *Child Psychiatry & Human Development*, *44*(1), 105–122. https://doi.org/10.1007/s10578-012-0313-2

Warburton, D. E. R., Nicol, C. W., & Bredin, S. S. D. (2006). Prescribing exercise as preventive therapy. *CMAJ : Canadian Medical Association Journal*, *174*(7), 961–974. https://doi.org/10.1503/cmaj.1040750

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology*, *54*(6), 1063–1070. https://doi.org/10.1037/0022-3514.54.6.1063

Wechsler, D. (2008). *Wechsler Adult Intelligence Scale – Fourth Edition (WAIS-IV)*. Pearson Assessment.

Xiong, J., Ye, M., Wang, L., & Zheng, G. (2021). Effects of physical exercise on executive function in cognitively healthy older adults: A systematic review and meta-analysis of randomized controlled trials. *International Journal of Nursing Studies*, *114*, 103810. https://doi.org/10.1016/j.ijnurstu.2020.103810

Xue, Y., Yang, Y., & Huang, T. (2019). Effects of chronic exercise interventions on executive function among children and adolescents: A systematic review with meta-analysis. *British Journal of Sports Medicine*, *53*(22), 1397–1404. https://doi.org/10.1136/bjsports-2018-099825

Zavecz, Z., Nagy, T., Galkó, A., Nemeth, D., & Janacsek, K. (2020). The relationship between subjective sleep quality and cognitive performance in healthy young adults: Evidence from three empirical studies. *Scientific Reports*, *10*(1), 4855. https://doi.org/10.1038/s41598-020-61627-6

Zhang, M., Jia, J., Yang, Y., Zhang, L., & Wang, X. (2023). Effects of exercise interventions on cognitive functions in healthy populations: A systematic review and meta-analysis. *Ageing Research Reviews*, *92*, 102116. https://doi.org/10.1016/j.arr.2023.102116

Zuk, J., Benjamin, C., Kenyon, A., & Gaab, N. (2014). Behavioral and neural correlates of executive functioning in musicians and non-musicians. *PLOS ONE*, *9*(6), e99868. https://doi.org/10.1371/journal.pone.0099868

CHAPTER 4: GENERAL DISCUSSION

4.1 Summary of Key Findings

The purpose of this dissertation was to investigate the relationships between PA and EFs in young adults, addressing important gaps in this research area, despite the critical role of EFs in supporting success during the transition to adulthood. Two studies were conducted. First, a systematic review of RCTs was conducted to identify how different exercise interventions affected EFs. Second, a cross-sectional study was conducted to explore relationships between PA patterns in the past month and over the lifetime and both performance-based and self-reported measures of EFs.

Overall, the findings of the systematic review supported the potential of exercise as a modifiable behaviour to enhance EFs during young adulthood. The majority of acute and chronic exercise interventions resulted in EF benefits, with moderate-intensity exercise yielding the most robust improvements, but low intensity resulting in no benefits and high intensity resulting in no or detrimental effects on EFs. Exercise duration also followed a similar pattern, with benefits observed across durations of 5–60 min, though the benefits at either end of this range (e.g., less than 15 min and greater than 50 min) were less clear. Aerobic and resistance exercises were the most frequently studied and alternative modalities, such as martial arts and yoga, which incorporate aspects such as mindfulness or coordination in addition to PA, also demonstrated promise. EF benefits were observed shortly following exercise sessions and all components of performance-based EFs were similarly affected by exercise. Results also highlighted gaps in the literature, including limited research examining the sustainability of the reported immediate and short-term EF improvements.

Results from the cross-sectional study indicated that PA related both positively and negatively to some aspects of EF (i.e., verbal fluency, working memory, respectively), but explained a very small amount of variance. Perceived sleep quality and positive affect were the strongest predictors of self-reported EFs, and musical training emerged as the most important predictor of performance-based EFs amongst those included in this study. After accounting for all other predictors, lifetime PA related positively with verbal fluency, whereas past month PA assessed using METS expended was negatively related with both measures of working memory. We also used these data to examine distinct EF profiles among young adults. Two distinct EF profiles were identified, representing Higher and Lower EFs. There were no significant differences in lifetime or previous month PA between profiles. However, participants with musical training were more likely to belong to the Higher EF profile.

4.2 Integration of Findings and Implications

By integrating the findings of the systematic review and cross-sectional study, we gained a more nuanced understanding of how exercise and other factors may influence EFs in young adults.

4.2.1 Exercise, Physical Activity, and Performance-based Executive Functions

Both acute and chronic exercise interventions of moderate intensity and medium duration (e.g., 15–50 min) were found to be optimal for short-term performance-based EF enhancement. This aligns with the inverted-U hypothesis of exercise intensity (Chang & Etnier, 2009) and duration (Chang et al., 2015), which posits that moderate levels of both intensity and duration (e.g., approximately 70% maximum exertion for 20 min) yield the most substantial cognitive benefits. Aerobic and resistance exercises at moderate intensity and duration quite

consistently result in short-term performance-based EF improvements, and alternative types such as yoga and martial arts also produce significant benefits, potentially yielding larger effects. These alternative methods may derive their added value from incorporating components beyond physical movement, such as mindfulness (Diamond & Ling, 2016, 2019) and coordination (Ludyga et al., 2020), which are thought to play a critical role in EF enhancement. Together, these findings underscore the importance of moderate exercise intensity and duration, and that the type of exercise may be less critical, allowing for personalized activity selection based on individual preferences. Previous researchers have recommended moderate-intensity exercise 3–4 times per week for 45–60 min over 3–6 months to benefit cognitive health, with findings primarily based on older adults (Zhang et al., 2023). While the current review supports moderate intensity exercise, our findings suggest that young adults may not require the same frequency or duration to experience cognitive benefits. Older adults may start from a greater cognitive deficit and require longer interventions, whereas young adults may experience more immediate gains, as evidenced by our findings with acute exercise interventions.

Effects on multiple EF domains, including working memory, cognitive flexibility, inhibitory control, and planning, are reported, supporting the idea that exercise has a global impact on EFs (Zhang et al., 2023). These positive effects were shown to emerge shortly after exercise completion and last up to 120 min following completion of exercise. Notably however, in contrast to research with children (e.g., Alvarez-Bueno et al., 2017; de Greeff et al., 2018; Song et al., 2023) and older adults (e.g., Contreras-Osorio et al., 2022; Xiong et al., 2021),

studies examining cumulative benefits of chronic exercise interventions with young adults are extremely limited.

In comparison, the cross-sectional study found that longer-term self-reported PA patterns – both in the past month and lifetime – predicted very little variance in young adults' self-reported and performance-based EFs. Lifetime PA was positively associated with verbal fluency, while past-month METs were negatively associated with both working memory tasks. Given that MET values incorporate both intensity and duration, this negative relationship may be consistent with the notion that excessive or high-intensity exercise can result in poorer cognitive performance (Chang et al., 2015).

A potential explanation for the difference between the effects of interventions and the cross-sectional research is that the Canada Fitness Survey (CFS) captured a wide range of PAs, including exercise and other physically demanding activities that were not necessarily structured exercise (e.g., household tasks). While it may be possible to isolate activities classified as exercise within the CFS, the positive association between young adults' self-reported moderate-vigorous exercise patterns and performance-based EFs has been established previously (Lambourne et al., 2006; Pachava & Shenoy, 2023; Salas-Gomez et al., 2020). Therefore, we prioritized examining habitual PA engagement more broadly. However, our results suggest that PA patterns may not capture the level of activity required to enhance EFs (e.g., exercise of moderate intensity and duration), and structured exercise interventions are likely more effective at eliciting such improvements.

Overall, the current evidence indicates that performing moderate intensity and duration exercise shortly before engaging in tasks that require high cognitive demand, such as academic

work or decision-making, may be optimal for young adults. For educators, institutions, and workplaces, incorporating exercise sessions into daily routines could enhance cognitive performance, supporting both academic success and workplace productivity. The lack of longitudinal data and multi-session interventions with this population significantly limit conclusions that can be drawn about longer-term effects in young adults.

4.2.2 Other Predictors of Performance-based Executive Functions

A self-reported history of musical training was the strongest predictor of performance-based EFs (i.e., Colour-Word Interference and Verbal Fluency). These results align with previous research demonstrating that musicians tend to outperform non-musicians on measures of EFs, likely due to the cognitive demands of musical engagement, such as inhibiting automatic responses, sustaining attention, and switching between rules (Moreno et al., 2011; Travis et al., 2011; Zuk et al., 2014). Given the overlap between skills required for musical training and those assessed in EF tasks, musical training can be viewed as a form of EF training (Rogers & Metzler-Baddeley, 2024). Importantly, our cross-sectional data do not allow us to determine the direction of the relationship between musical training and performance-based EFs. However, positive effects of musical training interventions for EFs have been reported in children (Rodriguez-Gomez & Talero-Gutierrez, 2022) and older adults (Rogers & Metzler-Baddeley, 2024), but not young adults to our knowledge.

It has been suggested that the learning of new cognitive-motor skills that involve multi-sensory-motor integration is particularly effective for training EFs, and musical training is a prime example of such an activity (Rogers & Metzler-Baddeley, 2024). While certain types of exercise may also engage these components, musical training may do so more effectively. For

example, in comparison to meta-analytic results that showed no effects of rhythmic exercise interventions (e.g., dancing and exercise to music) on EFs (Ma et al., 2023), playing an instrument resulted in improved EFs (Rogers & Metzler-Baddeley, 2024). These findings suggest that incorporating musical training into interventions aimed at strengthening the development of EFs during or prior to young adulthood could be particularly beneficial.

4.2.3 Self-reported Executive Functions

Research on PA and EFs in young adults has largely focused on performance-based EFs, neglecting self-reported EFs. We included both and found that our models explained more variance in self-reported EFs than in performance-based measures, likely in part due to shared measurement approach between self-reported predictors (e.g., mood, sleep, stress) and self-reported EFs (Podsakoff et al., 2003). In addition, self-report EF measures intend to capture how individuals apply their cognitive abilities to real-world circumstances, which introduces more variability due to external factors, such as daily stressors or personal circumstances (Diamond, 2013). The lack of significant relationships between self-reported and performance-based EFs and the findings that distinct variables predicted each are broadly consistent with prior research suggesting that performance-based and self-reported EFs are weakly correlated and may capture distinct constructs (Friedman & Gustavson, 2022). These findings highlight the unique contributions of self-reported and performance-based EFs, underscoring the importance of including both when assessing EFs in young adults.

Self-reported sleep quality and positive affect were the strongest predictors of self-reported EFs, suggesting that individuals who perceive their sleep and mood more positively also tend to rate their EF abilities more favorably. Individuals with higher positive affect may

exhibit affectivity bias and report better EFs even if their actual EF performance is unaffected. However, this likely does not fully explain the predictive relationship between positive affect, sleep, and self-reported EFs (Pettit et al., 2001). Prior research in a general population of adults found that self-reported sleep was more strongly associated with self-reported measures of cognition than performance-based measures (Kronholm et al., 2009). In addition to the suggested differences between constructs measured in self-reported and performance-based EFs, the undergraduate academic context may also be a contributing factor. Students are accustomed to completing structured assessments regardless of sleep, stress, or affect fluctuations (Cleary et al., 2011; Gardani et al., 2021). Prior research suggests their performance-based EFs remain stable despite such variations (VonDras et al., 2005; Zavecz et al., 2020), possibly due to developed coping mechanisms or strategies that enable them to maintain performance.

4.2.4 Executive Function Profiles

In contrast to the commonly used variable-centered approaches, person-centered methods, such as latent profile analyses (LPA), capture the interrelatedness of variables within individuals, allowing for a more holistic understanding of how different skills co-occur and interact (Chaku et al., 2021). However, this approach has rarely been applied to EFs in adults (Beltz, 2018). Self-reported and performance-based EFs were summarized for the undergraduate sample of the cross-sectional study with two distinct “profiles” - Higher EFs and Lower EFs. Despite the limited association between self-reported and performance-based EFs, Higher EFs profile reflected higher scores on both self-reported and performance-based EFs, while the Lower EFs profile reflected lower scores on both types of measures. This suggests that

while these two assessment methods capture distinct aspects of EF, they may still align in meaningful ways when examined holistically. By shifting the focus from variable-centered approaches examining isolated EF components to person-centered approaches may provide a better understanding of meaningful patterns of EFs and their relevance for cognitive and behavioural predictors and outcomes.

Consistent with our variable-centered findings, musical training predicted membership in the Higher EFs profile whereas PA was not associated with profile membership. If training programs, such as exercise or musical training, have a global rather than variable impact on specific EFs, early identification of individuals with lower EF performance could help inform intervention approaches. Tailored interventions that address the specific needs of individuals with specific cognitive profiles may improve factors such as academic performance, mental health, and PA. For example, Chaku and colleagues (2021) found that different EF profiles in adolescents were uniquely associated with academic performance, mental health, risk-taking behaviours, and the quality of social relationships. Furthermore, investigating relationships between individual EF patterns and other factors that influence health risk or resilience – such as stress management or maintaining a healthy diet – could offer important insights across multiple areas of psychology.

4.3 Strengths and Limitations

Given the importance of EFs for the well-being of young adults (McGrath et al., 2021) and the broad clinical utility of exercise—owing to its accessibility, adaptability, and capacity to be tailored to individual needs across cultural contexts (Kiuppis, 2016)—this dissertation offers valuable insights in a meaningful research area. The combination of a systematic review and

empirical cross-sectional study provides a comprehensive perspective, integrating controlled intervention-based evidence with real-world patterns of PA.

The systematic review contributed to a clearer evidence base for how exercise of varying intensities, durations, frequencies, and types might impact EFs in young adults and highlighted areas for further investigation. Restricting the review to RCTs provided a rigorous assessment of how exercise impacts EFs in young adults, clarifying current knowledge of causal inferences. The cross-sectional study further strengthened the investigation by examining both self-reported and performance-based EFs, addressing an important gap in prior research. By incorporating PA patterns over the past month and lifetime, as well as other important predictors (e.g., sleep, mood, musical training), this study captured broader lifestyle factors that may be important for EFs in young adults beyond the short-term benefits observed in controlled exercise interventions. Additionally, the use of LPA to identify EF profiles represents a novel approach, allowing for a more person-centered understanding of cognitive functioning in young adults.

Along with these strengths, key limitations should be acknowledged. Participants were predominately undergraduate students, which may limit generalizability to broader young adult populations, such as those with different educational backgrounds. While there is no strong evidence that university students have higher IQs than the general population (Uttl et al., 2024), advanced education has been linked to improvements in cognitive abilities, including aspects of EFs (Baars et al., 2015; Guerra-Carrillo et al., 2017). As a result, the variability in EFs among young adults may have been underestimated by the university sample, potentially influencing observed relationships between EFs and other variables or limiting findings of the EFs profile analyses.

In the systematic review, the heterogeneity in exercise intervention designs and measures of EFs may have limited the comparability of findings across studies. While we aimed to comprehensively search the existing literature, it is possible that relevant unpublished or non-English studies were missed, restricting the scope of the review. For example, publication bias occurs when studies with significant results are more likely to be published (Rosenthal, 1979), potentially inflating the overall interpretation of the effects of exercise when using a knowledge synthesis approach. We identified patterns of effects across a range of exercise variables. However, few studies systematically compared these factors directly. For instance, without accounting for how type, duration and intensity might jointly affect EFs, it is unclear if effects attributed to one variable (e.g., intensity) are partially driven by another (e.g., type).

The predictors included in the analyses for the cross-sectional study, accounted for little variance in performance-based EFs, suggesting that important factors may have been overlooked. The focus on self-reported PA patterns, rather than structured exercise implemented through an intervention, provided a naturalistic perspective, but likely obscured the relationship between exercise and EFs. Interestingly, other lifestyle factors emerged as more relevant than PA. Our findings suggest that musical training is the strongest predictor of EFs, though we cannot be certain about causality. That is, it is unclear whether musical training enhances EFs in young adults or whether those with stronger EFs are more likely to engage in musical training.

4.4 Future Research Directions

The findings of this dissertation highlight several promising avenues for future research. While acute and chronic exercise interventions show relatively consistent short-term benefits

for young adults' performance-based EFs, questions remain regarding the sustainability and cumulative effects of these benefits, which could be addressed with longitudinal designs. For example, longitudinal studies are needed to determine whether repeated engagement in optimal exercise patterns (e.g., moderate intensity, 15–50 min) leads to lasting EF improvements over weeks or months. Additionally, future research should explore whether benefits accumulate over time or if single-session effects remain stable with repeated engagement. It also remains unclear whether individuals reach a ceiling in EF improvements through exercise, and if so, how long those gains persist after exercise cessation. Further, examining whether certain populations, such as individuals with lower baseline EFs, experience greater or more prolonged benefits from exercise interventions could provide insights into the individual variability in responsiveness to exercise interventions.

Beyond exercise, the role of musical training for EFs warrants further exploration. While musical training was the strongest predictor of performance-based EFs in the cross-sectional study, the study design does not establish causality. Experimental studies examining the effects of musical training interventions on EFs in young adults, like those conducted with other age groups (Degé & Frischen, 2022; D'Souza et al., 2018; Zuk et al., 2014), would help clarify this relationship. Moreover, comparing the cognitive benefits of musical training to those of alternative interventions, such as exercise, mindfulness, or cognitive training, could provide insight into which activities offer the greatest EF enhancements.

In terms of assessing EFs, our findings reinforce the importance of considering both performance-based and self-reported measures in future research. Given the weak correlations between these measures, studies should further investigate their unique contributions to

understanding EFs in young adults. The incorporation of EF profiles offers an innovative approach to studying cognition in young adults. It may be beneficial for future research to refine methods for identifying and applying these profiles in larger and broader samples, particularly in relation to intervention effectiveness. Understanding how individuals with different EF profiles respond to exercise, musical training, or other cognitive interventions could lead to more personalized strategies for enhancing cognitive functioning.

Future research could also explore whether there are moderation effects between PA, EFs, and other key variables such as affect and sleep quality. Given that both PA and EFs are independently associated with these factors (Diamond, 2013; Chennaoui et al., 2015; Schöndube et al., 2016), it is possible that PA strengthens or buffers the links between EFs and well-being-related outcomes. For instance, individuals with stronger EFs may generally experience lower stress and better sleep quality, but these relationships could be amplified among those who engage in regular PA. Alternatively, PA may serve as a protective factor, mitigating the negative impact of poor sleep or high stress on EF performance. Examining these potential moderation effects could provide a more nuanced understanding of how PA interacts with cognitive and emotional processes, ultimately informing targeted interventions aimed at optimizing both EF and overall well-being.

4.5 Conclusions

In conclusion, this dissertation provides valuable insights into the relationship between PA and EFs in young adults, highlighting the potential of physical exercise as a modifiable behaviour for EF enhancement. The systematic review reinforced the role of moderate-intensity, moderate-duration exercise for improving performance-based EFs shortly following exercise

completion, while also noting potential added benefits of different types of exercise such as yoga and martial arts. The cross-sectional study further illustrated that while patterns of PA more broadly may have a limited relationship with EFs, factors such as sleep quality, positive affect, and musical training may be important predictors of EFs. This research also reflected the importance of integrating both self-reported and performance-based EFs and exploring the relevance of EF profiles for advancing both research and practical applications. Overall findings underscore the importance of considering both exercise and other lifestyle factors in the development of effective strategies to support cognitive functioning during the transition to adulthood, and they highlight the need for further investigation into the long-term effects of exercise for EFs.

REFERENCES

Abdalkareem Jasim, S., Singh, M., Baqir Al-Dhalimy, A. M., Zwamel, A. H., Jawad, I. A., & Shalaby, N. S. (2024). The impact of chronic exercise on cognitive function: An overview of reviews. *Iranian Journal of Psychiatry*. https://doi.org/10.18502/ijps.v19i4.16561

Aguirre-Loaiza, H., Arias, I., Bonilla, S., Ramírez, R., Ramírez-Herrera, S., Nanez, J., Barbosa-Granados, S., & Arenas-Granada, J. (2022). Effect of acute physical exercise on inhibitory control in young adults: High-intensity indoor cycling session. *Physiology & Behavior*, *254*, 113902. https://doi.org/10.1016/j.physbeh.2022.113902

Allan, J. L., McMinn, D., & Daly, M. (2016). A bidirectional relationship between executive function and health behavior: Evidence, implications, and future directions. *Frontiers in Neuroscience, 10*, 386. https://doi.org/10.3389/fnins.2016.00386

Alvarez-Bueno, C., Pesce, C., Cavero-Redondo, I., Sánchez-López, M., Pardo-Guijarro, M. J., & Martínez-Vizcaíno, V. (2017). The effect of physical activity interventions on children's cognition and metacognition: A systematic review and meta-analysis. *Journal of the American Academy of Child & Adolescent Psychiatry, 56*(9), 729–738. https://doi.org/10.1016/j.jaac.2017.06.012

Aly, M., & Kojima, H. (2020). Acute moderate-intensity exercise generally enhances neural resources related to perceptual and cognitive processes: A randomized controlled ERP study. *Mental Health and Physical Activity*, *19*, 100363. https://doi.org/10.1016/j.mhpa.2020.100363

Anderson, J. A. E., Mak, L., Keyvani Chahi, A., & Bialystok, E. (2018). The Language and Social Background Questionnaire: Assessing degree of bilingualism in a diverse population.

Behavior Research Methods, *50*(1), 250–263. https://doi.org/10.3758/s13428-017-0867-9

Baars, M. A. E., Nije Bijvank, M., Tonnaer, G. H., & Jolles, J. (2015). Self-report measures of executive functioning are a determinant of academic performance in first-year students at a university of applied sciences. *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.01131

Baron, I. S. (2000). Behavior rating inventory of executive function. *Child Neuropsychology: A Journal on Normal and Abnormal Development in Childhood and Adolescence*, *6*(3), 235–238. https://doi.org/10.1076/chin.6.3.235.3152

Baron, I. S. (2004). Delis-Kaplan Executive Function System. *Child Neuropsychology, 10*(2), 147–152. https://doi.org/10.1080/09297040490911140

Basso, J. C., Shang, A., Elman, M., Karmouta, R., & Suzuki, W. A. (2015). Acute exercise improves prefrontal cortex but not hippocampal function in healthy adults. *Journal of the International Neuropsychological Society*, *21*(10), 791–801. https://doi.org/10.1017/s135561771500106x

Beltz, A. M. (2018). Connecting theory and methods in adolescent brain research. *Journal of Research on Adolescence*, *28*(1), 10–25. https://doi.org/10.1111/jora.12366

Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child Development, 81*(6), 1641–1660. https://doi.org/10.1111/j.1467-8624.2010.01499.x

Blomstrand, P., & Engvall, J. (2021). Effects of a single exercise workout on memory and learning functions in young adults—A systematic review. *Translational Sports Medicine*, *4*(1), 115–127. https://doi.org/10.1002/tsm2.190

Brown, D. M. Y., & Bray, S. R. (2015). Isometric exercise and cognitive function: an investigation of acute dose–response effects during submaximal fatiguing contractions. *Journal of Sports Sciences*, *33*(5), 487–497. https://doi.org/10.1080/02640414.2014.947524

Brown, D. M. Y., & Bray, S. R. (2018). Acute effects of continuous and high-intensity interval exercise on executive function. *Journal of Applied Biobehavioral Research*, *23*(3). https://doi.org/10.1111/jabr.12121

Buchanan, T. (2016). Self-report measures of executive function problems correlate with personality, not performance-based executive function measures, in nonclinical samples. *Psychological Assessment*, *28*(4), 372–385. https://doi.org/10.1037/pas0000192

Burgess, P. W., Alderman, N., Evans, J., Emslie, H., & Wilson, B. A. (1998). The ecological validity of tests of executive function. *Journal of the International Neuropsychological Society, 4*(6), 547–558. https://doi.org/10.1017/S1355617706461073

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports, 100*(2), 126–131.

Castellanos-Ryan, N., Parent, S., Chaput-Langlois, S., Rioux, C., Jacques, S., Simard, C., Tremblay, R.E., Séguin, J.R., & Zelazo, P. D. (2023). Modelling executive function across early childhood: Longitudinal invariance, development from 3.5 to 7 years and later academic performance. *Cognitive Development*, 68, 101365.

Castellanos, I., Kronenberger, W. G., & Pisoni, D. B. (2018). Questionnaire-based assessment of executive functioning: Psychometrics. *Applied Neuropsychology. Child, 7*(2), 93–109. https://doi.org/10.1080/21622965.2016.1248557

Cattell, R. B. (1987). *Intelligence: Its structure, growth, and action.* North-Holland.

Chaku, N., Hoyt, L. T., & Barry, K. (2021). Executive functioning profiles in adolescence: Using person-centered approaches to understand heterogeneity. *Cognitive Development*, *60*, 101119. https://doi.org/10.1016/j.cogdev.2021.101119

Chang, H., Kim, K., Jung, Y., & Kato, M. (2017). Effects of acute high-intensity resistance exercise on cognitive function and oxygenation in prefrontal cortex. *Physical Activity and Nutrition*, *21*(2), 1–8. https://doi.org/10.20463/jenb.2017.0012

Chang, Y.-K., Chu, C.-H., Wang, C.-C., Wang, Y.-C., Song, T.-F., Tsai, C.-L., & Etnier, J. L. (2015). Dose-response relation between exercise duration and cognition. *Medicine and Science in Sports and Exercise*, *47*(1), 159–165. https://doi.org/10.1249/MSS.0000000000000383

Chang, Y.-K., Chu, C., Wang, C.-C., Wang, Y.-C., Song, T.-F., Tsai, C.-L., & Etnier, J. (2014). Dose-response relation between exercise duration and cognition. *Medicine and Science in Sports and Exercise*, *47*. https://doi.org/10.1249/MSS.0000000000000383

Chang, Y., & Etnier, J. L. (2009). Exploring the dose-response relationship between resistance exercise intensity and cognitive function. *Journal of Sport and Exercise Psychology*, *31*(5), 640–656. https://doi.org/10.1123/jsep.31.5.640

Chang, Y., Tsai, C., Hung, T., So, E. C., Chen, F., & Etnier, J. L. (2011). Effects of acute exercise on executive function: a study with a Tower of London Task. *Journal of Sport and Exercise Psychology*, *33*(6), 847–865. https://doi.org/10.1123/jsep.33.6.847

Chennaoui, M., Arnal, P. J., Sauvet, F., & Léger, D. (2015). Sleep and exercise: A reciprocal issue? *Sleep Medicine Reviews*, *20*, 59–72. https://doi.org/10.1016/j.smrv.2014.06.008

Chin, T. C., & Rickard, N. S. (2012). The music USE (MUSE) questionnaire: An instrument to measure engagement in music. *Music Perception*, *29*(4), 429–446. https://doi.org/10.1525/mp.2012.29.4.429

Cleary, M., Walter, G., & Jackson, D. (2011). "Not always smooth sailing": Mental health issues associated with the transition from high school to college. *Issues in Mental Health Nursing, 32*(4), 250–254. https://doi.org/10.3109/01612840.2010.548906

Cobb-Clark, D. A., Dahmann, S. C., Kamhöfer, D. A., & Schildberg-Hörisch, H. (2022). The predictive power of self-control for life outcomes. *Journal of Economic Behavior & Organization*, *197*, 725–744. https://doi.org/10.1016/j.jebo.2022.02.028

Cohen, J. F. W., Gorski, M. T., Gruber, S. A., Kurdziel, L. B. F., & Rimm, E. B. (2016). The effect of healthy dietary consumption on executive cognitive functioning in children and adolescents: A systematic review. *British Journal of Nutrition*, *116*(6), 989–1000. https://doi.org/10.1017/S0007114516002877

Cohen, S., Kamarck, T., & Mermelstein, R. (1983). A global measure of perceived stress. *Journal of Health and Social Behavior*, *24*(4), 385–396. https://doi.org/10.2307/2136404

Contreras-Osorio, F., Ramirez-Campillo, R., Cerda-Vega, E., Campos-Jara, R., Martínez-Salazar, C., Araneda, R., Ebner-Karestinos, D., Arellano-Roco, C., & Campos-Jara, C. (2022). Effects of sport-based exercise interventions on executive function in older adults: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health*, *19*(19). https://doi.org/10.3390/ijerph191912573

Cox, E. P., O'Dwyer, N., Cook, R., Vetter, M., Cheng, H. L., Rooney, K., & O'Connor, H. (2016). Relationship between physical activity and cognitive function in apparently healthy

young to middle-aged adults: A systematic review. *Journal of Science and Medicine in Sport*, *19*(8), 616–628. https://doi.org/10.1016/j.jsams.2015.09.003

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J. F., & Oja, P. (2003). International Physical Activity Questionnaire: 12-country reliability and validity. *Medicine & Science in Sports & Exercise*, *35*(8), 1381–1395. https://doi.org/10.1249/01.MSS.0000078924.61453.FB

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications.

Crush, E. A., & Loprinzi, P. D. (2017). Dose-response effects of exercise duration and recovery on cognitive functioning. *Perceptual and Motor Skills*, *124*(6), 1164–1193. https://doi.org/10.1177/0031512517726920

D'Souza, A. A., Moradzadeh, L., & Wiseheart, M. (2018). Musical training, bilingualism, and executive function: Working memory and inhibitory control. *Cognitive Research: Principles and Implications*, *3*(1), 11. https://doi.org/10.1186/s41235-018-0095-6

de Greeff, J. W., Bosker, R. J., Oosterlaan, J., Visscher, C., & Hartman, E. (2018). Effects of physical activity on executive functions, attention and academic performance in preadolescent children: A meta-analysis. *Journal of Science and Medicine in Sport, 21*(5), 501–507. https://doi.org/10.1016/j.jsams.2017.09.595

Degé, F., & Frischen, U. (2022). The impact of music training on executive functions in childhood—A systematic review. *Zeitschrift Für Erziehungswissenschaft*, *25*(3), 579–602. https://doi.org/10.1007/s11618-022-01102-2

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001). *Delis-Kaplan Executive Function System (D-KEFS)*. The Psychological Corporation.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*(1), 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Diamond, A., & Ling, D. S. (2016). Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience*, *18*, 34–48. https://doi.org/10.1016/j.dcn.2015.11.005

Diamond, A., & Ling, D. S. (2019). Aerobic-exercise and resistance-training interventions have been among the least effective ways to improve executive functions of any method tried thus far. *Developmental Cognitive Neuroscience*, *37*, 100572.

Douris, P. C., Handrakis, J. P., Apergis, D., Mangus, R. B., Patel, R., Limtao, J., Platonova, S., Gregorio, A., & Luty, E. (2018). The effects of aerobic exercise and gaming on cognitive performance. *Journal of Human Kinetics*, *61*(1), 73–83. https://doi.org/10.1515/hukin-2017-0134

Dube, S. L., Sigmon, S., Althoff, R. R., Dittus, K., Gaalema, D. E., Ogden, D. E., Phillips, J., Ades, P., & Potter, A. S. (2020). Association of self-reported executive function and mood with executive function task performance across adult populations. *Applied Neuropsychology. Adult, 29*(4), 1–12. Advance online publication. https://doi.org /10.1080/23279095.2020.1794869

Duckworth, A. L., & Kern, M. L. (2011). A meta-analysis of the convergent validity of self-control measures. *Journal of Research in Personality*, *45*(3), 259–268. https://doi.org/10.1016/j.jrp.2011.02.004

Duckworth, A. L., Taxer, J. L., Eskreis-Winkler, L., Galla, B. M., & Gross, J. J. (2019). Self-control and academic achievement. *Annual Review of Psychology*, *70*(1), 373–399. https://doi.org/10.1146/annurev-psych-010418-103230

Eather, N., Riley, N., Miller, A., Smith, V., Poole, A., Vincze, L., Morgan, P. J., & Lubans, D. R. (2019). Efficacy and feasibility of HIIT training for university students: The Uni-HIIT RCT. *Journal of Science and Medicine in Sport*, *22*(5), 596–601. https://doi.org/10.1016/j.jsams.2018.11.016

Eisenberg, D. T., Johnson, M. W., & Barch, D. M. (2019). Cognitive performance and the reliability of self-report measures of executive function. *Journal of Cognitive Enhancement*, 3(1), 44-59. https://doi.org/10.1007/s41465-019-00066-2

Elkana, O., Bustanai, N. Y. K., Louzia-Timen, R., Kodesh, E., Franco, M., & Doniger, G. M. (2018). Conscientiousness is associated with improvement in visuospatial working memory and mood following acute physical exercise: A randomized controlled trial. *Personality and Individual Differences*, *132*, 126–132. https://doi.org/10.1016/j.paid.2018.05.018

Elkana, O., Louzia-Timen, R., Kodesh, E., Levy, S., & Netz, Y. (2020). The effect of a single training session on cognition and mood in young adults – is there added value of a dual-task over a single-task paradigm? *International Journal of Sport and Exercise Psychology*, *20*(1), 36–56. https://doi.org/10.1080/1612197x.2020.1854821

Engel, G. L. (1977). The need for a new medical model: A challenge for biomedicine. *Science*, 196(4286), 129–136. https://doi.org/10.1126/science.847460

Enkavi, A. Z., Verde, J. R., & Falk, E. B. (2019). The reliability and validity of self-reported cognitive abilities in behavioral research. *Psychological Science*, 30(5), 688-697. https://doi.org/10.1177/0956797619849927

Ferguson, H. J., Brunsdon, V. E. A., & Bradford, E. E. F. (2021). The developmental trajectories of executive function from adolescence to old age. *Scientific Reports*, *11*(1), 1382. https://doi.org/10.1038/s41598-020-80866-1

Festa, F., Medori, S., & Macrì, M. (2023). Move your body, boost your brain: The positive impact of physical activity on cognition across all age groups. *Biomedicines, 11*(6), Article 1765. https://doi.org/10.3390/biomedicines11061765

Flexon, J. L., Meldrum, R. C., Young, J. T. N., & Lehmann, P. S. (2016). Low self-control and the Dark Triad: Disentangling the predictive power of personality traits on young adult substance use, offending and victimization. *Journal of Criminal Justice*, *46*, 159–169. https://doi.org/10.1016/j.jcrimjus.2016.05.006

Friedman, N. P., & Gustavson, D. E. (2022). Do rating and task measures of control abilities assess the same thing? *Current Directions in Psychological Science*, *31*(3), 262–271. https://doi.org/10.1177/09637214221091824

Friese, M., Frankenbach, J., Job, V., & Loschelder, D. D. (2017). Does self-control training improve self-control? A meta-analysis. *Perspectives on Psychological Science, 12*(6), 1077–1099. https://doi.org/10.1177/1745691617697076

Frye, W. S., & Shapiro, S. K. (2021). The role of executive functioning on the intention-behaviour relationship of health behaviours: A temporal self-regulatory perspective. *Psychology & Health*, *36*(5), 612–627. https://doi.org/10.1080/08870446.2020.1767778

Gardani, M., Bradford, D. R. R., Russell, K., Allan, S., Beattie, L., Ellis, J., & Akram, U. (2021). A systematic review and meta-analysis of poor sleep, insomnia symptoms and stress in undergraduate students. *Sleep Medicine Reviews*, 101565. https://doi.org/10.1016/j.smrv.2021.101565

Gentile, A., Thomas, E., Feka, K., Di Vincenzo, A., Restifo, M., Amata, V., Alesi, M., Drid, P., Maksimovic, N., Bianco, A., & Boca, S. (2020). A single bout of physical exercise does not affect young adults' executive functions. *Biomedical Human Kinetics*, *12*(1), 226–235. https://doi.org/10.2478/bhk-2020-0029

Gioia, G. A., Isquith, P. K., Guy, S. C., & Kenworthy, L. (2000). Test review Behavior Rating Inventory of Executive Function. *Child Neuropsychology, 6*(3), 235–238. https://doi.org/10.1076/chin.6.3.235.3152

Granero-Jiménez, J., López-Rodríguez, M. M., Dobarrio-Sanz, I., & Cortés-Rodríguez, A. E. (2022). Influence of physical exercise on psychological well-being of young adults: A quantitative study. *International Journal of Environmental Research and Public Health*, *19*(7), 4282. https://doi.org/10.3390/ijerph19074282

Grant, M. J., & Booth, A. (2009). A typology of reviews: An analysis of 14 review types and associated methodologies. *Health Information & Libraries Journal, 26*(2), 91–108. https://doi.org/10.1111/j.1471-1842.2009.00848.x

Grissom, N. M., & Reyes, T. M. (2019). Let's call the whole thing off: Evaluating gender and sex differences in executive function. *Neuropsychopharmacology*, *44*(1), 86–96. https://doi.org/10.1038/s41386-018-0179-5

Grömping, U. (2006). Relative importance for linear regression in R. The package relaimpo. *Journal of Statistical Software, 17*(1), 1–27. https://doi.org/10.18637/jss.v017.i01

Guerra-Carrillo, B., Katovich, K., & Bunge, S. A. (2017). Does higher education hone cognitive functioning and learning efficacy? Findings from a large and diverse sample. *PLoS ONE*, *12*(8), e0182276. https://doi.org/10.1371/journal.pone.0182276

Gutierrez-Colina, A. M., Davis, M., & Eaton, C. K. (2020). The role of executive functioning in health self-management and the transition to adult health care among college students. *Journal of American College Health, 68*(8), 845–852. https://doi.org/10.1080/07448481.2020.1775605

Hall, P. A., Fong, G. T., Epp, L. J., & Elias, L. J. (2008). Executive function moderates the intention-behavior link for physical activity and dietary behavior. *Psychology & Health, 23*(3), 309–326. https://doi.org/10.1080/14768320701212099

Hartman, S. J., Nelson, S. H., Myers, E., Natarajan, L., Sears, D. D., Palmer, B. W., Weiner, L. S., Parker, B. A., & Patterson, R. E. (2018). Randomized controlled trial of increasing physical activity on objectively measured and self-reported cognitive functioning among breast cancer survivors: The memory & motion study. *Cancer*, *124*(1), 192–202. https://doi.org/10.1002/cncr.30987

Haverkamp, B. F., Wiersma, R., Vertessen, K., van Ewijk, H., Oosterlaan, J., & Hartman, E. (2020). Effects of physical activity interventions on cognitive outcomes and academic

performance in adolescents and young adults: A meta-analysis. *Journal of Sports Sciences*, *38*(23), 2637–2660. https://doi.org/10.1080/02640414.2020.1794763

Hays, R. D., Martin, S. A., Sesti, A. M., & Spritzer, K. L. (2005). Psychometric properties of the Medical Outcomes Study Sleep measure. *Sleep Medicine*, *6*(1), 41–44. https://doi.org/10.1016/j.sleep.2004.07.006

Higgins, J. P. T., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M. J., & Welch, V. A. (Eds.). (2022). *Cochrane handbook for systematic reviews of interventions* (version 6.3). Wiley-Blackwell.

Hillman, C. H., McAuley, E., Erickson, K. I., Liu-Ambrose, T., & Kramer, A. F. (2018). On mindful and mindless physical activity and executive function: A response to Diamond and Ling (2016). *Developmental Cognitive Neuroscience*, *37*. https://doi.org/10.1016/j.dcn.2018.01.006

Ho, S., Gooderham, G. K., & Handy, T. C. (2018). Self-reported free-living physical activity and executive control in young adults. *PLOS ONE*, *13*(12), e0209616. https://doi.org/10.1371/journal.pone.0209616

Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends in Cognitive Sciences, 16*(3), 174–180. https://doi.org/10.1016/j.tics.2012.01.006

Horn, J. L., & Cattell, R. B. (1967). Age differences in fluid and crystallized intelligence. *Acta Psychologica, 26*, 107–129. https://doi.org/10.1016/0001-6918(67)90011-X

Huang, T.-Y., Chen, F.-T., Li, R.-H., Hillman, C. H., Cline, T. L., Chu, C.-H., Hung, T.-M., & Chang, Y.-K. (2022). Effects of acute resistance exercise on executive function: A systematic review of

the moderating role of intensity and executive function domain. *Sports Medicine - Open*, *8*(1), 141. https://doi.org/10.1186/s40798-022-00527-7

Hung, T., Tsai, C., Chen, F., Wang, C., & Chang, Y. (2013). The immediate and sustained effects of acute exercise on planning aspect of executive function. *Psychology of Sport and Exercise*, *14*(5), 728–736. https://doi.org/10.1016/j.psychsport.2013.05.004

Hwang, J., & Lu, A. S. (2018). Narrative and active video game in separate and additive effects of physical activity and cognitive function among young adults. *Scientific Reports*, *8*(1). https://doi.org/10.1038/s41598-018-29274-0

Hwang, J., Brothers, R. M., Castelli, D. M., Glowacki, E. M., Chen, Y. T., Salinas, M. M., Kim, J., Jung, Y., & Calvert, H. G. (2016). Acute high-intensity exercise-induced cognitive enhancement and brain-derived neurotrophic factor in young, healthy adults. *Neuroscience Letters*, *630*, 247–253. https://doi.org/10.1016/j.neulet.2016.07.033

IBM Corp. (2022). *IBM SPSS Statistics for Windows, Version 28.0.1.1* [Computer software]. IBM Corp.

Jacques, S., & Zelazo, P. D. (2001). The Flexible Item Selection Task (FIST): A measure of executive function in preschoolers. *Developmental Neuropsychology*, *20*(3), 573–591. https://doi.org/10.1207/S15326942DN2003_2

Jaffery, A., Edwards, M. K., & Loprinzi, P. D. (2018). The effects of acute exercise on cognitive Function: Solomon Experimental Design. *The Journal of Primary Prevention*, *39*(1), 37–46. https://doi.org/10.1007/s10935-017-0498-z

Jones, S. A. H., Butler, B. C., Kintzel, F., Johnson, A., Klein, R. M., & Eskes, G. A. (2016). Measuring the performance of attention networks with the Dalhousie Computerized Attention

Battery (DalCAB): Methodology and reliability in healthy adults. *Frontiers in Psychology*, *7*. https://doi.org/10.3389/fpsyg.2016.00823

Karbach, J., & Kray, J. (2020). Executive function training. In T. Strobach & J. Karbach (Eds.), *Cognitive Training: An Overview of Features and Applications* (pp. 199–212). Springer International Publishing. https://doi.org/10.1007/978-3-030-39292-5_14

Kasap, E. Z., Ağzıtemiz, F., & Ünal, G. (2021). Cognitive, mental and social benefits of interacting with nature: A systematic review. *Journal of Happiness and Health*, *1*(1), Article 1.

Khandekar, P., Shenoy, S., & Sathe, A. (2022). Prefrontal cortex hemodynamic response to acute high intensity intermittent exercise during executive function processing. *The Journal of General Psychology*, *150*(3), 295–322. https://doi.org/10.1080/00221309.2022.2048785

Kim, Y. (2015). The effect of regular Taekwondo exercise on Brain-derived neurotrophic factor and Stroop test in undergraduate student. *Physical Activity and Nutrition*, *19*(2), 73–79. https://doi.org/10.5717/jenb.2015.15060904

Kiuppis, F. (2016). Inclusion in sport: Disability and participation. *Sport in Society, 21*(1), 4–21. https://doi.org/10.1080/17430437.2016.1225882

Kmet, L. M., Lee, R. C., & Cook, L. S. (2004). *Standard quality assessment criteria for evaluating primary research papers from a variety of fields*. Alberta Heritage Foundation for Medical Research (AHFMR). https://doi.org/10.7939/R37M04F16

Kohl, H.W., Blair, S.N., Paffenbarger, R.S., Macera, C.A. and Kronenfeld, J.J. (1988). A mail survey of physical activity habits as related to measured physical fitness. *American Journal of Epidemiology*, 127, 1228-1239.

Kronenberger, W. G. (2014). The Learning, Executive, and Attention Functioning Scale (LEAF): A new tool for assessing cognitive functioning in children and adolescents. *Journal of Clinical Child & Adolescent Psychology, 43*(2), 289–300. https://doi.org/10.1080/15374416.2013.860697

Kronenberger, W. G., Pisoni, D. B., Henning, S. C., Colson, B. G., & Hazzard, L. M. (2014). Executive functioning skills in long-term users of cochlear implants: A case control study. *Journal of Pediatric Psychology, 39*(6), 653–661. https://doi.org/10.1093/jpepsy/jsu012

Kronholm, E., Sallinen, M., Suutama, T., Sulkava, R., Era, P., & Partonen, T. (2009). Self-reported sleep duration and cognitive functioning in the general population. *Journal of Sleep Research*, *18*(4), 436–446. https://doi.org/10.1111/j.1365-2869.2009.00765.x

Lambourne, K. (2006). The relationship between working memory capacity and physical activity rates in young adults. *Journal of Sports Science & Medicine*, *5*(1), 149–153.

Lambourne, K., & Tomporowski, P. (2010). The effect of exercise-induced arousal on cognitive task performance: A meta-regression analysis. *Brain Research*, *1341*, 12–24. https://doi.org/10.1016/j.brainres.2010.03.091

Lambourne, K., & Tomporowski, P. (2010). The effect of exercise-induced arousal on cognitive task performance: A meta-regression analysis. *Brain Research*, *1341*, 12–24. https://doi.org/10.1016/j.brainres.2010.03.091

Larson, M. J., LeCheminant, J. D., Carbine, K., Hill, K. R., Christenson, E., Masterson, T., & LeCheminant, R. (2015). Slow walking on a treadmill desk does not negatively affect executive abilities: an examination of cognitive control, conflict adaptation, response

inhibition, and post-error slowing. *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.00723

Lee, S., Charles, S. T., & Almeida, D. M. (2021). Change is good for the brain: activity diversity and cognitive functioning across adulthood. *The Journals of Gerontology: Series B*, *76*(6), 1036–1048. https://doi.org/10.1093/geronb/gbaa020

Legrand, F., Albinet, C., Canivet, A., Gierski, F., Morrone, I., & Besche-Richard, C. (2018). Brief aerobic exercise immediately enhances visual attentional control and perceptual speed. Testing the mediating role of feelings of energy. *Acta Psychologica*, *191*, 25–31. https://doi.org/10.1016/j.actpsy.2018.08.020

Levin, K. A. (2006). Study design III: Cross-sectional studies. *Evidence-Based Dentistry, 7*(1), 24–25. https://doi.org/10.1038/sj.ebd.6400375

Li, L., Zhang, J., Cao, M., Hu, W., Zhou, T., Huang, T., Chen, P., & Quan, M. (2020). The effects of chronic physical activity interventions on executive functions in children aged 3–7 years: A meta-analysis. *Journal of Science and Medicine in Sport*, *23*(10), 949–954. https://doi.org/10.1016/j.jsams.2020.03.007

Li, L., Zhang, J., Cao, M., Hu, W., Zhou, T., Huang, T., Chen, P., & Quan, M. (2020). The effects of chronic physical activity interventions on executive functions in children aged 3–7 years: A meta-analysis. *Journal of Science and Medicine in Sport*, *23*(10), 949–954. https://doi.org/10.1016/j.jsams.2020.03.007

Liguori, G., & American College of Sports Medicine. (2020). *American College of Sports Medicine's Guidelines for Exercise Testing and Prescription*. Lippincott Williams & Wilkins.

Liu, J., Min, L., Liu, R., Zhang, X., Wu, M., Di, Q., & Ma, X. (2023). The effect of exercise on cerebral blood flow and executive function among young adults: a double-blinded randomized controlled trial. *Scientific Reports*, *13*(1). https://doi.org/10.1038/s41598-023-33063-9

Liu, J., Zhu, L., & Liu, C. (2020). Sleep quality and self-control: The mediating roles of positive and negative affects. *Frontiers in Psychology*, *11*. https://doi.org/10.3389/fpsyg.2020.607548

Loprinzi, P. D., & Kane, C. J. (2015). Exercise and cognitive function: a randomized controlled trial examining acute exercise and free-living physical activity and sedentary effects. *In Mayo Clinic Proceedings* (Vol. 90, No. 4, pp. 450-460). Elsevier. https://doi.org/10.1016/j.mayocp.2014.12.023

Loprinzi, P. D., Frith, E., Edwards, M. K., Sng, E., & Ashpole, N. (2018). The effects of exercise on memory function among young to middle-aged adults: Systematic review and recommendations for future research. *American Journal of Health Promotion*, *32*(3), 691–704. https://doi.org/10.1177/0890117117737409

Luciana, M. (2020). Risks versus consequences of adolescent and young adult substance use: A focus on executive control. *Current Addiction Reports*, *7*(4), 453–463. https://doi.org/10.1007/s40429-020-00341-9

Ludyga, S., Gerber, M., Pühse, U., Looser, V. N., & Kamijo, K. (2020). Systematic review and meta-analysis investigating moderators of long-term effects of exercise on cognition in healthy individuals. *Nature Human Behaviour*, *4*(6), 603–612. https://doi.org/10.1038/s41562-020-0851-8

Ludyga, S., Held, S., Rappelt, L., Donath, L., & Klatt, S. (2023). A network meta-analysis comparing the effects of exercise and cognitive training on executive function in young and middle-aged adults. *European Journal of Sport Science*, *23*(7), 1415–1425. https://doi.org/10.1080/17461391.2022.2099765

Ma, C., Li, M., Li, R., & Wu, C. (2023). The effect of rhythmic movement on physical and cognitive functions among cognitively healthy older adults: A systematic review and meta-analysis. *Archives of Gerontology and Geriatrics*, *104*, 104837. https://doi.org/10.1016/j.archger.2022.104837

Malagoli, C., Chiorri, C., Traverso, L., & Usai, M. C. (2022). Inhibition and individual differences in behavior and emotional regulation in adolescence. *Psychological Research*, *86*(4), 1132–1144. https://doi.org/10.1007/s00426-021-01565-8

May, R. W., Hutchinson, M., Seibert, G. S., Fincham, F., & Sanchez-Gonzalez, M. A. (2017). Improving cognitive performance via high intensity interval aerobic exercise: A randomized controlled trial. *Journal Exercise Physiology Online, 20,* 141-147.

McGrath, A. B., Weinstock, J., Cloutier, R., Christensen, M., Taylor, D. J., & Henderson, C. E. (2021). Examination of college student health behaviors and self-reported executive functions. *Journal of American College Health*, *71*(2), 1–11. https://doi.org/10.1080/07448481.2021.1904951

McHugh, M. L. (2012). Interrater reliability: The kappa statistic. *Biochemia Medica*, 276–282. https://doi.org/10.11613/BM.2012.031

McInerney, R. (2004). Victoria Computerized Adaptation of the Paced Auditory Serial Addition Task (PASAT). Retrieved from http://www.mcinerney.ca/pasat.html

McMorris, T., Sproule, J., Turner, A., & Hale, B. J. (2011). Acute, intermediate intensity exercise, and speed and accuracy in working memory tasks: A meta-analytical comparison of effects. *Physiology & Behavior*, *102*(3–4), 421–428. psyh. https://doi.org/10.1016/j.physbeh.2010.12.007

Microsoft Corporation. (2024). *Microsoft Excel* (Version 16.91). Microsoft Corporation. https://www.microsoft.com

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current Directions in Psychological Science, 21*(1), 8–14. https://doi.org/10.1177/0963721411429458

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734

Moore, R. D., Romine, M. W., O'connor, P. J., & Tomporowski, P. D. (2012). The influence of exercise-induced fatigue on cognitive function. *Journal of Sports Sciences*, *30*(9), 841–850. https://doi.org/10.1080/02640414.2012.675083

Moreau, D., & Chou, E. (2019). The acute effect of high-intensity exercise on executive function: A meta-analysis. *Perspectives on Psychological Science*, *14*(5), 734–764. https://doi.org/10.1177/1745691619850568

Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Cepeda, N. J., & Chau, T. (2011). Short-term music training enhances verbal intelligence and executive function. *Psychological Science*, *22*(11), 1425–1433. https://doi.org/10.1177/0956797611416999

Müller, I., Rowsell, A., Stuart, B., Hayter, V., Little, P., Ganahl, K., Müller, G., Doyle, G., Chang, P., Lyles, C. R., Nutbeam, D., Yardley, L., & Müller, G. (2017). Effects on engagement and health literacy outcomes of web-based materials promoting physical activity in people with diabetes: An international randomized trial. *Journal of Medical Internet Research, 19*(1), e6601. https://doi.org/10.2196/jmir.6601

Munroe, C. A., Leckey, J., Johnson, S. A., & Jacques, S. (2025). Factor Structure and Psychometric Properties of the Learning, Executive, and Attention Functioning (LEAF) Scale in Young Adults. *Assessment*. https://doi.org/10.1177/10731911251317788

Murray, N. P., & Russoniello, C. (2012). Acute physical activity on cognitive function: A heart rate variability examination. *Applied Psychophysiology and Biofeedback*, *37*(4), 219–227. https://doi.org/10.1007/s10484-012-9196-z

Muthén, L. K., & Muthén, B. O. (2017). *Mplus User's Guide* (8th ed.). Muthén & Muthén.

Oberste, M., Bloch, W., Hübner, S. T., & Zimmer, P. (2016). Do reported effects of acute aerobic exercise on subsequent higher cognitive performances remain if tested against an instructed self-myofascial release training control group? A randomized controlled trial. *PLoS ONE*, *11*(12), e0167818. https://doi.org/10.1371/journal.pone.0167818

ObjectPlanet. (1998-2025). *Opinio 7.26* [Computer software]. https://www.opinio.net

Othman, N., Ahmad, F., El Morr, C., & Ritvo, P. (2019). Perceived impact of contextual determinants on depression, anxiety and stress: A survey with university students. *International Journal of Mental Health Systems*, *13*(1), 17. https://doi.org/10.1186/s13033-019-0275-x

Pachava, S. R., & Shenoy, S. (2023). Association of self-reported physical activity with cognitive function in young adults. *Cognition, Brain, Behavior: An Interdisciplinary Journal*, *27*(1), 49–68. https://doi.org/10.24193/cbb.2023.27.03

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ, 372*, n71. https://doi.org/10.1136/bmj.n71

Patton, J. H., Stanford, M. S., & Barratt, E. S. (1995). Factor structure of the Barratt Impulsiveness Scale. *Journal of Clinical Psychology*, *51*(6), 768–774. https://doi.org/10.1002/1097-4679(199511)51:6<768::AID-JCLP2270510607>3.0.CO;2-1

Peduzzi, P., Concato, J., Kemper, E., Holford, T. R., & Feinstein, A. R. (1996). A simulation study of the number of events per variable in logistic regression analysis. *Journal of Clinical Epidemiology, 49*(12), 1373–1379. https://doi.org/10.1016/S0895-4356(96)00236-3

Pettit, J. W., Kline, J. P., Gencoz, T., Gencoz, F., & Joiner, T. E. Jr. (2001). Are happy people healthier? The specific role of positive affect in predicting self-reported health symptoms. *Journal of Research in Personality, 35*(4), 521–536. doi:10.1006/jrpe.2001.2327

Piercy, K. L., Troiano, R. P., Ballard, R. M., Carlson, S. A., Fulton, J. E., Galuska, D. A., George, S. M., & Olson, R. D. (2018). The physical activity guidelines for Americans. *JAMA*, *320*(19), 2020–2028. https://doi.org/10.1001/jama.2018.14854

Podsakoff, P. M., MacKenzie, S. B., Lee, J.-Y., & Podsakoff, N. P. (2003). Common method biases in behavioral research: A critical review of the literature and recommended remedies. *Journal of Applied Psychology*, *88*(5), 879–903. https://doi.org/10.1037/0021-9010.88.5.879

Rathore, A., & Lom, B. (2017). The effects of chronic and acute physical activity on working memory performance in healthy participants: A systematic review with meta-analysis of randomized controlled trials. *Systematic Reviews*, *6*(1), 124. https://doi.org/10.1186/s13643-017-0514-7

Rau, H. K., Suchy, Y., Butner, J. E., & Williams, P. G. (2016). Latent profiles of executive functioning in healthy young adults: Evidence of individual differences in hemispheric asymmetry. *Psychological Research*, *80*(6), 997–1019. https://doi.org/10.1007/s00426-015-0706-5

Razon, S., Lebeau, J., Basevitch, I., Foster, B., Akpan, A., Mason, J., Boiangin, N., & Tenenbaum, G. (2017). Effects of acute exercise on executive functioning: Testing the moderators. *International Journal of Sport and Exercise Psychology*, *17*(4), 303–320. https://doi.org/10.1080/1612197x.2017.1349821

Reilly, D. (2012). Gender, culture, and sex-typed cognitive abilities. *PLOS ONE*, *7*(7), e39904. https://doi.org/10.1371/journal.pone.0039904

Reynolds, B. W., Basso, M. R., Miller, A. K., Whiteside, D. M., & Combs, D. (2019). Executive function, impulsivity, and risky behaviors in young adults. *Neuropsychology*, *33*(2), 212–221. https://doi.org/10.1037/neu0000510

Richardson, M., Hunt, A., Hinds, J., Bragg, R., Fido, D., Petronzi, D., Barbett, L., Clitherow, T., & White, M. (2019). A measure of nature connectedness for children and adults: Validation, performance, and insights. *Sustainability*, *11*(12), Article 12. https://doi.org/10.3390/su11123250

Rodriguez-Gomez, D. A., & Talero-Gutiérrez, C. (2022). Effects of music training in executive function performance in children: A systematic review. *Frontiers in Psychology*, *13*. https://doi.org/10.3389/fpsyg.2022.968144

Rogers, F., & Metzler-Baddeley, C. (2024). The effects of musical instrument training on fluid intelligence and executive functions in healthy older adults: A systematic review and *meta*-analysis. *Brain and Cognition*, *175*, 106137. https://doi.org/10.1016/j.bandc.2024.106137

Salas-Gomez, D., Fernandez-Gorgojo, M., Pozueta, A., Diaz-Ceballos, I., Lamarain, M., Perez, C., Kazimierczak, M., & Sanchez-Juan, P. (2020). Physical Activity Is Associated With Better Executive Function in University Students. *Frontiers in Human Neuroscience*, *14*. https://doi.org/10.3389/fnhum.2020.00011

Sanderson, C., & Loprinzi, P. D. (2019). Acute exercise on reversal learning. *OBM Neurobiology*, *3*(4), 1. https://doi.org/10.21926/obm.neurobiol.1904043

Schöndube, A., Kanning, M., & Fuchs, R. (2016). The bidirectional effect between momentary affective states and exercise duration on a day level. *Frontiers in Psychology*, *7*. https://doi.org/10.3389/fpsyg.2016.01414

Shao, Z., Janse, E., Visser, K., & Meyer, A. S. (2014). What do verbal fluency tasks measure? Predictors of verbal fluency performance in older adults. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.00772

Shen, Q., Yin, H., Cui, L., Zhang, J., Wang, D., Zhu, L., Wang, Y., & Li, X. (2021). The potential advantages of Tai Chi Chuan in promoting inhibitory control and spontaneous neural activity in young adults. *Frontiers in Behavioral Neuroscience*, *15*. https://doi.org/10.3389/fnbeh.2021.747733

Shields, G. S., Moons, W. G., & Slavich, G. M. (2017). Better executive function under stress mitigates the effects of recent life stress exposure on health in young adults. *Stress*, *20*(1), 92–102. https://doi.org/10.1080/10253890.2017.1286322

Song, W., Feng, L., Wang, J., Ma, F., Chen, J., Qu, S., & Luo, D. (2022). Play smart, be smart? Effect of cognitively engaging physical activity interventions on executive function among children 4-12 years old: A systematic review and meta-analysis. *Brain Sciences*, *12*(6). https://doi.org/10.3390/brainsci12060762

Spurk, D., Hirschi, A., Wang, M., Valero, D., & Kauffeld, S. (2020). Latent profile analysis: A review and "how to" guide of its application within vocational behavior research. *Journal of Vocational Behavior*, *120*, 103445. https://doi.org/10.1016/j.jvb.2020.103445

Statistics Canada. (1983). *Canada Fitness Survey: A survey of the physical activity patterns of Canadians*. Ottawa: Statistics Canada.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*(6), 643–662. https://doi.org/10.1037/h0054651

Su, R., Wang, C., Liu, W., Han, C., Fan, J., Ma, H., Li, H., & Zhang, D. (2022). Intensity-dependent acute aerobic exercise: Effect on reactive control of attentional functions in acclimatized lowlanders at high altitude. *Physiology & Behavior*, *250*, 113785. https://doi.org/10.1016/j.physbeh.2022.113785

Suchy, Y. (2009). Executive functioning: Overview, assessment, and research issues for non-neuropsychologists. *Annals of Behavioral Medicine, 37*(2), 106–116. https://doi.org/10.1007/s12160-009-9097-4

Sudo, M., Komiyama, T., Aoyagi, R., Nagamatsu, T., Higaki, Y., & Ando, S. (2017). Executive function after exhaustive exercise. *European Journal of Applied Physiology*, *117*(10), 2029–2038. https://doi.org/10.1007/s00421-017-3692-z

Tabachnick, B. G., & Fidell, L. S. (2014). *Using multivariate statistics* (6th ed.). Pearson.

Thomas, J., & D, V. (2017). A comparative study of the effects of Superbrain yoga and aerobic exercise on cognitive functions. *National Journal of Physiology Pharmacy and Pharmacology*, 1. https://doi.org/10.5455/njppp.2017.7.0309126062017

Tomporowski, P. D., Davis, C. L., Miller, P. H., & Naglieri, J. A. (2008). Exercise and children's intelligence, cognition, and academic achievement. *Educational Psychology Review, 20*(2), 111–131. https://doi.org/10.1007/s10648-007-9057-0

Toplak, M. E., West, R. F., & Stanovich, K. E. (2013). Practitioner review: Do performance-based measures and ratings of executive function assess the same construct? *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *54*(2), 131–143. https://doi.org/10.1111/jcpp.12001

Travis, F., Harung, H. S., & Lagrosen, Y. (2011). Moral development, executive functioning, peak experiences and brain patterns in professional and amateur classical musicians: Interpreted in light of a Unified Theory of Performance. *Consciousness and Cognition*, *20*(4), 1256–1264. https://doi.org/10.1016/j.concog.2011.03.020

Tremblay, M. S., Carson, V., Chaput, J.-P., Connor Gorber, S., Dinh, T., Duggan, M., Faulkner, G., Gray, C. E., Gruber, R., Janson, K., Janssen, I., Katzmarzyk, P. T., Kho, M. E., Latimer-Cheung, A. E., LeBlanc, C., Okely, A. D., Olds, T., Pate, R. R., Phillips, A., … Zehr, L. (2016). Canadian 24-hour movement guidelines for children and youth: An integration of physical activity, sedentary behaviour, and sleep. *Applied Physiology, Nutrition, and Metabolism*, *41*(6 (Suppl. 3)), S311–S327. https://doi.org/10.1139/apnm-2016-0151

Tsai, C., Wang, C., Pan, C., Chen, F., Huang, T., & Chou, F. (2014). Executive function and endocrinological responses to acute resistance exercise. *Frontiers in Behavioral Neuroscience*, *8*. https://doi.org/10.3389/fnbeh.2014.00262

Umegaki, H., Sakurai, T., & Arai, H. (2021). Active life for brain health: A narrative review of the mechanism underlying the protective effects of physical activity on the brain. *Frontiers in Aging Neuroscience*, *13*. https://doi.org/10.3389/fnagi.2021.761674

Uttl, B., Violo, V., & Gibson, L. (2024). Meta-analysis: On average, undergraduate students' intelligence is merely average. *ScienceOpen Research*, 20240002. https://doi.org/10.14293/S2199-1006.1.SOR.2024.0002.v1

Vassiliu, C., Leong, V., & Hendriks, H. (2024). The influence of multilingual experience on executive function and structure learning: Effects in young adults in the UK and Singapore. *Languages*, *9*(4), Article 4. https://doi.org/10.3390/languages9040136

Vaughan, L., & Giovanello, K. S. (2010). Executive function in daily life: Age-related influences of executive processes on instrumental activities of daily living. *Psychology and Aging, 25*(2), 343–355. https://doi.org/10.1037/a0017729

Verburgh, L., Königs, M., Scherder, E. J. A., & Oosterlaan, J. (2014). Physical exercise and executive functions in preadolescent children, adolescents and young adults: A meta-analysis. *British Journal of Sports Medicine*, *48*(12), 973–979. https://doi.org/10.1136/bjsports-2012-091441

Veritas Health Innovation. (2022). *Covidence systematic review software*. Melbourne, Australia. Available at https://www.covidence.org

VonDras, D. & Powless, M. & Olson, A. K. & Wheeler, D. & Snudden, A. L. (2005). Differential effects of everyday stress on the episodic memory test performances of young, mid-life, and older adults. *Aging & Mental Health, 9*, 60-70. 10.1080/13607860412331323782

Voss, M. W., Vivar, C., Kramer, A. F., & Praag, H. van. (2013). Bridging animal and human models of exercise-induced brain plasticity. *Trends in Cognitive Sciences*, *17*(10), 525–544. https://doi.org/10.1016/j.tics.2013.08.001

Vuontela, V., Carlson, S., Troberg, A.-M., Fontell, T., Simola, P., Saarinen, S., & Aronen, E. T. (2013). Working memory, attention, inhibition, and their relation to adaptive functioning and behavioral/emotional symptoms in school-aged children. *Child Psychiatry & Human Development*, *44*(1), 105–122. https://doi.org/10.1007/s10578-012-0313-2

Wang, C., Chu, C., Chu, I., Chan, K., & Chang, Y. (2013). Executive function during acute exercise: the role of exercise intensity. *Journal of Sport and Exercise Psychology*, *35*(4), 358–367. https://doi.org/10.1123/jsep.35.4.358

Wang, C., Shih, C., Pesce, C., Song, T., Hung, T., & Chang, Y. (2015). Failure to identify an acute exercise effect on executive function assessed by the Wisconsin Card Sorting Test. *Journal of Sport and Health Science/Journal of Sport and Health Science*, *4*(1), 64–72. https://doi.org/10.1016/j.jshs.2014.10.003

Wang, Y., Tian, J., & Yang, Q. (2023). Tai Chi exercise improves working memory capacity and emotion regulation ability. *Frontiers in Psychology*, *14*. https://doi.org/10.3389/fpsyg.2023.1047544

Warburton, D. E. R., Nicol, C. W., & Bredin, S. S. D. (2006). Prescribing exercise as preventive therapy. *CMAJ : Canadian Medical Association Journal*, *174*(7), 961–974. https://doi.org/10.1503/cmaj.1040750

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology*, *54*(6), 1063–1070. https://doi.org/10.1037/0022-3514.54.6.1063

Wechsler, D. (2008). *Wechsler Adult Intelligence Scale – Fourth Edition (WAIS-IV)*. Pearson Assessment.

Wilke, J. (2020). Functional high-intensity exercise is more effective in acutely increasing working memory than aerobic walking: an exploratory randomized, controlled trial. *Scientific Reports*, *10*(1). https://doi.org/10.1038/s41598-020-69139-z

Wilke, J., Stricker, V., & Usedly, S. (2020). Free-weight resistance exercise is more effective in enhancing inhibitory control than machine-based training: a randomized, controlled trial. *Brain Sciences*, *10*(10), 702. https://doi.org/10.3390/brainsci10100702

Xiong, J., Ye, M., Wang, L., & Zheng, G. (2021). Effects of physical exercise on executive function in cognitively healthy older adults: A systematic review and meta-analysis of randomized controlled trials. *International Journal of Nursing Studies*, *114*, 103810. https://doi.org/10.1016/j.ijnurstu.2020.103810

Xue, Y., Yang, Y., & Huang, T. (2019). Effects of chronic exercise interventions on executive function among children and adolescents: A systematic review with meta-analysis. *British Journal of Sports Medicine*, *53*(22), 1397–1404. https://doi.org/10.1136/bjsports-2018-099825

Zavecz, Z., Nagy, T., Galkó, A., Nemeth, D., & Janacsek, K. (2020). The relationship between subjective sleep quality and cognitive performance in healthy young adults: Evidence from three empirical studies. *Scientific Reports*, *10*(1), 4855. https://doi.org/10.1038/s41598-020-61627-6

Zelazo, P. D., Carlson, S. M., & Kesek, A. (2016). The development of executive function in childhood. In V. Anderson, R. Jacobs, & P. J. Anderson (Eds.), *Executive functions and the frontal lobes: A lifespan perspective* (pp. 21–35). Taylor & Francis.

Zhang, M., Jia, J., Yang, Y., Zhang, L., & Wang, X. (2023). Effects of exercise interventions on cognitive functions in healthy populations: A systematic review and meta-analysis. *Ageing Research Reviews*, *92*, 102116. https://doi.org/10.1016/j.arr.2023.102116

Zhou, F., & Qin, C. (2019). Acute moderate-intensity exercise generally enhances attentional resources related to perceptual processing. *Frontiers in Psychology*, *10*. https://doi.org/10.3389/fpsyg.2019.02547

Zhu, H., Zhu, L., Xiong, X., Dong, X., Chen, D., Wang, J., Cai, K., Wang, W., & Chen, A. (2021). Influence of aerobic fitness on white matter integrity and inhibitory control in early adulthood: A 9-week exercise intervention. *Brain Sciences*, *11*(8), 1080. https://doi.org/10.3390/brainsci11081080

Zhu, L., Yu, Q., Herold, F., Cheval, B., Dong, X., Cui, L., Xiong, X., Chen, A., Yin, H., Kong, Z., Mueller, N., Kramer, A. F., & Zou, L. (2021). Brain structure, cardiorespiratory fitness, and executive control changes after a 9-week exercise intervention in young adults: A randomized controlled trial. *Life*, *11*(4), 292. https://doi.org/10.3390/life11040292

Ziemnik, R. E., & Suchy, Y. (2019). The ecological validity of executive function tests: Implications for assessment and everyday functioning. *Applied Neuropsychology: Adult, 26*(2), 99–110. https://doi.org/10.1080/23279095.2017.1387253

Zuk, J., Benjamin, C., Kenyon, A., & Gaab, N. (2014). Behavioral and neural correlates of executive functioning in musicians and non-musicians. *PLOS ONE*, *9*(6), e99868. https://doi.org/10.1371/journal.pone.0099868

Appendix A: Database Search Terms

CINAHL

MH (“Executive Function” OR "Selective Attention” OR “Wisconsin Card Sorting Test”) OR TI (“Attention* Shift*” OR “Attention* Switch*” OR “Cognitive Control” OR “Cognitive Flexibility” OR “Cognitive Inhibition” OR “Executive Attention” OR “Executive Function*” OR “Inhibitory Control” OR “Mental Flexibility” OR “Response Inhibition” OR “Selective Atten*” OR “Set Switch*” OR "Set Shift*” OR “Sustain* Attention” OR “Task Shift*” OR “Task Switch*” OR “Working Memory” OR “Cantab” OR “Delis kaplan” OR “Design Fluency” OR “Digit Span” OR “D-KEFS” OR “Flanker” OR “GNG” OR “Go-no-go” OR “GoNoGo” OR “Interference Control” OR “N-back” OR “Nback” OR “paced auditory serial addition test” OR “PASAT” OR “Ruff Figural Fluency Test” OR “Stop Signal Task” OR “Stroop” OR “Tower of Hanoi” OR “Tower of London” OR “Trail Making” OR “Verbal Fluency” OR “WCST” OR “Wisconsin Card Sorting” OR “Word Span” OR “Word Fluency”) OR AB (“Attention* Shift*” OR “Attention* Switch*” OR “Cognitive Control” OR “Cognitive Flexibility” OR “Cognitive Inhibition” OR “Executive Attention” OR “Executive Function*” OR “Inhibitory Control” OR “Mental Flexibility” OR “Response Inhibition” OR “Selective Atten*” OR “Set Switch*” OR "Set Shift*” OR “Sustain* Attention” OR “Task Shift*” OR “Task Switch*” OR “Working Memory” OR “Cantab” OR “Delis kaplan” OR “Design Fluency” OR “Digit Span” OR “D-KEFS” OR “Flanker” OR “GNG” OR “Go-no-go” OR “GoNoGo” OR “Interference Control” OR “N-back” OR “Nback” OR “paced auditory serial addition test” OR “PASAT” OR “Ruff Figural Fluency Test” OR “Stop Signal Task” OR “Stroop” OR “Tower of Hanoi” OR “Tower of London” OR “Trail Making” OR “Verbal Fluency” OR “WCST” OR “Wisconsin Card Sorting” OR “Word Span” OR “Word Fluency”)

AND

(MH (“Athletic Training” OR "Physical Activity” OR "Exercise” OR "Physical Fitness” OR “Physical Endurance” OR “Physical Performance” OR “Sports” OR “Aerobic Exercises” OR “Martial Arts” OR “Yoga” OR “Resistance Training” OR “Exergames”)) OR (TI (“Exercis*” OR “physical activity” OR “Physical* Fit*” OR “Physical Endurance” OR “Physical Performance” OR “Sport” OR “Sports” OR “Martial Arts” OR “Yoga” OR “Resistance” OR “Exergam*”) N3 (“Acute” OR “Bout” OR “Bouts” OR “Intervention” OR “Training” OR “Program” OR “Session*” OR “Effect” OR “Effects”)) OR (AB (“Exercis*” OR “physical activity” OR “Physical* Fit*” OR “Physical Endurance” OR “Physical Performance” OR “Sport” OR “Sports” OR “Martial Arts” OR “Yoga” OR “Resistance” OR “Exergam*”) N3 (“Acute” OR “Bout” OR “Bouts” OR “Intervention” OR “Training” OR “Program” OR “Session*” OR “Effect” OR “Effects”))

AND

MH ("Clinical Trials” OR "Experimental Studies” OR “Randomized Controlled Trials” OR “Random Sample” OR “Double-Blind Studies” OR “Single-Blind Studies”) OR TI ("Clinical Trial*” OR (“Between” W1 (“Group” OR “Groups” OR “Subjects”)) OR (“Experimental” W1 (“Design” OR “Study” OR “Method” OR “Trial”)) OR (“Controlled” W2 (“Design” OR “Study” OR “Method” OR

“Trial”)) OR ((“Double” OR “Single” OR “Doubly” OR “Singly”) W1 (“Blind” OR “Blinded”)) OR “Random*” OR “Compare” OR “Comparison” OR “Comparing” OR “Compared” OR “Control Group*”) OR AB ("Clinical Trial*” OR (“Between” W1 (“Group” OR “Groups” OR “Subjects”)) OR (“Experimental” W1 (“Design” OR “Study” OR “Method” OR “Trial”)) OR (“Controlled” W2 (“Design” OR “Study” OR “Method” OR “Trial”)) OR ((“Double” OR “Single” OR “Doubly” OR “Singly”) W1 (“Blind” OR “Blinded”)) OR “Random*” OR “Compare” OR “Comparison” OR “Comparing” OR “Compared” OR “Control Group*”)
NOT
TI (“Alzheimer*” OR “ADHD” OR “attention deficit hyperactivity disorder” OR “attention deficit disorder” OR “ASD” OR “Autism” OR “dementia” OR “diabetes” OR "down syndrome" OR “multiple sclerosis” OR “obesity” OR “obese” OR "parkinson*" OR "schizophrenia" OR “children” OR “childhood” OR “preschool” OR “elementary” OR “elderly” OR “older adult*” OR “elder adult*”)

Embase

('attention switching’/de OR 'cognitive flexibility’/de OR 'cognitive inhibition’/de OR 'executive attention’/de OR 'executive function’/de OR 'inhibitory control’/de OR 'mental flexibility’/de OR 'response inhibition’/de OR 'set shifting’/de OR 'sustained attention’/de OR 'task switching’/de OR 'working memory’/de OR ‘cognitive control network’/de OR ‘selective attention’/de OR ‘executive function test’/de OR ‘verbal fluency’/de OR ‘Stroop test’/de OR ‘Wisconsin Card Sorting Test’/de OR ‘Delis-Kaplan executive function system’/de OR ‘figural fluency test’/de OR ‘tower of London test’/de OR ‘trail making test’/de OR ‘Go No Go task’/de OR 'stop signal reaction time’/de OR ‘n-back test’/de OR ‘paced auditory serial addition test’/de OR ‘flanker task’/de OR ‘flanker test’/de OR ‘Attention* Shift*’:ti,ab,kw OR ‘Attention* Switch*’:ti,ab,kw OR ‘Cognitive Control’:ti,ab,kw OR ‘Cognitive Flexibility’:ti,ab,kw OR ‘Cognitive Inhibition’:ti,ab,kw OR ‘Executive Attention’:ti,ab,kw OR ‘Executive Function*’:ti,ab,kw OR ‘Inhibitory Control’:ti,ab,kw OR ‘Mental Flexibility’:ti,ab,kw OR ‘Response Inhibition’:ti,ab,kw OR ‘Selective Attention’:ti,ab,kw OR ‘Set Switch*’:ti,ab,kw OR ‘Set Shift*’:ti,ab,kw OR ‘Sustain* Attention’:ti,ab,kw OR ‘Task Shift*’:ti,ab,kw OR ‘Task Switch*’:ti,ab,kw OR ‘Working Memory’:ti,ab,kw OR ‘Cantab’:ti,ab,kw OR ‘Delis kaplan’:ti,ab,kw OR ‘Design Fluency’:ti,ab,kw OR ‘Digit Span’:ti,ab,kw OR ‘D-KEFS’:ti,ab,kw OR ‘Flanker’:ti,ab,kw OR ‘GNG’:ti,ab,kw OR ‘Go-no-go’:ti,ab,kw OR ‘GoNoGo’:ti,ab,kw OR ‘Interference Control’:ti,ab,kw OR ‘N-back’:ti,ab,kw OR ‘Nback’:ti,ab,kw OR ‘paced auditory serial addition test’:ti,ab,kw OR ‘PASAT’:ti,ab,kw OR ‘Ruff Figural Fluency Test’:ti,ab,kw OR ‘Stop Signal Task’:ti,ab,kw OR ‘Stroop’:ti,ab,kw OR ‘Tower of Hanoi’:ti,ab,kw OR ‘Tower of London’:ti,ab,kw OR ‘Trail Making’:ti,ab,kw OR ‘Verbal Fluency’:ti,ab,kw OR ‘WCST’:ti,ab,kw OR ‘Wisconsin Card Sorting’:ti,ab,kw OR ‘Word Span’:ti,ab,kw OR ‘Word Fluency':ti,ab,kw)
AND

((‘physical activity, capacity and performance’/de OR ‘Physical Activity’/de OR ‘Exercise’/de OR ‘Sport’/de OR ‘Aerobic Exercise’/de OR ‘Martial Arts’/de OR ‘Yoga’/de OR ‘resistance training’/de) OR ((‘Exercis*’ OR ‘physical activity’ OR ‘Physical* Fit*’ OR ‘Physical Endurance’ OR ‘Physical Performance’ OR ‘Sport’ OR ‘Sports’ OR ‘Martial Arts’ OR ‘Yoga’ OR ‘Resistance’ OR ‘Exergam*’):ti,ab,kw NEAR3 (‘Acute’ OR ‘Bout’ OR ‘Bouts’ OR ‘Intervention’ OR ‘Training’ OR ‘Program’ OR ‘Session*’ OR ‘Effect’ OR ‘Effects’):ti,ab,kw))
AND
((‘clinical trial'/de OR 'experimental design'/de OR ‘experimental study'/de OR 'randomized controlled trial'/de OR ‘double blind procedure’/de OR ‘single blind procedure’/de) OR ((‘Clinical Trial*’ OR (‘Between’ NEXT1 (‘Group’ OR ‘Groups’ OR ‘Subjects’)) OR (‘Experimental’ NEXT1 (‘Design’ OR ‘Study’ OR ‘Method’ OR ‘Trial’)) OR (‘Controlled’ NEXT2 (‘Design’ OR ‘Study’ OR ‘Method’ OR ‘Trial’)) OR ((‘Double’ OR ‘Single’ OR ‘Doubly’ OR ‘Singly’) NEXT1 (‘Blind’ OR ‘Blinded’)) OR ‘Random*’ OR ‘Compare’ OR ‘Comparison’ OR ‘Comparing’ OR ‘Compared’ OR ‘Control Group*’):ti,ab,kw))
NOT
(‘Alzheimer*’ OR ‘ADHD’ OR ‘attention deficit hyperactivity disorder’ OR ‘attention deficit disorder’ OR ‘ASD’ OR ‘Autism’ OR ‘dementia’ OR ‘diabetes’ OR ‘down syndrome’ OR ‘multiple sclerosis’ OR ‘obesity’ OR ‘obese’ OR ‘parkinson*’ OR ‘schizophrenia’ OR ‘children’ OR ‘childhood’ OR ‘preschool’ OR ‘elementary’ OR ‘elderly’ OR ‘older adult*’ OR ‘elder adult*’):ti

PsycInfo

(DE ("Cognitive Control” OR “Cognitive Flexibility” OR "Executive Function” OR "Executive Functioning Measures” OR "Response inhibition” OR "Set Shift*” OR "Selective Attention” OR "Sustained attention") OR KW (“Attention* Shift*” OR “Attention* Switch*” OR “Cognitive Control” OR “Cognitive Flexibility” OR “Cognitive Inhibition” OR “Executive Attention” OR “Executive Function*” OR “Inhibitory Control” OR “Mental Flexibility” OR “Response Inhibition” OR “Selective Attention” OR “Set Switch*” OR "Set Shift*” OR “Sustain* Attention” OR “Task Shift*” OR “Task Switch*” OR “Working Memory”) OR TI (“Attention* Shift*” OR “Attention* Switch*” OR “Cognitive Control” OR “Cognitive Flexibility” OR “Cognitive Inhibition” OR “Executive Attention” OR “Executive Function*” OR “Inhibitory Control” OR “Mental Flexibility” OR “Response Inhibition” OR “Selective Attention” OR “Set Switch*” OR "Set Shift*” OR “Sustain* Attention” OR “Task Shift*” OR “Task Switch*” OR “Working Memory”) OR AB (“Attention* Shift*” OR “Attention* Switch*” OR “Cognitive Control” OR “Cognitive Flexibility” OR “Cognitive Inhibition” OR “Executive Attention” OR “Executive Function*” OR “Inhibitory Control” OR “Mental Flexibility” OR “Response Inhibition” OR “Selective Attention” OR “Set Switch*” OR "Set Shift*” OR “Sustain* Attention” OR “Task Shift*” OR “Task Switch*” OR “Working Memory”)) OR (DE (“Digit Span Testing” OR “Verbal Fluency” OR “Stroop Effect” OR “Stroop Colour Word Test” OR “Wisconsin Card Sorting Test”) OR KW (“Cantab” OR “Delis

kaplan” OR “Design Fluency” OR “Digit Span” OR “D-KEFS” OR “Flanker” OR “GNG” OR “Go-no-go” OR “GoNoGo” OR “Interference Control” OR “N-back” OR “Nback” OR “paced auditory serial addition test” OR “PASAT” OR “Ruff Figural Fluency Test” OR “Stop Signal Task” OR “Stroop” OR “Tower of Hanoi” OR “Tower of London” OR “Trail Making” OR “Verbal Fluency” OR “WCST” OR “Wisconsin Card Sorting” OR “Word Span” OR “Word Fluency”) OR TI (“Cantab” OR “Delis kaplan” OR “Design Fluency” OR “Digit Span” OR “D-KEFS” OR “Flanker” OR “GNG” OR “Go-no-go” OR “GoNoGo” OR “Interference Control” OR “N-back” OR “Nback” OR “paced auditory serial addition test” OR “PASAT” OR “Ruff Figural Fluency Test” OR “Stop Signal Task” OR “Stroop” OR “Tower of Hanoi” OR “Tower of London” OR “Trail Making” OR “Verbal Fluency” OR “WCST” OR “Wisconsin Card Sorting” OR “Word Span” OR “Word Fluency”) OR AB (“Cantab” OR “Delis kaplan” OR “Design Fluency” OR “Digit Span” OR “D-KEFS” OR “Flanker” OR “GNG” OR “Go-no-go” OR “GoNoGo” OR “Interference Control” OR “N-back” OR “Nback” OR “paced auditory serial addition test” OR “PASAT” OR “Ruff Figural Fluency Test” OR “Stop Signal Task” OR “Stroop” OR “Tower of Hanoi” OR “Tower of London” OR “Trail Making” OR “Verbal Fluency” OR “WCST” OR “Wisconsin Card Sorting” OR “Word Span” OR “Word Fluency”))
AND
(DE (“Athletic Training” OR "Physical Activity” OR "Exercise” OR "Physical Fitness” OR “Physical Endurance” OR “Sports” OR “Aerobic Exercise” OR “Martial Arts” OR “Yoga”)) OR (KW (“Exercis*” OR “physical activity” OR “Physical* Fit*” OR “Physical Endurance” OR “Physical Performance” OR “Sport” OR “Sports” OR “Martial Arts” OR “Yoga” OR “Resistance” OR “Exergam*”) N3 (“Acute” OR “Bout” OR “Bouts” OR “Intervention” OR “Training” OR “Program” OR “Session*” OR “Effect” OR “Effects”)) OR (TI (“Exercis*” OR “physical activity” OR “Physical* Fit*” OR “Physical Endurance” OR “Physical Performance” OR “Sport” OR “Sports” OR “Martial Arts” OR “Yoga” OR “Resistance” OR “Exergam*”) N3 (“Acute” OR “Bout” OR “Bouts” OR “Intervention” OR “Training” OR “Program” OR “Session*” OR “Effect” OR “Effects”)) OR (AB (“Exercis*” OR “physical activity” OR “Physical* Fit*” OR “Physical Endurance” OR “Physical Performance” OR “Sport” OR “Sports” OR “Martial Arts” OR “Yoga” OR “Resistance” OR “Exergam*”) N3 (“Acute” OR “Bout” OR “Bouts” OR “Intervention” OR “Training” OR “Program” OR “Session*” OR “Effect” OR “Effects”))
AND
DE (“Between Groups Design” OR "Clinical Trials” OR "Experimental Design” OR "Randomized Clinical Trials” OR “Randomized Controlled Trials” OR “Random Sampling”) OR KW ("Clinical Trial*” OR (“Between” W1 (“Group” OR “Groups” OR “Subjects”)) OR (“Experimental” W1 (“Design” OR “Study” OR “Method” OR “Trial”)) OR (“Controlled” W2 (“Design” OR “Study” OR “Method” OR “Trial”)) OR ((“Double” OR “Single” OR “Doubly” OR “Singly”) W1 (“Blind” OR “Blinded”)) OR “Random*” OR “Compare” OR “Comparison” OR “Comparing” OR “Compared” OR “Control Group*”) OR TI ("Clinical Trial*” OR (“Between” W1 (“Group” OR “Groups” OR “Subjects”)) OR (“Experimental” W1 (“Design” OR “Study” OR “Method” OR “Trial”)) OR

(“Controlled” W2 (“Design” OR “Study” OR “Method” OR “Trial”)) OR ((“Double” OR “Single” OR “Doubly” OR “Singly”) W1 (“Blind” OR “Blinded”)) OR “Random*” OR “Compare” OR “Comparison” OR “Comparing” OR “Compared” OR “Control Group*”) OR AB ("Clinical Trial*” OR (“Between” W1 (“Group” OR “Groups” OR “Subjects”)) OR (“Experimental” W1 (“Design” OR “Study” OR “Method” OR “Trial”)) OR (“Controlled” W2 (“Design” OR “Study” OR “Method” OR “Trial”)) OR ((“Double” OR “Single” OR “Doubly” OR “Singly”) W1 (“Blind” OR “Blinded”)) OR “Random*” OR “Compare” OR “Comparison” OR “Comparing” OR “Compared” OR “Control Group*”)
NOT
TI (“Alzheimer*” OR “ADHD” OR “attention deficit hyperactivity disorder” OR “attention deficit disorder” OR “ASD” OR “Autism” OR “dementia” OR “diabetes” OR "down syndrome" OR “multiple sclerosis” OR “obesity” OR “obese” OR "parkinson*" OR "schizophrenia" OR “children” OR “childhood” OR “preschool” OR “elementary” OR “elderly” OR “older adult*” OR “elder adult*”)

PubMed

"Executive Function”[Mesh] OR “Inhibition, Psychological”[Mesh] OR "Stroop Test"[Mesh] OR "Trail Making Test"[Mesh] OR “Wisconsin Card Sorting Test”[Mesh] OR “Attention* Shift*”[tiab] OR “Attention* Switch*”[tiab] OR “Cognitive Control”[tiab] OR “Cognitive Flexibility”[tiab] OR “Cognitive Inhibition”[tiab] OR “Executive Attention”[tiab] OR “Executive Function*”[tiab] OR “Inhibitory Control”[tiab] OR “Mental Flexibility”[tiab] OR “Response Inhibition”[tiab] OR “Selective Attention”[tiab] OR “Set Switch*”[tiab] OR "Set Shift*”[tiab] OR “Sustain* Attention”[tiab] OR “Task Shift*”[tiab] OR “Task Switch*”[tiab] OR “Working Memory”[tiab] OR “Cantab”[tiab] OR “Delis kaplan”[tiab] OR “Design Fluency”[tiab] OR “Digit Span”[tiab] OR “D-KEFS”[tiab] OR “Flanker”[tiab] OR “GNG”[tiab] OR “Go-no-go”[tiab] OR “GoNoGo”[tiab] OR “Interference Control”[tiab] OR “N-back”[tiab] OR “Nback”[tiab] OR “paced auditory serial addition test”[tiab] OR “PASAT”[tiab] OR “Ruff Figural Fluency Test”[tiab] OR “Stop Signal Task”[tiab] OR “Stroop”[tiab] OR “Tower of Hanoi”[tiab] OR “Tower of London”[tiab] OR “Trail Making”[tiab] OR “Verbal Fluency”[tiab] OR “WCST”[tiab] OR “Wisconsin Card Sorting”[tiab] OR “Word Span”[tiab] OR “Word Fluency”[tiab]
AND
"Exercise”[Mesh] OR “Physical Fitness”[Mesh] OR “Physical Endurance”[Mesh] OR “Exergaming”[Mesh] OR “Physical Conditioning, Human”[Mesh] OR “Endurance Training”[Mesh] OR “Resistance Training”[Mesh] OR “Yoga”[Mesh] OR “Sports”[Mesh] OR "Martial Arts"[Mesh] OR ((“Exercis*”[tiab] OR “physical activity”[tiab] OR “Physical* Fit*”[tiab] OR “Physical Endurance”[tiab] OR “Physical Performance”[tiab] OR “Sport”[tiab] OR “Sports”[tiab] OR “Martial Arts”[tiab] OR “Yoga”[tiab] OR “Resistance”[tiab] OR

“Exergam*”[tiab]) AND (“Acute”[tiab] OR “Bout”[tiab] OR “Bouts”[tiab] OR “Intervention”[tiab] OR “Training”[tiab] OR “Program”[tiab] OR “Session*”[tiab] OR “Effect”[tiab] OR “Effects”[tiab]))
AND
“Double-Blind Method”[Mesh] OR “Single-Blind Method”[Mesh] OR “Clinical Trial”[Publication Type] OR “Controlled Clinical Trial”[Publication Type] OR "Randomized Controlled Trial"[Publication Type] OR "Clinical Trial*”[tiab] OR “Between Group”[tiab] OR “Between Groups”[tiab] OR “Between Subjects”[tiab] OR “Experimental Design”[tiab] OR “Experimental Study”[tiab] OR “Experimental Method”[tiab] OR “Experimental Trial”[tiab] OR “Controlled Design”[tiab] OR “Controlled Study”[tiab] OR “Controlled Method”[tiab] OR “Controlled Trial”[tiab] OR “Double Blind”[tiab] OR “Single Blind”[tiab] OR “Doubly Blind”[tiab] OR “Singly Blind”[tiab] OR “Double Blinded”[tiab] OR “Single Blinded”[tiab] OR “Doubly Blinded”[tiab] OR “Singly Blinded”[tiab] OR “Random*”[tiab] OR “Compare”[tiab] OR “Comparison”[tiab] OR “Comparing”[tiab] OR “Compared”[tiab] OR “Control Group*”[tiab]
NOT
“Alzheimer*”[ti] OR “ADHD”[ti] OR “attention deficit hyperactivity disorder”[ti] OR “attention deficit disorder”[ti] OR “ASD”[ti] OR “Autism”[ti] OR “dementia”[ti] OR “diabetes”[ti] OR "down syndrome”[ti] OR “multiple sclerosis”[ti] OR “obesity”[ti] OR “obese”[ti] OR "parkinson*”[ti] OR "schizophrenia”[ti] OR “children”[ti] OR “childhood”[ti] OR “preschool”[ti] OR “elementary”[ti] OR “elderly”[ti] OR “older adult*”[ti] OR “elder adult*”[ti]

Scopus
TITLE-ABS-KEY (“Attention* Shift*” OR “Attention* Switch*” OR “Cognitive Control” OR “Cognitive Flexibility” OR “Cognitive Inhibition” OR “Executive Attention” OR “Executive Function*” OR “Inhibitory Control” OR “Mental Flexibility” OR “Response Inhibition” OR “Selective Atten*” OR “Set Switch*” OR "Set Shift*” OR “Sustain* Attention” OR “Task Shift*” OR “Task Switch*” OR “Working Memory” OR “Cantab” OR “Delis kaplan” OR “Design Fluency” OR “Digit Span” OR “D-KEFS” OR “Flanker” OR “GNG” OR “Go-no-go” OR “GoNoGo” OR “Interference Control” OR “N-back” OR “Nback” OR “paced auditory serial addition test” OR “PASAT” OR “Ruff Figural Fluency Test” OR “Stop Signal Task” OR “Stroop” OR “Tower of Hanoi” OR “Tower of London” OR “Trail Making” OR “Verbal Fluency” OR “WCST” OR “Wisconsin Card Sorting” OR “Word Span” OR “Word Fluency”)
AND
(TITLE-ABS-KEY ("Exercis*" OR "physical activity" OR "Physical* Fit*" OR "Physical Endurance" OR "Physical Performance" OR "Sport" OR "Sports" OR "Martial Arts" OR "Yoga" OR "Resistance" OR "Exergam*") W/3 ("Acute" OR "Bout" OR "Bouts" OR "Intervention" OR "Training" OR "Program" OR "Session*" OR "Effect" OR "Effects"))
AND

TITLE-ABS-KEY ("Clinical Trial*" OR ("Between" PRE/1 ("Group" OR "Groups" OR "Subjects")) OR ("Experimental" PRE/1 ("Design" OR "Study" OR "Method" OR "Trial")) OR ("Controlled" PRE/2 ("Design" OR "Study" OR "Method" OR "Trial")) OR (("Double" OR "Single" OR "Doubly" OR "Singly") PRE/1 ("Blind" OR "Blinded")) OR "Random*" OR "Compare" OR "Comparison" OR "Comparing" OR "Compared" OR "Control Group*")
AND NOT
TITLE ("Alzheimer*" OR "ADHD" OR "attention deficit hyperactivity disorder" OR "attention deficit disorder" OR "ASD" OR "Autism" OR "dementia" OR "diabetes" OR "down syndrome" OR "multiple sclerosis" OR "obesity" OR "obese" OR "parkinson*" OR "schizophrenia" OR "children" OR "childhood" OR "preschool" OR "elementary" OR "elderly" OR "older adult*" OR "elder adult*")

SPORTDiscus
ZU ("cognitive flexibility" OR "executive function" OR "response inhibition" OR "stroop effect") OR (KW ("Attention* Shift*" OR "Attention* Switch*" OR "Cognitive Control" OR "Cognitive Flexibility" OR "Cognitive Inhibition" OR "Executive Attention" OR "Executive Function*" OR "Inhibitory Control" OR "Mental Flexibility" OR "Response Inhibition" OR "Selective Atten*" OR "Set Switch*" OR "Set Shift*" OR "Sustain* Attention" OR "Task Shift*" OR "Task Switch*" OR "Working Memory") OR TI ("Attention* Shift*" OR "Attention* Switch*" OR "Cognitive Control" OR "Cognitive Flexibility" OR "Cognitive Inhibition" OR "Executive Attention" OR "Executive Function*" OR "Inhibitory Control" OR "Mental Flexibility" OR "Response Inhibition" OR "Selective Atten*" OR "Set Switch*" OR "Set Shift*" OR "Sustain* Attention" OR "Task Shift*" OR "Task Switch*" OR "Working Memory") OR AB ("Attention* Shift*" OR "Attention* Switch*" OR "Cognitive Control" OR "Cognitive Flexibility" OR "Cognitive Inhibition" OR "Executive Attention" OR "Executive Function*" OR "Inhibitory Control" OR "Mental Flexibility" OR "Response Inhibition" OR "Selective Atten*" OR "Set Switch*" OR "Set Shift*" OR "Sustain* Attention" OR "Task Shift*" OR "Task Switch*" OR "Working Memory")) OR (KW ("Cantab" OR "Delis kaplan" OR "Design Fluency" OR "Digit Span" OR "D-KEFS" OR "Flanker" OR "GNG" OR "Go-no-go" OR "GoNoGo" OR "Interference Control" OR "N-back" OR "Nback" OR "paced auditory serial addition test" OR "PASAT" OR "Ruff Figural Fluency Test" OR "Stop Signal Task" OR "Stroop" OR "Tower of Hanoi" OR "Tower of London" OR "Trail Making" OR "Verbal Fluency" OR "WCST" OR "Wisconsin Card Sorting" OR "Word Span" OR "Word Fluency") OR TI ("Cantab" OR "Delis kaplan" OR "Design Fluency" OR "Digit Span" OR "D-KEFS" OR "Flanker" OR "GNG" OR "Go-no-go" OR "GoNoGo" OR "Interference Control" OR "N-back" OR "Nback" OR "paced auditory serial addition test" OR "PASAT" OR "Ruff Figural Fluency Test" OR "Stop Signal Task" OR "Stroop" OR "Tower of Hanoi" OR "Tower of London" OR "Trail Making" OR "Verbal Fluency" OR "WCST" OR "Wisconsin Card Sorting" OR "Word Span" OR "Word Fluency") OR AB ("Cantab" OR "Delis kaplan" OR "Design Fluency" OR "Digit Span" OR "D-KEFS" OR "Flanker" OR

“GNG” OR “Go-no-go” OR “GoNoGo” OR “Interference Control” OR “N-back” OR “Nback” OR “paced auditory serial addition test” OR “PASAT” OR “Ruff Figural Fluency Test” OR “Stop Signal Task” OR “Stroop” OR “Tower of Hanoi” OR “Tower of London” OR “Trail Making” OR “Verbal Fluency” OR “WCST” OR “Wisconsin Card Sorting” OR “Word Span” OR “Word Fluency”))
AND
(ZU ("Physical Activity” OR "Exercise” OR "Physical Fitness” OR “Sports” OR “Aerobic Exercises” OR “Martial Arts” OR “Yoga” OR “Resistance Training”)) OR (KW (“Exercis*” OR “physical activity” OR “Physical* Fit*” OR “Physical Endurance” OR “Physical Performance” OR “Sport” OR “Sports” OR “Martial Arts” OR “Yoga” OR “Resistance” OR “Exergam*”) N3 (“Acute” OR “Bout” OR “Bouts” OR “Intervention” OR “Training” OR “Program” OR “Session*” OR “Effect” OR “Effects”)) OR (TI (“Exercis*” OR “physical activity” OR “Physical* Fit*” OR “Physical Endurance” OR “Physical Performance” OR “Sport” OR “Sports” OR “Martial Arts” OR “Yoga” OR “Resistance” OR “Exergam*”) N3 (“Acute” OR “Bout” OR “Bouts” OR “Intervention” OR “Training” OR “Program” OR “Session*” OR “Effect” OR “Effects”)) OR (AB (“Exercis*” OR “physical activity” OR “Physical* Fit*” OR “Physical Endurance” OR “Physical Performance” OR “Sport” OR “Sports” OR “Martial Arts” OR “Yoga” OR “Resistance” OR “Exergam*”) N3 (“Acute” OR “Bout” OR “Bouts” OR “Intervention” OR “Training” OR “Program” OR “Session*” OR “Effect” OR “Effects”))
AND
ZU ("Clinical Trials” OR "Experimental Design” OR “Randomized Controlled Trials” OR “Random Sampling”) OR KW ("Clinical Trial*” OR (“Between” W1 (“Group” OR “Groups” OR “Subjects”)) OR (“Experimental” W1 (“Design” OR “Study” OR “Method” OR “Trial”)) OR (“Controlled” W2 (“Design” OR “Study” OR “Method” OR “Trial”)) OR ((“Double” OR “Single” OR “Doubly” OR “Singly”) W1 (“Blind” OR “Blinded”)) OR “Random*” OR “Compare” OR “Comparison” OR “Comparing” OR “Compared” OR “Control Group*”) OR TI ("Clinical Trial*” OR (“Between” W1 (“Group” OR “Groups” OR “Subjects”)) OR (“Experimental” W1 (“Design” OR “Study” OR “Method” OR “Trial”)) OR (“Controlled” W2 (“Design” OR “Study” OR “Method” OR “Trial”)) OR ((“Double” OR “Single” OR “Doubly” OR “Singly”) W1 (“Blind” OR “Blinded”)) OR “Random*” OR “Compare” OR “Comparison” OR “Comparing” OR “Compared” OR “Control Group*”) OR AB ("Clinical Trial*” OR (“Between” W1 (“Group” OR “Groups” OR “Subjects”)) OR (“Experimental” W1 (“Design” OR “Study” OR “Method” OR “Trial”)) OR (“Controlled” W2 (“Design” OR “Study” OR “Method” OR “Trial”)) OR ((“Double” OR “Single” OR “Doubly” OR “Singly”) W1 (“Blind” OR “Blinded”)) OR “Random*” OR “Compare” OR “Comparison” OR “Comparing” OR “Compared” OR “Control Group*”)
NOT
TI (“Alzheimer*” OR “ADHD” OR “attention deficit hyperactivity disorder” OR “attention deficit disorder” OR “ASD” OR “Autism” OR “dementia” OR “diabetes” OR "down syndrome" OR “multiple sclerosis” OR “obesity” OR “obese” OR "parkinson*" OR "schizophrenia" OR “children”

OR “childhood” OR “preschool” OR “elementary” OR “elderly” OR “older adult*” OR “elder adult*”)

Appendix B: List of Physical Activities Provided (in order presented)

Walking, Running, Cycling
Walking for exercise
Walking upstairs for exercise
Jogging
Running
Roller skating
Orienteering

Calisthenics/Conditioning
Home calisthenics (conditioning)
Exercise classes
Weight training
Body building
Skipping rope
Yoga
Relaxation exercises (e.g., meditating)

Individual/Dual Sports
Archery
Badminton
Equestrian events
Fencing
Figure skating
Golf, walking and carrying clubs
Golf, walking and pulling clubs in a cart
Golf, riding a golf cart
Gymnastics/Tumbling
Handball (4-wall)
Horseback riding
Racquetball
Skateboarding
Squash
Table tennis
Tennis
Weightlifting
Baseball
Basketball
Broomball
Cheerleading
Cricket
Curling
Football
Handball
Floor hockey
Field hockey
Road hockey
Ice hockey
Lacrosse
Officiating/Refereeing
Ringette
Rugby
Soccer
Softball
Volleyball
Water polo

Aquatics
Canoeing/Rowing for pleasure
Canoeing for camping trip/portage
Diving
Kayaking
Rowing
Sailing
Scuba diving
Snorkeling
Swimming at a beach
Swimming at a pool
Wake boarding
Water skiing

Winter Sports
Alpine skiing

Cross-country skiing
Freestyle skiing
Skating
Snowboarding
Snowmobiling
Snowshoeing
Tobogganing

Outdoor Sports
Backpacking
Camping with backpacking
Camping on prepared grounds
Fishing in a boat
Fishing from a riverbank
Fishing in a stream
Hiking
Hunting small game
Hunting large game
Motor cycling
Mountaineering/Rock-climbing/Bouldering

Dance
Ballet
Ballroom dancing
Hip-hop dancing
Folk dancing
Jazz dancing
Square dancing
Tap dancing
Zumba

Combatives/Self-Defence
Wrestling
Boxing/Kickboxing
Martial arts
Washer toss
Spike ball
Catch (e.g., with a football, baseball, etc.)
Frisby
Tag games
Bowling
Horseshoes
Croquet
Bocce (Italian lawn game)

Home-Related Activities
Light housework (cooking, ironing, washing dishes, making beds, lawn mowing with a ride- on lawn mower))
Heavy housework (washing windows, washing/waxing floors, shopping and carrying grocery bags, painting, carpentry, repairing, remodelling)
Spading, digging, filling in, weeding, gardening, raking
Snow shoveling
Snow blowing
Mowing lawn using a push mower
Wood cutting

Activities that Participants Added

Airsoft
Art creation
Biking
Car cruising
Carry heavy things
Competitive dance
Competitive swimming
Contemporary (dance)

Cycling
Disc golf
Dog walking
Downhill ski racing
Driving range
Home workouts
Ice skating
Indoor cycling
Javelin
Lyrical (dance)
Mixed cardio
Modern dance
Paintball
Performing musician
Physio exercises
Pickleball
Pilates
Play VR table tennis or other game
Pointe (dance)
Respite work
Ring toss
Roller blading
Serving/bartending
Spin class
Sprint canoe/kayak
Stationary bike
Stretching
Swim racing
Swimming
Track and Field
Ultimate frisbee
Violin
Walking dog
Working/serving