Title
Supporting Cognitive Health in Aging: Investigating the Influence of Music and Activity Engagement

Author
Weaver, Alexandria Nicole

Publication Date
2023

UNIVERSITY OF CALIFORNIA,
IRVINE

Supporting Cognitive Health in Aging: Investigating the Influence of Music and Activity Engagement

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Education

by

Alexandria N. Weaver

Dissertation Committee:
Professor Susanne M. Jaeggi, Chair
Professor Susan T. Charles
Professor Elizabeth D. Peña
Professor Lindsey E. Richland

2023

DEDICATION

To

Everyone that participated, engaged with, supported, and inspired this work

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

To my advisor, Susanne Jaeggi: I would like to express my biggest thank you. It has been an honor getting to work with and learn from you and I am incredibly grateful for the unwavering support, effort, and encouragement you've given me throughout my graduate training as well as providing countless opportunities to help me grow as a scholar. Thank you for guiding and supporting my research ideas (even the ones that weren't too good haha), every proposal, poster, fellowship applications, and more. I have learned to be much more confident in my skills and ideas and I attribute a lot of that growth to your mentorship. In addition, thank you for creating a wonderful community with the WMP Lab. I have loved being a part of this community and getting to work amongst creative, kind, and fun individuals. Lastly, for me, academia opened a door to a whole world of opportunities that my younger self would have never imagined would be possible. Thank you for holding that door open for me and taking me on as one of your students.

I would also like to thank Susan Charles, Elizabeth Peña, and Lindsey Richland for their work on my committee. Thank you for your thoughtful questions, perspectives, and guidance from my proposal to my defense.

Thank you, Corey White, and Tim Nokes-Malach, my undergraduate and postbaccalaureate advisors. My love for research started with your labs and inspired work that contributed to this dissertation.

In addition, thank you to all my mentors who have supported me throughout my academic journey (Cristina, Nabila, Michelle, Nestor, Elham and many more). You all have helped me immensely from applying to grad school, writing fellowships applications, navigating grad school, and more. All of which have contributed to this final milestone. I am dedicated to mentoring others because of the amazing experiences I have had with you all.

To my colleagues and friends, Daniela, Jennifer, Hye Rin, and Maritza, this journey would not have been the same without you. I thought I was just going to get my degree at UCI, but I've gotten much more. I am grateful we're in each other's lives and I am so proud of how far we've come. Thank you for cheering me on and I look forward to continuing to celebrate one another.

To Sabrina, thank you for your friendship and support over the past decade. You and Pickles have been a light in my life.

Lastly, I would like to thank Faith. Thank you for reading every disorganized sentence, listening to every practice presentation, testing out my roughest prototypes, and for always reminding me to take a step back so I can see the bigger picture. You've been with me through each piece of this work, here is final product.

Study 1 of this dissertation is a reprint of the material as it appears in Weaver, A. N., & Jaeggi, S. M. (2021). Activity Engagement and Cognitive Performance Amongst Older Adults. *Frontiers in Psychology*, *12*. https://doi.org/10.3389/fpsyg.2021.620867

, used with permission from Frontiers. The co-author listed in this publication is Susanne M. Jaeggi. This work was supported by National Institute on Aging (Grants #1R01AG049006 and #1K02AG054665) awarded to SMJ.

Study 2 was supported by the National Science Foundation Graduate Research Fellowship Program under Grant No. (DGE-1839285) awarded to Alexandria N. Weaver. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF. Thank you to Emily Lee and Vena Ho for your help organizing and coding the data.

Study 3: Ideas and materials developed for this project were supported by the National Science Foundation Graduate Research Fellowship Program under Grant No. (DGE-1839285) awarded to Alexandria N. Weaver. This work was also supported by the Susan Samueli Integrative Health Institute Pilot Studies Award awarded to Alexandria N. Weaver and Susanne M. Jaeggi, and National Institute on Aging (Grant #R61AG073668) awarded to Susanne M. Jaeggi at University of California, Irvine and Aaron R. Seitz at University of California, Riverside. Thank you to our collaborators at the University of California, Riverside and Oregon Health & Science University, specifically Frederick J. Gallun at Oregon, and Alex Mauric our music composer. Thank you to the undergraduate research assistants who have been an integral part to various stages of development and piloting of this project; Guillermo, Meghna, Jan, Natashza, Stacy, Haley, Theresa, and Michael. Thank you to our Jr. Specialist, Giancarlo Arzu who has also been an integral part to various aspects of development and piloting of this project. Lastly, thank you to our participants who provided us with valuable insights.

VITA

Alexandria N. Weaver

2016	B.A. in Psychology, Syracuse University
2018	Postbaccalaureate in Cognitive Psychology, University of Pittsburgh
2018-2019	Graduate Student Researcher, ADHD project, University of California, Irvine
2018-2023	Graduate Student Researcher, EngAge project, University of California, Irvine
2021-2023	Teaching Assistant/Reader, University of California, Irvine
2021	M.A. in Education, University of California, Irvine
2023	Ph.D. in Education, University of California, Irvine

FIELD OF STUDY

Human Development in Context, Cognitive Aging & Activity Engagement

PEER REVIEWED PUBLICATIONS

Jaeggi, S. M., Weaver, A. N., Carbone, E., Trane, F. E., Smith-Peirce, R. N., Buschkuehl, M., Flueckiger, C., Carlson, M., Jonides, J., & Borella, E. (2023). EngAge – A metacognitive intervention to supplement working memory training: A feasibility study in older adults. *Aging Brain, 4*, 100083. https://doi.org/10.1016/j.nbas.2023.100083

Weaver, A. N., & Jaeggi, S. M. (2021). Activity engagement and cognitive performance amongst older adults. *Frontiers in Psychology*, *12*.

White, C. N., Skokin, K., Carlos, B., & Weaver, A. N. (2015). Using decision models to decompose anxiety-related bias in threat classification. *Emotion, 16*(2), 196–207.

WORK IN PROGRESS

Weaver, A. N., Jaeggi, S. M., Huong Do, Q. T. (2023). Behind the Scenes of Cognitive Training: A Qualitative Evaluation of Perceptions of Training-Related Changes.

Weaver, A. N., Wan, S., Vodyanyk, M., & Jaeggi, S. M. (2023). Activity engagement and cognitive performance in older adulthood: A meta-analysis.

PEER REVIEWED BLOG ARTICLES

Weaver, A., Vodyanyk, M., & Jaeggi, S.M. (2023). How Music and Art Sculpt our Brain's Architecture. Frontiers for Young Minds (Under review).

Weaver, A. (2019, February 28). Music for the Mind: How Music Nurtures Cognitive Development. Retrieved from https://knowingneurons.com/2019/02/28/music-for-the-mind-how-music-nurtures-cognitive-development/

SELECTED PRESENTATIONS

Weaver, A. N., (2022) *Following the Sound of Music: Training to Improve Auditory and Cognitive Abilities*. Presented at Beall Applied Innovation, Irvine, CA.

Jaeggi, S. M., Weaver, A. N., Arzu, G., Seitz, A. R. Gallun, F. J., Acevedo, K., (2022) Following the Sound of Music: Testing the Benefits of a Music-Based Intervention On Auditory Processing in Older Adults. Susan Samueli Integrative Health Institute Annual Meeting, Newport, CA.

Weaver, A. N., Wan, S., Vodyanyk, M., Jaeggi, S. M., (2022) Activity Engagement and Cognitive Performance in Older Adulthood: A Meta-Analysis. Cognitive Aging Conference, Atlanta, GA.

Weaver, A. N., Trane, F., Min Moon, S., Buschkuehl, M., Carbone, E., Borella, E., Flueckiger, C., & Jaeggi, S. M., (2019) Investigating the Benefits of a Combined Cognitive and Motivational Intervention for Older Adults. Poster presented at the Psychonomic Society's 60th Annual Meeting, Montreal, Canada.

Weaver, A. N., & Jaeggi, S. M., (2019) Music to My Ears: A Proposed Intervention for Speech Discrimination in Noise. Poster Presented at the 14th Annual CHR Hearing Symposium, Irvine, CA.

Weaver, A. N., & Jaeggi, S. M., (2019) Exploring Associations Between Leisure Activities and Cognitive Performance in Older Adults. Poster presented at the Learning and Plasticity 2019 Conference, Äkäslompolo, Finland.

Weaver, A. N., & Jaeggi, S. M., (2019) Investigating the Benefits of a Combined Cognitive and Motivational Intervention for Older Adults. Presented at the Games for Engaged Learning 2019 Conference, Pittsburgh, PA.

Weaver, A. N., (2019) Music to My Ears: A Proposed Intervention for Speech Discrimination in Noise. Presented at the Associated Graduate Students Symposium. Irvine, CA.

Weaver, A. N., & Jaeggi, S. M., (2019) Activity Engagement and Cognitive Performance in Older Adults. Poster presented at the Annual First Year Poster Session, Irvine, CA.

GUEST LECTURES

2022	EDUC 40: Theories of Development and Learning Applied to Education; University of California, Irvine.
2019	EDUC 173: Cognition and Learning in Educational Settings; University of California, Irvine.

2019	EDUC 150: Changing the High School Experience; University of California, Irvine.

AWARDS AND GRANTS

2022-2023	Public Impact Fellowships, awarded $1,000 for research that demonstrates the potential to significantly improve or enrich the lives of people in California and beyond.
2022-2023	Beall Graduate Innovation Fellow, awarded $5,000 to participate in one-year program aimed to guide graduate students in the process of translation and commercialization of research.
2022	2nd Place AGS Symposium UCI, for oral presentation “Following the Sound of Music: Training to Improve Auditory and Cognitive Abilities”.
2021	National Institute on Aging R61AG073668, Following the Sound of Music – Comparing the effects of music vs. non-music-based interventions on auditory and cognitive processing in older adults. National institute on Aging. Jaeggi, S. M. (PI), Seitz, A. R.(co-PI). Awarded $2,600,000 (2021-2026). Assisted in grant writing, study development, and responsible for managing project progress.
2021	Susan Samueli Integrative Health Institute, Jaeggi, S. M (PI), Weaver, A. N. Awarded $25,000 to develop and test the feasibility and acceptability of a music-based intervention aimed at improving speech-in-competition abilities amongst older adults.
2021	Sallie P. Asche Travel Award, awarded $500 for attendance to Dallas Cognition and Aging Conference.
2021	CNLM Jared M. Roberts Memorial Award, awarded $1,000 for project “Keeping the Mind Sharp is Music to my Ears”.
2019	National Science Foundation Graduate Research Fellowship, awarded $138,000 towards research and graduate tuition.
2018	UC Irvine Diversity Fellowship, awarded $5,000 to support participation in Competitive Edge 8-week summer research program.

PROFESSIONAL AFFILIATIONS

American Association of University Women

SPARK

Women in Cognitive Sciences

Graduate Ambassador for Center for the Neurobiology of Learning & Memory

ABSTRACT OF THE DISSERTATION

Supporting Cognitive Health in Aging: The Influence of Music and Activity Engagement

by

Alexandria N. Weaver

Doctor of Philosophy in Education

University of California, Irvine, 2023

Professor Susanne M. Jaeggi, Chair

Aging is an intricate process that is commonly accompanied by physical and cognitive changes over time. My dissertation covers three studies that aim to contribute to the literature in supporting cognitive health with aging. In Study 1, I broadly examine various types of activity engagement such as cognitive, social, and physical activities, and their role in supporting cognitive performance in older adults. Using data from an existing dataset, I examined whether activity category, frequency of engagement, predicted cognitive performance. Although these factors were not found to be predicative of cognitive performance, age and years of education were significant predictors. These results did not support the predominant consensus that at least some types of activity engagement contribute to cognitive performance. The findings from this study raised questions regarding what the overall effect of activity engagement and cognitive performance is amongst healthy older adults. In Study 2, I dove deeper into this relationship through conducting a meta-analysis to examine the overall effect of this relation amongst older adults using data from correlational studies. Using PRISMA guidelines, we identified 35 studies resulting in 484 effect sizes. A small significant relation was found between activity engagement and cognitive performance and moderators and exploratory analyses are discussed in further detail. Lastly, I examine the activity of music engagement, a prominent lifestyle activity shown to be beneficial to cognitive performance and hearing abilities later in life. In Study 3, I discuss

the development of a music-based intervention that aims to improve cognition and speech-in-competition abilities for the older adult population and the results of early prototype testing in preparation for the intervention implementation. Overall, I critically examine the idea that engaging in various types of activities across the lifespan contributes to preserved cognitive abilities in later life, mitigating severe age-related cognitive decline.

INTRODUCTION

Lifestyle Activities and Cognitive Performance

For years, research has investigated factors contributing to longevity and maintenance of cognitive functioning in older age, characteristics associated with what has commonly been referred to as “successful”, optimal, or healthy aging (R. Y. Wong, 2018). Although maintaining well intact cognitive abilities and preventing memory disorders is ideal (Annele et al., 2019), with aging, it is common to experience some form of change in cognitive performance. In some instances, individuals may be at risk of developing more severe forms of cognitive impairment such as Alzheimer’s disease and other dementias that greatly impact their everyday lives. Genetics play a role in determining whether an individual is at risk of developing Alzheimer’s disease specifically, however, there are various modifiable lifestyle factors that have been associated with reduced risk of developing Alzheimer’s and experiencing severe cognitive decline such as nutrition, whether or not someone smokes, alcohol consumption, and more (Flicker, 2010). In this dissertation, I focus on one modifiable lifestyle factor, activity engagement, that is associated with maintaining cognitive performance and reducing the risk of developing Alzheimer’s disease.

Engaging in a variety of activities has been associated with better cognitive performance in old age as well as a decreased risk of experiencing cognitive decline (Ihle et al., 2015; James et al., 2011), although, physical and social activities may not contribute as much as cognitive activities in later life (Marioni et al., 2012; Opdebeeck et al., 2016). While the exact functioning of the reserve is debated, the cognitive reserve, as defined by Cabeza and colleagues, is a collection of brain resources that are accumulated over the lifespan that are sustained and employed when needed (Cabeza et al., 2018). Under this theoretical framework, the cognitive reserve is ever-changing and is cultivated through different experiences, also meaning there can be vast individual differences. For this reason, the everyday activities an individual engages with are examples of lifestyle factors that have been hypothesized to play a protective role in maintaining cognitive functioning through their contribution to the cognitive reserve (Guiney et al., 2021; S. Lee et al., 2020; Scarmeas & Stern, 2003a).

The cognitive reserve serves as the framework to the studies in my dissertation and is commonly referenced in the activity engagement and aging literature as it helps to explain differences in the susceptibility of cognitive abilities to the effects of aging (Y. Stern et al., 2020). The concept of the cognitive reserve suggests that the brain is constantly managing challenges by using its own existing cognitive processes as a way to compensate in the face of those challenges (Y. Stern, 2012). Given that neuroplasticity is initiated by new learning and experiences, the mechanism I propose for the relationship between activity engagement and cognitive performance in older age is that the frequent or repetitive engagement and practice with activities leads to the strengthening of the neural connections developed, making them resilient in the face of challenges. I do not mean to suggest that simply going through the motions of doing the same activities leads to the strengthening of these connections, but rather, participating in these activities in a way that goes beyond passive engagement and requires effort. Effort is key and what is important for strengthening neural connections that have been developed as a result of new learning.

How activity engagement may contribute to the reserve and what is optimal remains unclear. Common debates in the literature are in regard to activity type (i.e., social, cognitive or physical), and amount of activity engagement such as frequency vs. less frequent but diverse engagement in many activities. Activities such as socializing with friends and family, playing musical instruments, and walking leisurely or for exercise are all examples of different forms of activity engagement across all three categories. Although the literature generally agrees that there seems to be some relationship between activity engagement and cognitive performance in older age, there are conflicting findings regarding the equality in contribution to the reserve certain activity categories may have. For example, some studies finding a positive relationship between one activity engagement category and performance and not others, and some finding negative or no relationship at all (Aartsen et al., 2002; Baker et al., 2005; Bielak et al., 2012). In addition to activity categories, frequency is one of the most common measures of engagement amongst studies finding a positive relationship between engagement and cognitive performance (Verghese et al., 2003). However, others, such as Carlson and colleagues and Lee and colleagues have found that participating in a greater assortment of activities, or a variety, are more predictive of performance than frequency (Carlson et al., 2012; Lee et al., 2020). Given the mixed findings in the literature, it is necessary to further examine the relationship between activity engagement and cognitive performance as this may give further insight into the underlying mechanisms at play as well as deepen our understanding of the cognitive reserve in aging. Further, with this understanding, we are one step closer to helping improve individuals' overall well-being and quality of life.

OVERVIEW OF THE DISSERTATION

This dissertation aims to further investigate the relationship between activity engagement and cognitive performance amongst older adults through two cross-sectional studies, and one feasibility study that aids in the development of an intervention to investigate underlying mechanisms between cognitive performance, hearing, and mindful music listening.

Study 1 explored whether engaging in social, physical, and cognitive activities would be predictive of a global cognitive performance composite composed of working memory, episodic memory, and processing speed amongst healthy older adults. In addition, I tested whether frequency of engagement or breadth (i.e., participating in a variety of activities across categories) were predictive of performance.

Based on cognitive reserve theory, I hypothesized that the cognitive performance composite would be best predicted by engagement in cognitive activities. In comparison to social and physical activities, cognitive activities could potentially demand more neural resources more closely associated with the cognitive areas assesses, which may lead to the maintenance of these abilities. In the second part of this study, I hypothesized frequency would be more predictive of performance than breadth. This hypothesis assumes that once new learning or engagement in an activity is initiated, frequent engagement and practice with this activity would lead to its strengthened neural pathways, making them more resilient in the face of challenges. Our results found that no activity category was predictive of the global cognitive performance composite, and neither were frequency or breadth. However, we did find that age and education were predictors of performance across all hierarchical regression models. This study has since been published in Frontiers in Psychology and is included thereafter.

Given unclear findings on the impact of activity engagement on cognitive performance amongst older adults, Study 2 dives deeper into the relation by estimating the overall effect through a systematic review and meta-analysis of correlational studies. The main research questions for this study are as follows: 1) Among older adults, to what extent are lifestyle activities associated with cognitive performance? 2) To what extent does the relation between activity engagement and cognitive performance vary by age, activity category, timeframe of retrospective assessment, cognitive domain? In addition, we explored a variety of potential moderators to examine the potential strength of the relation between our independent and dependent variables such as age, activity type, education, time of retrospective assessment, performance index, and cognitive domain as well as a few exploratory analyses. Using PRISMA guidelines, we identified 35 studies and 484 effect sizes. We found a small significant correlation between older adults' activity engagement and cognitive performance ($r = .16$, 95% CI = [0.12, 0.20], $p < .001$). Our findings support that certain types of activity engagement may play an important role in cognitive performance. The relationship is not as large as commonly assumed, suggesting that there are likely additional factors at play (e.g., health, income, and more). We discuss the implications for successful aging.

Study 3 was inspired to create a larger study to take a closer look at a specific type of activity for engagement (music), and experimentally investigate the potential underlying mechanisms between mindful and effortful music listening and cognitive performance in older adults. We investigate the effects of music on cognition as this is a well-known activity demonstrated to be beneficial to cognitive performance and hearing abilities later in life. In this dissertation, Study 3 aimed to develop and test the usability of early prototypes of an attention-based music intervention and assessments targeting auditory processing and cognition amongst older adults ages 65+. Here, we aimed to gain insights from participants on their experience with the prototypes, usability, their general enjoyment of the stimuli intended for the experimental group, and their feedback on if they would complete more sessions over a longer period. This study is part of a larger project that aims to test for intervention-specific improvement in cognition and speech-in-competition abilities and determine whether experimental and control interventions differentially impact auditory processing, attention, and working memory, and how these changes may mediate improvements in speech-in-competition abilities.

Study 1

Activity Engagement and Cognitive Performance Amongst Older Adults

Published in Frontiers in Psychology as:

Weaver, A. N., & Jaeggi, S. M. (2021). Activity Engagement and Cognitive Performance Amongst Older Adults. *Frontiers in Psychology*, *12*. https://doi.org/10.3389/fpsyg.2021.620867

Currently, our global population is aging at a fast rate in comparison to individuals in younger age groups. In 2015, it was estimated that 8.5% of the people worldwide were aged 65 and older, and the number of older individuals was projected to continue to increase (He et al., 2016). By the year 2050, it was estimated that older individuals would represent 16.7% of the worldwide population (He et al. 2016). While an increase in life expectancy is an amazing advancement in humanity, the growing aging population presents various health and economic challenges (Power et al., 2019).

One of those challenges is age-related cognitive decline, which is a common human experience. However, the extent of cognitive decline and cognitive changes can be vastly different between individuals (Salthouse, 2009) One proposed explanation for those individual differences is variability in cognitive reserve. The cognitive reserve can be described as the accumulation of brain resources that are developed through a lifetime of experiences, including the types of activities one engages with, that are used when faced with challenges or damage (Cabeza et al., 2018; Cheng, 2016; Y. Stern, 2002). As an aging society, it is critical to understand whether activity engagement relates to cognitive performance and how it might lead to the development and maintenance of the cognitive reserve.

The literature broadly defines the cognitive reserve as the brain's ability to compensate in the face of atrophy or challenges, which can occur as the result of diseases such as Alzheimer's disease, and those that may be experienced as a natural consequence of aging (Cheng, 2016). This ability to compensate, also referred to as the brain reserve (Y. Stern, 2012), is often described as the employment of high functioning neural resources that work harder in order to attempt to maintain similar levels of functioning for brain regions that have suffered damage or are experiencing difficulties (Cheng, 2016). While the exact mechanisms and development/maintenance of the reserve are still debated, the current study operates under the definition of the cognitive reserve as described by Cabeza and colleagues 2018. They define the reserve as the accumulation of brain resources throughout the lifespan that are well maintained and utilized when necessary (Cabeza et al., 2018). We have adopted this definition of the reserve as previous studies have suggested that brain resources and cognitive performance may be maintained or enhanced as a result of one's activity engagement (Guiney et al., 2021; S. Lee et al., 2020; Phillips, 2017).

This conceptualization of the reserve attempts to account for individual differences in brain processing and focuses on how experiences such as education, complexity of occupations, and/or engaging in cognitively stimulating leisure activities might serve as protective factors against damage (Barnett et al., 2006; Opdebeeck et al., 2016). The cognitive reserve that may develop and accumulate as a result of years of experiences may be employed and used as a source of compensation, which we define as the neural recruitment that takes place in response to a high cognitive demand that results in some form of enhancement in cognitive performance (Bierre et al., 2017; Cabeza et al., 2018). Thus, this conceptualization assumes that the cognitive reserve is something that can be built upon, changed, and developed with different experiences. As a result of our unique experiences, we have varying amounts of neuronal connections and strengths between those connections across individuals. The cognitive reserve may also help to explain why two individuals who experience similar extents of brain disease or deterioration do not show the same levels of associated cognitive impairment (Barulli & Stern, 2013).

Numerous studies have assessed the association between engaging in a variety of activities such as social, physical and cognitive activities, and cognitive performance amongst older adults (Bielak et al., 2012; Y. Lee et al., 2019; D. C. Park et al., 2014a; Poelke et al., 2016;

Sposito et al., 2015). Engaging in these activities may contribute to the maintenance of the cognitive reserve (Baldivia et al., 2008; Chan et al., 2018) and result in preserved functioning in later life. In addition to activity engagement, other common proxies of the cognitive reserve include education and occupation (Y. Stern, 2009; Valenzuela & Sachdev, 2006).

It is well-known that our social environments, social support, and relationships have considerable benefits to our health. Individuals who have a greater amount of social connections have been shown to have lower mortality risks (Perissinotto et al., 2019). Social support and relationships are also associated with better mental and physical health (Cohen & Herbert, 1996; Menec, 2003; Seeman et al., 2001), as well as cognitive health. For example, studies reported that social engagement, such as volunteer work and visiting with friends and family, was associated with higher levels of cognitive functioning (Guiney et al., 2021; Krueger et al., 2009). However, not all studies report this positive association (Aartsen, 2002). While there are mixed findings on the relationship between social activities and cognitive functioning in older age, social engagement might still contribute to overall health and well-being (Baker et al., 2005).

Engagement in physical activities is also well documented on their benefits to health and well-being. Regular exercise, such as aerobic and anaerobic exercise, has shown to be helpful to manage symptoms of depression (Schuch et al., 2016). In addition, energy expenditure through physical activity is associated with lower risks of mortality amongst healthy older adults (Manini et al., 2006). Physical activity may also have protective benefits for cognitive functions as higher levels of physical activity in later life are associated with slower age-related cognitive decline (Kawas, 2008; Ku et al., 2012). Furthermore, a study by Chang and colleagues (2010) found that individuals who reported engaging in physical activities during midlife had higher scores for processing speed, memory, and executive function in comparison to individuals who reported no midlife activity. Their results suggest that physical activity during midlife could contribute to the maintenance of cognitive functioning via the cognitive reserve. However, others have not found this relationship (Sposito et al., 2015), and thus, the exact contributions of physical activities to cognitive maintenance are not fully understood. Nonetheless, the potential protective effects of physical activity have been observed through the association between physical activity engagement and lower risks of developing Alzheimer's disease and related dementias (Buchman et al., 2019; Palta et al., 2019).

Cognitive activities, including leisure-type activities, have also been recognized to play a protective role against cognitive decline. Activities such as reading, writing, and playing board games have been associated with higher cognitive performance (Marquine et al., 2012; Sposito et al., 2015), and a reduced risk of dementia (Verghese et al., 2003). In a study examining the benefits of physical and cognitive activities on simple and complex cognitive tasks amongst young and older adults, the authors found that both physical and cognitive activities were associated with better performance, but cognitive activities were a stronger predictor of complex cognitive tasks, especially amongst older adults (Newson & Kemps, 2006), 2006). Their results suggest that both physical and cognitive activities could serve as protective factors against age-related cognitive decline. However, differences in activity type within categories, such as activities of riding a bike vs. playing a sport such as tennis, might influence the cognitive reserve through different pathways (Newson & Kemps, 2006). Although various studies report a relationship between cognitive activities and cognitive functioning, others report conflicting findings. For example, Aartsen and colleagues (2002) reported that activities across social, physical, and cognitive categories were not related to an enhancement in cognitive performance over a 6-year period. In addition, others examining this relationship have found no association between leisure activities and cognitive functioning in individuals with higher education (Park et al., 2019).

While various activities have been found to be beneficial for cognitive performance in older age, less is known about the potential importance of the specifics of this activity engagement, such as frequency of participation and the variety of activities individuals are engaged in. Specifically, is it enough to maintain cognitive functions by participating in a broad variety of many activities, or is it frequency or repeated engagement in a select few activities that ultimately strengthens and maintains cognitive functions? Frequency of engagement is the most commonly used measure of activity engagement in the literature and has been found to be significantly associated with cognitive performance and is predictive of abilities such as perceptual speed and working memory (Bielak et al., 2012; Verghese et al., 2003). Nonetheless, Carlson and colleagues (2012) found an association between participating in a greater assortment of activities and a decreased risk of cognitive impairment, regardless of how cognitively demanding the activities were. In addition, they reported that activity variety (i.e., the participation in many different kinds of activities) was more predictive than frequency of engagement. Similarly, others investigating activity engagement and cognitive performance have found breadth to be predictive of performance over other variables such as time spent on activities (Lee et al., 2020). Yet, others such as Bielak and colleagues (2019) report conflicting findings, concluding that frequency and breadth seem to have similar associations with cognition.

Given the mixed results in the literature, there is a need to further investigate the potential impact of activity engagement and cognitive performance amongst older adults. The present study aims to answer the following questions using an exploratory, correlational approach: 1)

Which activity categories are most predictive of cognitive performance (social, physical or cognitive)? 2) Does breadth or frequency of activity engagement best predict cognitive performance? Our cognitive outcomes of interest are working memory, episodic memory, and processing speed as these are processes that have been shown to be particularly sensitive to the effects of aging (Hartshorne & Germine, 2015; Murman, 2015). Activity engagement and years of education served as proxies for the cognitive reserve. We define frequency of activity engagement as the number of times per week an individual engages with an activity and breadth as the number of activities an individual engages with across a variety of categories (i.e., social, physical, or cognitive).

Our hypothesis for our first research question rests on the assumption that cognitive functioning would be best predicted by engagement in cognitive activities. Cognitively stimulating activities may demand more neural resources associated with this category in comparison with social and physical activities (Fong et al., 2015), which may lead to the maintenance of cognitive abilities. For our second research question, we test whether frequency of activity engagement is more predictive for cognitive functioning than breadth of activity engagement. The reason why frequency of engagement might be more predictive rests on the assumption that once neuroplasticity is initiated by new learning or engagement, frequent engagement and practice with these activities leads to the strengthening of these connections, making them more resilient in the face of challenges (i.e., cognitive decline) (Phillips, 2017). In contrast, as others have demonstrated, variety/variability in activity engagement may be a critical factor that promotes learning and maintenance as well, especially if one engages in novel activities (Bielak et al., 2019; Lee et al., 2020).

Method

Participants, Data, and Procedure

Data for this analysis are combined from two broader multi-site interventions targeting cognitive and metacognitive skills amongst healthy older adults (Jaeggi et al., 2019). In total, 274 participants were recruited between Southern California and Southeast Michigan. Participants were eligible if they were between the ages of 65-85, had no diagnosis of neurological disorders including mild cognitive impairment, and scored within appropriate ranges of the Mini Mental State Exam (MMSE; > 24) (Folstein et al., 1975). Additionally, participants were eligible if they were not currently participating in any other cognitive interventions. The present study only utilizes participants' baseline assessments.

Sixty-eight total participants were excluded from the analysis. Participants were excluded if they were missing data on the activity engagement questionnaire (i.e., they did not respond at all; $n = 47$), the global cognitive performance composite (e.g., were missing all data for a subcomponent of the cognitive performance composite such as all tasks used to assess working memory; $n = 15$), or did not meet the screening criteria ($n = 6$). The final analytical sample consisted of 206 participants (*mean age* = 72.90; *SD* = 5.43; 74% women). Demographic information of the analytical sample is provided on Table 1. A post hoc power analysis was conducted using the software G*Power (Faul et al., 2007). The sample size of 206 was used for the analyses with 11 predictor variables as a baseline. We utilized the recommended effect sizes as follows: small ($f^2 = .10$), medium ($f^2 = .25$), and large ($f^2 = .40$) (Cohen, 1977) with an alpha level of $p < .05$. The analyses revealed that the statistical power for this study was .87 for detecting a small effect, while the power surpassed .99 for detecting a medium to large effect.

Prior to completing the assessments, participants were emailed various self-report questionnaires through the online system Qualtrics to capture demographic information, physical and mental health including overall well-being using the World Health Organization Quality of Life group (WHOQOL-Old; Fang et al., 2012). Participants were additionally screened for general cognitive status as assessed with the Mini-Mental State Examination (MMSE; Tombaugh, 2006), and for depression and generalized anxiety using the Geriatric Depression Scale (GDS; Yesavage, 1988), and Generalized Anxiety Depression Questionnaire (GAD; (Spitzer et al., 2006). Participants were then asked to come into the lab to complete a battery of assessments that took 2.5 hours on average (maximum of 3), to measuring various aspects of cognitive functioning. Because of the extensive testing time, participants took breaks roughly every 45 minutes or more frequently if requested.

Assessments

Activity Engagement

Participants completed the Community Healthy Activities Model Program for Seniors Physical Activity Questionnaire for Older adults (CHAMPS; Stewart et al., 2001) online through Qualtrics at least one week prior to coming into the lab. This 41-item self-report questionnaire assessed their participation, frequency, and duration of various activities within the past two weeks. For example, participants were asked if in the previous two weeks they visited with friends or family, how often during the week, and for how many hours. For a full list of the items used in the analyses, see Figure 1. The total number of activities has shown a test-retest reliability intraclass correlation coefficient (ICC) of 0.56–0.70 (Hekler et al., 2012). Times per week was used as the measure of each individual activity. Activities were excluded from the analysis if 75% or more participants did not engage in the individual activity. The final analysis included 20 activities that were then classified into categories as used in previous studies (C. Stern & Munn, 2010): cognitive, social, and physical to create category composites. Currently, there is no standardized method to categorize individual activities into social, physical and cognitive categories. Although all of the individual activities presented here could be classified under multiple categories (e.g., dancing could be considered a physical activity and social activity), and the fact that all activities we engage in have some cognitive component, the purpose of this analysis is to explore if there is any relationship between the broad classification of activities and cognitive performance. Specifically, we classified the individual activities into the categories they are most commonly associated with and have a greater emphasis on (e.g., dancing is more commonly considered to be a physical activity over a social one) by relying on previous studies (e.g. Stern and Munn, 2010). In addition, the distinction between light-intensity and moderate/high-intensity physical activities were made as defined by the CHAMPS subscales, and given that previous studies have found differences in cognitive performance based on exercise "intensity"(Hwang et al., 2016). In total, there were 5 cognitive activities, 5 social activities, and 10 physical activities. Physical activities were divided into light-intensity (4 activities), and moderate/high-intensity (6 activities). One question was excluded from the physical activity category ("participate in any other physical activity not mentioned") because the responses provided did not give any further insight beyond the questions already included. Specifically, participants either reported activities already listed, listed a non-physical activity that was a variant of an activity already included, or did not list an activity at all. See Figure 2 for the average times per week of engagement in activities. The CHAMPS initially captures frequency of each individual activity as an open-ended response. For analysis, the average value was imputed if a range of frequency was reported. To address missing data for frequency of engagement, hot deck imputation was used to keep random variability (Fang et al., 2012). Outliers were winsorized to the nearest non-outlying value. Frequency of activity engagement was measured as the sum of frequencies for each individual activity per participant, and breadth was measured as the total number of distinct activities across the three categories (cognitive, social, and physical). Our assessment of activity engagement served as a proxy for the cognitive reserve, along with participants' self-reported education level.

Cognitive Assessments

Global Cognitive Performance. Cognitive performance was measured as a global composite consisting of measures of working memory (WM), episodic memory, and processing speed. All cognitive tasks are described in Jaeggi et al (2020). Each cognitive domain was assessed with three separate tasks in order to capture various aspects of those constructs and to minimize task-specific error variance. Each task was scored individually prior to creating the global cognitive performance composite using z-scores. All cognitive tasks were administered face-to-face in the lab.

Working Memory. WM consisted of three individual tasks. The first task used was the Spatial n-back (Jaeggi et al., 2020) to assess WM updating and was administered via tablet. Stimuli were presented in a moving window that lasted for 1,000 ms with an interstimulus of 2,500 ms. Stimuli were presented one at a time on various locations of a diamond shape composed of circles. The task required indicating whether the presented location of a stimulus was the same as the one presented n trials previously. The stimuli presented could be targets, nontargets, or lures. A lure is an item that resembles the correct response, but is presented at the incorrect n trial. For example, if the participant is required to recall 2-back, the lure is presented 1-back. After one round of 1-back, participants completed three rounds of a 2-back without lures and three rounds with lures. Each round consisted of five target stimuli, 10 + n nontarget stimuli, as well as six lures in those rounds that contained lures. The dependent variable was the proportion of hits minus false alarms (pr) across all 2-back trials.

The second WM task was the Sternberg task (Iordan et al., 2018) and was used as a measure of WM maintenance. For this computerized task, participants were presented with a set of uppercase consonant letters (a set size of 4-8) and were given a few seconds to retain them. After their retention period, they were then presented with a lowercase probe letter and had to indicate whether this letter was a part of their initial memory set. Participants completed three blocks of 20 trials. The dependent variable for this task was the average of accurate responses across all trials.

The third WM task was the Symmetry span (Redick et al., 2012) which was used as a variant of a complex WM span, capturing storage and processing. In this computerized task, participants had to indicate whether or not a pattern was symmetrical. After this decision, they were presented with a square that was placed in 1 of 16 locations on a grid. After two to six trials of a symmetry decision and a location on the grid, participants were asked to recall the locations of the squares in order with their computer mouse. The dependent variable was the number of correctly recalled sets.

Episodic Memory. Episodic memory consisted of three individual tasks. The first episodic memory task used was a verbal Metamemory task (McGillivray & Castel, 2011). Participants were presented with five, 12-word lists and were asked to place a bet between 0 and 10 points after each word on their likelihood of remembering that word in the future. At the end of each list, participants were asked to recall as many words as possible. For every correctly remembered word, their bet for that word was added to their score. For every failure to recall a word, their bet for that word was subtracted from their score. At the end of each list, participants were shown their score before moving onto the next list. Here, the number of correctly recalled words across all lists served as the dependent variable (cf. Parlett-Pelleriti, 2019 for a report on the other variables).

The second task used was a measure of visual long-term memory (Perrig et al., 2011). Participants were shown two arrangements of line drawings of objects, patterns, and words on one page similar to Snodgrass and Vanderwart (1980) and were asked to mark all the differences they saw between the two arrangements within three minutes. After about 20 minutes, participants were asked to perform a surprise recall and report as much as they could from the pictures as well as the differences they found. The total number of correctly recalled items served as the dependent variable.

The third measure used was the Characterization of the Elderly on Daily Activities in the Real-World (CEDAR*;* Thomas, 2015). This was an everyday memory task that required participants to take on the role of a fictitious neighbor and complete a series of fictitious errands that involved tasks such as managing medications, finances, and making long-term decisions as a favor for a fictitious character. Accuracy was standardized across subtasks and averaged into a single measure to serve as the dependent variable.

Processing Speed. Processing speed consisted of three individual tasks. The first used was the D2 (Brickenkamp & Seisdedos Cubero, 2012*)*. This task consisted of 14 lines of letters presented as either p or d's, with one to four dashes below and/or above each letter. Participants were given 20 seconds per line and were asked to cross out any d's with two dashes as quickly as possible while ignoring the other items. The index of processing speed was the total number of items completed minus any type of error (TN-E).

The second and third tasks consisted of the pattern and letter comparison as used in Ribaupierre & Lecerf (2006). In the pattern comparison task, participants were asked to decide as quickly as possible if two patterns presented next to each other were identical or not (e.g., QLXVST __ QLNSVT) (60 items total). The letter comparison task required the comparison of letter strings (42 items in total). The dependent variables used were total time in seconds it took to complete each of the tasks.

Covariates

Covariates used in this analysis included self-reported age, gender, socio-economic status (SES; Adler & Stewart, 2007), years of education, and physical health. To report SES, participants were shown a ladder with 10 rungs to represent where people stand in the United States. The top of the ladder (labeled number 10) represented people with the most money, education, and respected jobs. The bottom of the ladder (labeled number 1) represented people with the least money, education, and respected jobs. Participants were asked to place themselves on the ladder (between 1 and 10) of where they currently stood relative to others in the United States. To report physical health, participants were asked to compare their physical health to others their own age on a scale of 1 much worse than average, to 5 much better than average.

Analytical Approach

Data was analyzed using IBM SPSS Statistics Version 25. For the analyses, a series of multiple regressions were conducted. To address the first hypothesis of which activities were predictive of global cognitive performance, four separate hierarchical regressions (one for each activity type) were conducted with global cognitive performance as the outcome variable. For each hierarchical regression, demographic variables; age, gender, SES, year of education, and self-reported health were entered at step one, and the activity categories (social, light-intensity physical, moderate/high-intensity physical, cognitive) were entered at step two.

To address the second hypothesis of breadth or frequency of activity engagement predicting global cognitive performance, two hierarchical regressions were conducted. Just as in the previous regressions, demographic variables were entered at step one and then breadth or frequency of activity engagement was entered at step two.

Exploratory regression analyses were used to investigate whether certain categories were more predictive of the subcomponents of the global cognitive performance composite (i.e., WM, episodic memory, or processing speed). The data underwent assumptions testing appropriate for multiple regressions and met the criteria of linearity, multicollinearity, and homoscedasticity. However, the activity categories (social, light-intensity physical, moderate/high-intensity physical, cognitive) as well as frequency of activity engagement, violated the assumption of normality. Nonetheless, we proceeded with this choice of method as regressions have been found to be robust to this violation (Schmidt & Finan, 2018).

Results

Activity Categories as Predictors of Global Cognitive Performance

For correlations, see table S1 in Supplementary Material. See Table 2 for hierarchical regression results. Overall, none of the activity categories were predictive of global cognitive performance. However, age and education were significant predictors of global cognitive performance.

Activity Frequency and Breadth as Predictors of Global Cognitive Performance

See Table 3 for hierarchical regression results. Overall, activity frequency and breadth were not found to be predictive of global cognitive performance, but age and education remained to be significant predictors of global cognitive performance.

Exploratory Analyses of Cognitive Composite Subcomponents

Hierarchical regressions were conducted to examine the relationship between the activity categories and each subcomponent of the global cognitive composite (i.e., WM, episodic memory, and processing speed). None of the activity categories were found to predict any of the cognitive subcomponents.

Discussion

Previous research suggests that engaging in a variety of activities may provide protective benefits against the effects of age-related cognitive decline as these types of activities may contribute to one's cognitive reserve by building new and strengthening existing neuronal connections (Newson & Kemps, 2006; Sposito et al., 2015). In the present study, we examined whether social, physical, and cognitive activities were predictive of global cognitive performance, and furthermore, if breadth or frequency of activity engagement was predictive of cognitive performance utilizing a series of hierarchical regressions. Based on previous studies (Bielak et al., 2012; Marquine et al., 2012; Sposito et al., 2015; Verghese et al., 2003), we hypothesized that cognitive activities and frequency of activity engagement would be predictive of global cognitive performance.

In contrast to previous findings (Bielak et al., 2012; Carlson et al., 2012; Lee et al., 2019; Singh-Manoux, & Marmot, 2003; Verghese et al., 2003), our results indicate that none of the activity categories or breadth/frequency of activity engagement were predictive of global cognitive performance. However, age and years of education significantly predicted cognitive performance. Exploratory analyses examined if activity categories were predictive of any of the subcomponents of the global cognitive performance composite (i.e., WM, episodic memory, and processing speed), however, none were predictive of the cognitive subcomponents.

Our finding that age and education were predictive of cognitive performance is in line with previous research on cognitive aging, and they illustrate the importance of education as one of the key contributing factors to the cognitive reserve (Baldivia et al., 2008; Thow et al., 2017; Valenzuela & Sachdev, 2006). Global cognitive performance got worse as a function of higher age reflecting age-related cognitive decline, whereas higher education was associated with better performance. Importantly, age and education were predictive of global cognitive performance across all hierarchical regression models.

Although activity engagement was our primary variable of interest, education is often used as the primary indicator for the cognitive reserve (Stern, 2009; Valenzuela & Sachdev, 2006). Previous studies have consistently observed a relationship between education and cognitive health (Farfel et al., 2013; Sattler et al., 2012; Tucker-Drob et al., 2009), which has been interpreted in that education might facilitate the development of cognitive strategies as well as help maintain cognitive performance, especially if education is pursued into late adulthood (Thow et al., 2017). Other studies that have found this relationship have suggested that higher levels of education might lead to various lifestyle choices that could impact health (Hooren et al., 2007). An additional explanation may be that more education may lead to mental stimulation throughout life that results in the maintenance of cognitive functions and is likely that individuals with more education might have occupations that involve more mental stimulation (Baldivia et al., 2008; Hooren et al, 2007). Unfortunately, we do not have data collected in our population that could speak to this hypothesis. However, our sample has a relatively high level of education on average albeit with some variability (range of 8 to 20 years, $M = 16.57$), which may speak to our finding of higher education predicting better performance.

While various studies report a positive association between activity engagement and cognitive performance (Lee et al., 2019; Lee et al., 2020; Park et al., 2014), findings have been inconsistent across studies, especially with regards to the type of activities assessed, and the constructs of cognitive functioning they are associated with (Bielak, 2017; Parisi et al., 2009; Poelke et al., 2016). Our results do not seem to provide more clarity to the current literature on activity engagement and cognitive performance. It is possible that the variation in results can be attributed to differences in how cognitive performance is defined and assessed, differences in measurement and classification of activity engagement and activity type, the age range of the population, as well as participants' overall level of engagement. One potential reason for our findings might be the fact that we relied exclusively on the CHAMPS questionnaire to assess activity engagement. The CHAMPS questionnaire was originally created as a measure of physical activity and caloric expenditure. As a result, there was an overrepresentation of physical activities for participants to select from than what we categorized as social and cognitive. As such, our measure of activity engagement might not fully capture the various activity categories as well as activities one could engage with within those categories, including breadth and frequency. In addition, the questionnaire asks participants to report if they have engaged with these activities in the previous two weeks, and it is possible that participants may have been reporting engagement in activities that they do not regularly engage with. For various activities in the questionnaire, we cannot conclude that participants engage with these activities regularly and consistently, and furthermore, we have no knowledge about how many years they might have participated in these activities. It is possible that more long-term and consistent engagement in activities might be related to cognitive performance in later life and a more long-term measure of activity engagement might better capture this (Chan et al., 2018; Chang et al., 2010). However, the interpretation of the literature is challenging because studies have differed in their specifications of the time interval of activity engagement, ranging from no specification (Ihle et al., 2017), to indicating once per month to daily engagement (Krell-Roesch et al., 2019). Despite those variations in timing, previous studies have generally reported a positive relationship with cognitive performance. Although it seems to be a valid assumption that more long-term engagement may reflect cognitive reserve more adequately, activity engagement measurement with shorter time interval specifications have also reported positive relationships with cognition, even though our results do not. Thus, it is possible that activity engagement as assessed here does not have a strong effect on the specific areas of cognition we measured.

Several limitations of this study should be noted. The first limitation pertains to the population recruited, which was generally high-functioning and likely not representative of the greater population. People were recruited via flyering and through databases participants register for to be contacted about participating in research studies. As such, participants self-selected to participate in this memory study. It is possible that individuals who are concerned with their cognitive functioning with aging may already proactively engage in a variety of lifestyle activities aimed at maintaining or increasing their cognitive performance, including generally participating in memory-related studies. Indeed, participants in this study presented to be a highly engaged group as there was little variation in individuals who engaged in a lot of activities vs. individuals who engaged in fewer activities. Participants reported that they were generally in very good health in comparison to others their age. This could result in greater or more long-term engagement with activities that could contribute to the maintenance of cognitive functions, although we only measured activities they engaged with in the previous two weeks upon joining the study. Because there was little variation between individuals, we might not have been able to detect a difference in cognitive performance based on activity engagement.

As previously mentioned, the measurement of activity engagement used here may not be an ideal and comprehensive measure of activity engagement. The CHAMPS questionnaire asks participants to report whether or not they engage in an activity and the hours and times per week spent on those activities. It is possible that the data may not be representative or accurate. Previous studies have suggested that individuals may under- or over-report their time spent engaging in activities (Parisi et al., 2009; Salthouse et al., 2002), which could have been even further exacerbated by the fact that we implemented a retrospective assessment that relied on participants' memory functions. If participants under or over reported their activity engagement, then the missing data imputation method may have only further distorted the data.

In conclusion, the overall goal of this study was to examine the relationship between activity engagement and cognitive performance amongst older adults. We found that only age and education were predictive of cognitive performance, not activity category, activity breadth, or frequency of engagement. Our results are consistent with previous work demonstrating that education plays a significant role in contributing to the cognitive reserve, which is associated with higher cognitive performance. Our results further suggest that education may be a better predictor of cognitive functioning in older age than one's activity engagement, potentially reflecting lifestyle choices that have long-term impacts on cognitive health. However, our findings should be interpreted with caution. Although we did not find a relationship between activity engagement and overall cognitive performance, it does not mean that one's activity engagement does not contribute to cognitive functioning. Engaging in activities one enjoys can have positive effects on overall well-being that may impact health, which might ultimately affect cognitive functioning as well (Aartsen, 2002; Baker et al., 2005). Our study is in line with this hypothesis, as we found positive correlations between well-being and social activities ($r = .37$, $p < .01$), as well as with frequency ($r = .28$, $p < .05$) and breadth of engagement ($r = .22$; $p < .05$) (see Table S1 in Supplementary Material). Future studies should consider using more holistic measurements of activity engagement, inquire about activity engagement over one's lifetime, and consider including a broader range of cognitive measures. Additional longitudinal and interventional research is also necessary to determine a causal relationship between one's activity engagement and cognitive performance in older age.

Appendix A

Table 1.1

Demographic Characteristics of Participants

Variable	*n*	*M*	*SD*	*Range*
Age	206	72.90	5.43	65-85
Gender				
Female	152			
Male	54			
SES	201	6.77	1.83	3-10
Education (years)	204	16.57	2.53	8-12
Health	202	3.41	.83	2-5
Anxiety (GAD)	196	1.23	1.85	0-12
Depression (GDS)	194	1.11	1.74	0-9
Well-being (WHOQOL-Old)	193	73.19	11.36	47-100
Cognitive status (MMSE)	206	28.76	1.53	24-30

Note. Cases were deleted listwise. Socioeconomic status (SES) ranged on a scale from 1-10 with higher meaning more well off in comparison to others in the United States. Health was rated on a scale of 1-5, with 5 meaning above average compared to others their same age. Anxiety (GAD) score of 4 and below out of 21 indicates no anxiety symptoms. A score of ≥ 15 indicate severe anxiety. Depression (GDS) score of 4 and below out of 30 indicates no depressive symptoms. A score ≥ 10 is indicative of depression. Well-being (WHOQOL) high scores indicate high well-being; scores out of 100 possible points. Cognitive status (MMSE) scores of 24 or greater out of 30 suggest no presence of dementia.

Table 1.2

Hierarchical Regression Results for Activity Categories as Predictors of Global Cognitive Performance

	Social		Light-intensity		Moderate/high-intensity		Cognitive	
Variable	Step 1	Step 2	Step 1	Step 2	Step 1	Step 2	Step 1	Step 2
Age	-.34***	-.35***	-.37***	-.37***	-.33***	-.33***	-.33***	-.33***
	(.06)	(.06)	(.06)	(.06)	(.06)	(.06)	(.06)	(.06)
Gender	.00	-.03	.01	.00	.01	.01	.00	.00
	(.72)	(.75)	(.70)	(.70)	(.71)	(.72)	(.72)	(.72)
SES	-.10	-.13	-.11	-.13	-.11	-.11	-.10	-.10
	(.18)	(.19)	(.18)	(.18)	(.18)	(.18)	(.19)	(.19)
Education	.20*	.20*	.18*	.18*	.20*	.20*	.20*	.20*
	(.13)	(.13)	(.12)	(.12)	(.13)	(.13)	(.13)	(.13)
Health	.02	.11	.08	.08	.05	.05	.03	.03
	(.38)	(.38)	(.38)	(.38)	(.38)	(.47)	(.38)	(.38)
Social activities		.11						
		(.38)						
Light-intensity physical activities				.11				
				(.34)				
Moderate/high-intensity physical activities						-.01		
						(.47)		
Cognitive activities								-.01
								(.19)
Constant	15.35**	15.98**	16.82***	16.34***	14.54**	14.54**	14.53**	14.72**
	(5.02)	(5.03)	(4.83)	(4.83)	(5.00)	(5.01)	(5.05)	(5.20)
N	148	148	148	148	145	145	147	147
R^2	.15	.16	.17	.18	.15	.15	.14	.16
ΔR^2	.15***	.01	.17***	.01	.15***	.00	.11**	.00

Note. For the variable gender, 0 = male, 1 = female. Standardized coefficients are reported and standard errors are in parentheses. Cases were deleted listwise.

**p* < .05, ***p* < .01, ****p* < .001

Table 1.3

Hierarchical Regression Results for Breadth and Frequency of Activity Engagement as Predictors of Global Cognitive Performance

	Breadth		Frequency	
Variable	Step 1	Step 2	Step 1	Step 2
Age	-.37***	-.37***	-.34***	-.34***
	(.06)	(.06)	(.06)	(.06)
Gender	.02	.03	.01	.01
	(.70)	(.71)	(.71)	(.72)
SES	-.11	-.11	-.10	-.10
	(.18)	(.18)	(.18)	(.19)
Education	.20*	.20*	.19*	.18*
	(.13)	(.13)	(.13)	(.13)
Health	.05	.05	.08	.08
	(.38)	(.38)	(.39)	(.39)
Breadth		-.02		
		(.13)		
Frequency				.05
				(.02)
Constant	16.57**	16.86**	14.43***	14.12***
	(4.89)	(5.04)	(5.02)	(5.06)
N	145	145	141	141
R^2	.18	.18	.15	.15
ΔR^2	.18***	.00	.15***	.00

Note. For the variable gender, 0 = male, 1 = female. Standardized coefficients are reported and standard errors are in parentheses. Cases were deleted listwise.
**p* < .05, ***p* < .01, ****p* < .001

Social	Light-intensity physical	Moderate/high-intensity physical	Cognitive
Visiting with friends or family (other than those you live with) [a]	Do light work around the house (such as sweeping or vacuuming) [a]	Dance (such as square, folk, line, ballroom) (do not count aerobic dancing here) [b]	Use a computer [a]
Go to the senior center [a]	Walk leisurely for exercise or pleasure [a]	Play golf carrying or pulling your equipment (count walking time only) [b]	Do woodworking, needlework, drawing, or other arts and crafts [a]
Do volunteer work [a]	Do light gardening (such as watering plants) [b]	Play doubles tennis (do not count singles) [b]	Play cards, bingo, or board games with other people [a]
Attend church or take part in church activities [a]	Do stretching or flexibility exercises (do not count yoga or Tai-chi) [a]	Do heavy work around the house (such as washing windows, cleaning gutters) [a]	Shoot pool or billiards [b]
Attend other club or group meetings [a]	Walk to do errands [a]	Do heavy gardening (such as spading, raking) [a]	Play a musical instrument [b]
Attend a concert, movie, lecture, or sporting event [a]	Do general conditioning exercises such as light calisthenics or chair exercises (do not count strength training) [b]	Jog or run [b]	Read [a]
	Play golf riding a cart (count walking time only) [b]	Walk uphill or hike uphill (count uphill only) [a]	Work on your car, truck, lawnmower, or other machinery [a]
	Do yoga or Tai-chi [b]	Walk fast or briskly for exercise (do not count walking leisurely or uphill) [a]	
		Ride a bicycle or stationary cycle [a]	
		Do other aerobic machines such as rowing, or step machines (do not count treadmill or stationary cycle) [b]	
		Do water exercises (do not count other swimming) [b]	
		Swim moderately or fast [b]	
		Swim gently [b]	
		Do aerobics or aerobic dancing [b]	
		Do moderate to heavy strength training (such as hand-held weights of more than 5lbs., weight machines, or push-ups) [a]	
		Do light strength training (such as hand-held weights of 5lbs. or less or elastic bands) [a]	
		Play basketball, soccer, or racquetball (do not count time on sidelines) [b]	
		Skate (ice, roller, in-line) [b]	
		Play singles tennis (do not count doubles) [b]	
		Do other type of physical activity not previously mentioned (please specify) [c]	

Figure 1.1
List of Items in CHAMPS Questionnaire
Note. [a] Indicates activities were included in the analyses, [b] indicates activities were left out of the analyses because 75% or greater of participants reported no engagement in that activity, [c] indicates activity was left out of analyses because it did not contribute additional information.

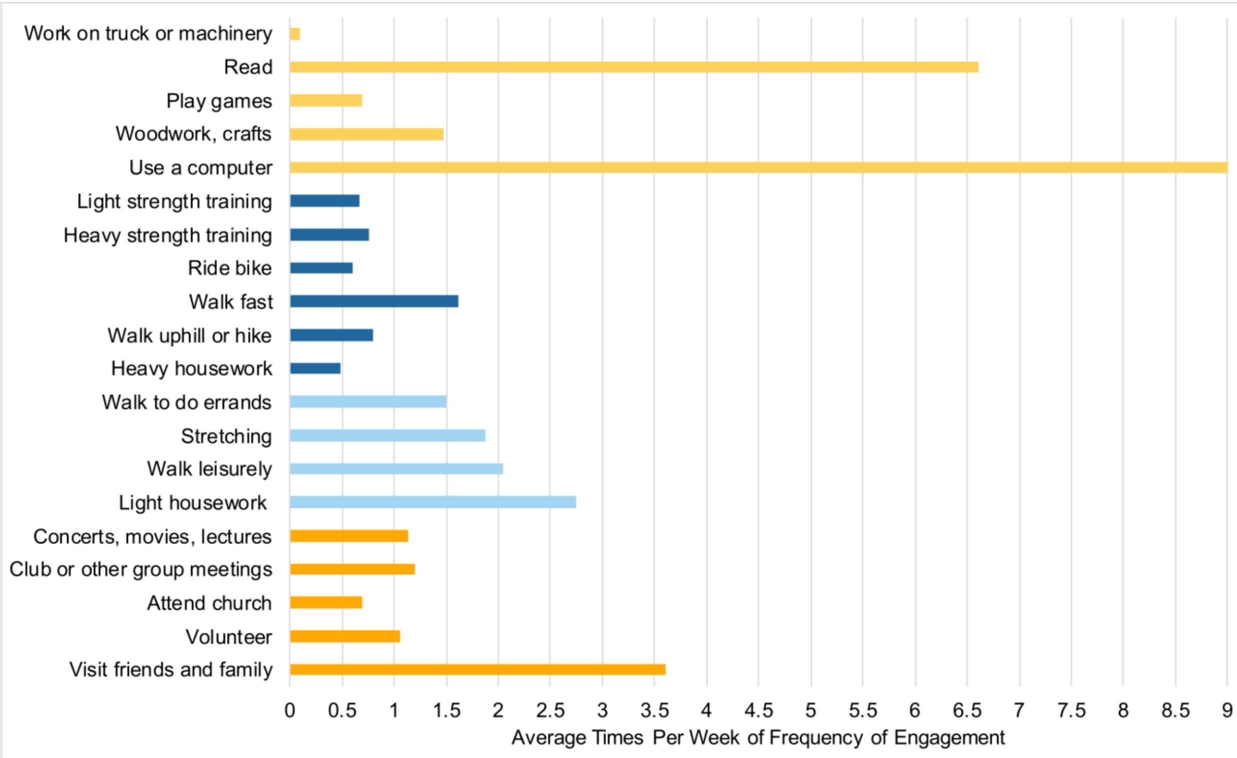

Figure 1.2

Average Times Per Week of Engaging in Activities

Note. Cognitive activities are in light orange, moderate/high-intensity physical activities in dark blue, light-intensity physical activities in light blue, social activities are in dark orange.

Study 2

The Association Between Activity Engagement and Cognitive Performance Amongst Healthy Older Adults: A Meta-Analysis

Weaver, A. N., Wan, S., Vodyanyk, M., & Jaeggi, S. M. (2023). Activity engagement and cognitive performance in older adulthood: A meta-analysis

To be submitted to Psychological Bulletin

Introduction

Individuals of ages 65+ are estimated to make up 1.6 billion people worldwide by the year 2050, more than roughly 16% of the global population (United Nations, 2023). While people are living longer than ever before, there is debate as to whether we are simultaneously living healthier (Jagger et al., 2016; Jivraj et al., 2020; Zheng et al., 2020). It is well established that aging is associated with declines in cognitive functions which has downstream effects on individuals' everyday lives (e.g., decision making, functional independence, etc.). Moreover, some individuals may develop more severe forms of cognitive decline such as Alzheimer's disease and other dementias that greatly impact their everyday functioning. Living longer is not only associated with health-related and economic costs, but also the cost of the individual's and their families' mental well-being. Taking preventative measures early on are efforts that have the potential to mitigate much greater health, social, and financial costs in the future.

A growing body of research on aging and longevity suggests that activity engagement, a modifiable lifestyle factor, may delay and mitigate the effects of age-related cognitive decline and even dementia as a result of a robust cognitive reserve (Scarmeas & Stern, 2003). Thus, understanding the impact of modifiable preventative measures, i.e., activity engagement, is imperative to directing recommendations for health-related behaviors. In this study, we refer to activity engagement as a "diverse behavioral repertoire" (Parisi et al., 2009), frequency of participation.

Various studies have reported positive associations between activity engagement and cognitive performance (Borgeest et al., 2020; Change et al., 2010). However, there have been inconsistent findings in the literature with some studies reporting little to no relation between engagement and cognitive performance (Aartsen et al., 2002; Sposito et al., 2015). As such, the purpose of the current study is to estimate the overall association between activity engagement and cognitive performance amongst healthy older adults using a meta-analytic approach. In addition, we aim to identify potential moderators of such association. We start with reviewing the literature on how different types of activities may play a role in older adults' cognitive functioning. We focus broadly on social, cognitive, and physical activities as these are the most commonly used categorizations in the literature (Sposito et al., 2015). Then, we present meta-analytic evidence of the association between activity engagement and cognitive performance amongst healthy older adults. Lastly, we discuss the implication of our findings to work on optimal aging and provide future directions.

Cognitive Activities and Cognitive Functioning

Cognitive, or intellectually demanding activities are a lifestyle factor that have been found to be associated with maintained cognitive performance amongst older adults. For example, activities such as playing board games, reading, or playing musical instruments have been associated with maintained cognitive functions as well as reduced risk of dementia in aging (Arab et al., 2021; Böttcher et al., 2021; Dodge et al., 2008). Specifically, Arab and colleagues found that engaging in intellectually challenging activities such as pursuing educational opportunities, art, music, or taking evening classes was related with improved long-term outcomes of memory in adults over the age of 50. These results were most apparent in those who engaged in such activities for at least four years. Although the mechanisms of these outcomes are not fully understood, the authors argue that cognitive activity engagement might tap into broad networks that are critical for healthy cognitive functioning, and as such, induce neuroplastic changes in the brain through the recruitment of wide-scale neuronal pathways (Arab et al., 2021). Long-term activity engagement might strengthen these neuronal networks, thus translating to better performance in more general cognitive tasks. Complex cognitive activities such as playing music involve the integration of motor, sensory, emotional, and social factors in addition to tapping into cognitive functions. This multisensory integration could further promote brain plasticity in older adults (Böttcher et al., 2021; Lappe et al., 2008). Notably, multisensory integration has shown to facilitate performance in various cognitive areas outside of the specific practiced activity (Pahor et al., 2021). In older adults, frequently engaging in cognitive or intellectually stimulating activities have been associated with cognitive performance in domains such as language, attention, and memory (Iizuka et al., 2021).

Across studies, there have been inconsistencies found for the association between cognitive activity engagement and cognitive performance. While many have found a positive relation between engagement and performance, others such as Sposito and colleagues found no relation between intellectual activities of daily living and memory as assessed by the Mini-Mental State Exam (MMSE) -- a dementia screening instrument (Sposito et al., 2015). Aartsen and colleagues reported that higher cognitive performance over a 6-year period was not associated with social, physical, or cognitive activity after controlling for factors such as age, gender, education, and functional ability in their models (Aartsen et al., 2002). Conversely, they found that information processing speed was associated with intellectual and creative activities. Although causality could not be inferred from this study, they reported that their finding of the relation between processing speed and activity engagement were in line with previous findings (Hultsch et al., 1999). Still, it is unclear whether limitations in such activities lead may have an association with cognitive decline. Additionally, others have reported that amongst individuals with higher education, activity engagement was not found to be associated with cognitive performance as assessed by the MMSE in participants 1 SD above the mean no education.

However, for those who scored 1 SD below the mean on education demonstrated a significant relation between leisure activities and cognitive performance (S. Park et al., 2018). Similarly, Weaver and Jaeggi reported that across social, physical, and cognitive activities, no activity category was found to be predictive of global cognitive performance in a highly educated population, but rather, age and years of education were found to be the main predictors (Weaver & Jaeggi, 2021). Overall, these results illustrate the importance of further investigating whether and to what extent intellectually demanding activities are associated with increased cognitive performance in older adults.

Physical Activities and Cognitive Functioning

Amongst various lifestyle activities, physical activity seems to have the most representation in the literature, supporting that engaging in physical activities is beneficial in older adult health, well-being, and cognitive functioning (Taylor et al., 2004; Vogel et al., 2009). Not only are there clear cardiovascular benefits associated with physical activity, but it has also been demonstrated that physical exercise has the potential to reduce risk of chronic disease (Buchner, 2009; Sattelmair et al., 2009). Physical activities such as aerobic and strength exercise have shown to be important in the protection against cognitive decline and dementia by demonstrating effects on brain structure, function, and connectivity (Colcombe et al., 2006). Additionally, physical activity has been found to provide cognitive benefits in areas such as working memory, processing speed, cognitive flexibility, and attention (Chang et al., 2012; Kramer & Erickson, 2007). Newson and Kemps found that both cognitive and physical activities were associated with higher cognitive performance, however, cognitive activities were a better predictor of performance on higher-level cognitive tasks (Newson & Kemps, 2006). Physical activity intensity (i.e., light, moderate, and vigorous) has been proposed as a potential reason for differences seen in cognitive performance amongst older adults (Arab et al., 2021; Taylor et al., 2004).

Despite the literature generally indicating a positive relation between physical activity engagement and cognitive functions, a few studies have found only small or no association. In a meta-analysis, Chang and colleagues reported an overall positive small effect between physical exercise and cognitive performance (Chang et al., 2012). However, these results were not exclusive to older adults as their sample ranged from children to older adults with the most effects reported from young adults. Thus, it remains unclear if the magnitude of this relation may differ for older adults. Similarly, Weaver and Jaeggi (2021) found no association between physical activity and cognitive performance. Although they discuss their measurement of activity engagement as a potential limitation, overall, they concluded that there may be little to no relation seen in activity engagement and cognitive performance amongst individuals who are generally highly engaged, especially if they have engaged in these activities over a longer period of time.

Even though various studies have suggested that the relation between physical exercise and cognitive functioning may be due to direct biological effects as induced by physical activity, the exact mechanisms remain to be clarified. For example, physical exercise has shown to increase cerebral blood flow and oxygenation and has been associated with neurogenesis, which in turn, may induce positive effects on cognition (Mandolesi et al., 2018). Others have proposed that exercise may have more indirect effects of improving areas of health such as reducing stress and risk of disease, which also impacts cognitive functioning (Kramer & Erickson, 2007).

Overall, physical activities have been found to be beneficial to cognitive performance. However, to what extent their protective benefits may provide, and which cognitive domains benefit most in relation to other activities such as social and cognitive activities remain unclear.

Social Activities and Cognitive Functioning

Research has consistently shown that social engagement or social activities are associated with a variety of benefits, including cognitive functioning. Social engagement may be beneficial to cognitive performance through means of having opportunities to engage in cognitively stimulating activities (Brown et al., 2012). For example, having a supportive social circle that encourages new learning or playing cognitively challenging games could foster cognitive function as a result of engaging with that social circle. Further, others have suggested that because social engagement/activities provide beneficial effects through multiple pathways, these may in turn overlap with those that simultaneously affect cognition, as cognitive activity may mediate this relation. Consistent with this hypothesis, Brown and colleagues found that amongst their participants that displayed a greater than usual increase in their social participation also displayed a greater than usual increase in their performance on cognitive tasks (Brown et al., 2012; Seeman et al., 2001). However, the exact mechanisms underlying/driving the relation between social activities and cognition remain unknown.

Still, having social connections and engaging in various social activities have been reported to be particularly important for older individuals as they may provide protective benefits against negative effects associated with aging (Huxhold et al., 2014). A longitudinal study following individuals over the course of 12 years reported that being engaged with more social activities was associated with less cognitive decline in areas such as episodic memory and working memory amongst individuals when followed-up at a 5.2 year mark (James et al., 2011).

In addition, activities such as volunteering have been found to be associated with lower cognitive decline in areas of executive functioning and language (Corrêa et al., 2020; Tan et al., 2006).

The benefits of social engagement seem to be additive, as studies examining the effects of less frequent social engagement or perceived absence of engagement have been found to be predictive of an increased risk of cognitive decline (Zunzunegui et al., 2003). Although there is evidence to support the association between social engagement and cognitive performance, findings are inconsistent in regards to the overall protective benefits they may provide as some studies report negative associations, observed maintenance effects may depend on the quality and type of social engagement, and may differ by gender (Kesse-Guyot et al., 2012; Köhncke et al., 2016; Y. Lee & Jean Yeung, 2019; Sims et al., 2014). Overall, there is considerable variability in findings, and it remains unclear if there is a direct association between social engagement and cognition, or whether the relation is mediated by other factors.

Findings such as these included in this review highlight the nuances in activity engagement as they may provide differential effects in cognitive performance and the importance of further investigating this observed association. It is important to note that in terms of investigation of individual activity engagement categories (i.e., social, cognitive, and physical), the relation between physical activity and cognitive performance have much greater support from interventional studies in comparison to the other activity categories (this does not include interventional studies of individual activities such as playing an instrument). For instance, a previous meta-analysis including 19 studies with 23 interventions suggested that exercise training may delay the decline in cognitive function that occurs in individuals who are at risk of or have Alzheimer's disease (Panza et al., 2018).

Current Study

Although many studies have reported positive associations between various types of activity engagement (e.g., social, physical, cognitive, etc.) and cognitive performance, several studies have reported a negative or no association between the two. Further, studies vary greatly in their measurement of activity engagement as well as the cognitive domains assessed. Given the inconsistencies found amongst studies, the magnitude of the relation between activity engagement and cognitive performance remains unclear. Having a greater insight of the overall association and the extent to which they might be moderated by other factors may serve as a tool to better understand the complexities of the aging process and inform interventional work to target the cognitive domains that show the most promise, as well as what populations might benefit most.

The current study aims to address these gaps through systematically searching literature and synthesizing findings on the associations between social, cognitive, and physical activity engagement and cognitive performance amongst healthy older adults. Using meta-analytic techniques, we aim to quantify the relation between various areas of activity engagement and cognitive performance measures using Pearson's correlation coefficients as our measure of effect size. We opted to only include studies reporting Pearson's correlations (as opposed to intraclass correlation coefficient or Spearman's correlation) as we were most interested in the linear relation between activity engagement and cognitive performance. As such, there are various studies in this area that were not included in this meta-analytic review. In addition, we examined the potential moderating effects of age, activity category, timeframe of retrospective assessment of engagement, and cognitive domain. This analysis was guided by the following research questions: 1) Among older adults, to what extent are lifestyle activities associated with cognitive performance? 2) To what extent does the relation between activity engagement and cognitive performance vary by age, activity category, timeframe of retrospective assessment, cognitive domain? This study seeks to contribute to the expanding work in optimal aging by quantifying the association between activity engagement and cognitive performance amongst healthy older adults.

Moderators of interest

We explored a variety of potential moderators to examine the potential strength of the relation between our independent and dependent variables. First and foremost, we focused on age given that our population consisted of older adults and the considerable individual differences in cognitive aging. We hypothesized that there may be a difference between younger-older adults, and older-older adults as age could be an important factor related to physical abilities, time, income, and more that impact the types of activities one engages with (Agahi & Parker, 2005; Bielak, 2010). Education was also included as a moderator as education has been found to be associated with higher cognitive performance and has been hypothesized to contribute to individual differences in developed cognitive skills that last into older adulthood (Lövdén et al., 2020; W. Zhang et al., 2019). Activity category was another moderator of interest. We hypothesized that if there is a relation between activity engagement and cognitive performance, it may be due to the specific type of activity, and in this case, we believed it would be physical activities as physical activity has been greatly associated with cognitive maintenance in later life (Yaffe et al., 2009). Time frame of retrospective assessment was also included as a moderator given that studies have varied in the amount of time they ask participants to recall how often they engage in activities. For example, some studies ask individuals to report what activities they engaged in within the previous two weeks, others ask them to recall over the past few months, and others over a span of a year or more, etc. It is possible that we may only see a relation between activity engagement and cognitive performance after individuals have engaged with these activities for a longer timeframe (D. C. Park et al., 2014; Small et al., 2012). We included performance index (i.e., whether the assessment measured accuracy/correct responses, reaction time/time, adjusted scores, other, and missing) as a moderator, as we hypothesized that differences in how a cognitive area was assessed could potentially moderate the relation. We believe this could be important because the relation between activity engagement and cognitive performance may be more sensitive to assessments of accuracy vs reaction time for example. Lastly, we included cognitive domain as a moderator, hypothesizing that the relation between activity engagement and cognitive performance might be especially pronounced in fluid cognitive abilities. From there, we broadly categorized cognitive domain into fluid and crystallized abilities which are described in more detail in the method section. We hypothesized that more malleable abilities may play a role in maintaining high cognitive performance, especially for individuals that are highly engaged.

Method

Study Selection

To extract studies investigating the relation between activity engagement and cognitive performance amongst older adults, we conducted a systematic literature search using the PsycInfo database. Within PsycInfo, we searched titles, abstracts, and keywords using the following keywords and Boolean operators: (cognitive OR cognition) AND (engagement OR activity) And (aging OR "older adults"). Using the PsycInfo filters, we restricted our search to include all papers up to the date February 21st, 2023, with participants aged 65+, human, and in English, and to exclude letters and editorials, reviews, books, columns/opinion and comments/replies, interviews, qualitative studies, and focus groups.

The literature search identified 3,694 papers. Following PRISMA guidelines (Moher et al., 2009), article titles, abstracts, and keywords were screened to identify papers that would meet our inclusion criteria. See Figure 1 for an illustration of the study screening process. One author was contacted and asked to provide correlations and additional relevant information for inclusion in our study (cf., Jeon et al., 2022). Upon screening these papers, 941 were selected to be independently examined in closer detail. Of the 941 papers, 45 were selected for coding, and 35 were included in the final analysis including 42 independent samples, 45,619 participants, and 484 effect sizes. The average age of individuals was 72.92 years of age SD = 4.73, with an average education level of 13.29 years, SD = 2.72.

Inclusion and Exclusion Criteria

We included studies that met the following criteria. First, samples of participants should have an average age of 65 or older and were considered a typically healthy population (no diagnosis of neurological diseases, cognitive impairments, etc.). Second, studies had to include a quantifiable index of activity engagement assessing at least one category of activity engagement (e.g., social, physical, etc.), and at least one measure of cognitive performance (e.g., processing speed, working memory, episodic memory, etc.), as well as a reported zero-order correlation between these two variables. Studies that focused on one specific activity, such as examining the effects of playing a musical instrument or church attendance alone were not included as we were interested in examining studies that looked at activity engagement as a whole rather than the impact of individual activities. Studies utilizing Activities of daily Living (IADLs) as the primary assessment of activity engagement were selected for coding but were not included in the final analysis. Similarly, studies utilizing the MOCA or MMSE as the primary assessment of cognition were selected for coding but were not included for the final analysis as these assessments are common screening tools for cognitive illnesses and impairment and were likely close to ceiling in healthy populations, which was the focus of the present analysis. If studies were interventional, the pre-test or baseline correlations were coded if the sample met the inclusion criteria. Lastly, only peer-reviewed studies were included, and dissertations and conference presentations were excluded (for details, see Figure 1).

Coding

Members of the team created a codebook to reference for clear objective coding of all variables and to assist with reproducibility of the analyses. After studies were selected for the final coding, every article was independently coded by at least two members of the team. Percent agreement between coders was 97%. Coders met weekly to discuss the individual coding of studies and to resolve any disagreements.

Study characteristics extracted were authors and year of publication, the sample size, and whether it was primary or secondary data, waves of assessment, and effect sizes (zero-order correlations). Participant characteristics extracted were mean age, country, and years of education. We also coded socioeconomic status (SES), however, most of the studies included did not provide enough information, so we decided to not include this variable in the analysis; however, we were able to include years of education, which is often considered as a proxy for SES. Assessment characteristics extracted were the names of the activity engagement assessment, the type of activity assessed (e.g., social, cognitive, physical), examples provided of individual activities (e.g., volunteering, board games, hiking), and the index of assessment (e.g., frequency, variety). For cognitive assessments, we extracted the names of the cognitive assessment, the cognitive domain assessed (e.g., executive functioning, episodic memory, perceptual speed), and the performance index of assessment (e.g., accuracy, reaction time).

Pearson's r was converted to Fisher's z and variance was calculated using the sample sizes from each study.

Type of Activity Engagement

The type of activity engagement was one of our moderators of interest. Due to variety in categorizations of activity engagement across studies, for analyses, we coded the areas assessed broadly as either social, physical, cognitive, combined, or other in a separate column. Activities that broadly represented one category more than others, were coded as that category (i.e., social, physical, or cognitive). For example, volunteering and participating in clubs were commonly reported as social activities. Board games and playing musical instruments were commonly reported as cognitive activities, and physical activities had a wide range of potential activities but included examples such as walking and sports. If the activities were representative of more than one category, they were coded as "combined". Activities were coded as "other" if the original categorization did not clearly fit into any other category (e.g., no examples reported or activities such as watching television) or if the activities were primarily activities of daily functioning/maintenance (e.g., doing laundry, grocery shopping), or typically considered as passive engagement (e e.g., listening to the radio, and passive information processing). We primarily relied on the original categorizations provided by the study authors. However, if a category did not clearly fit into one of our coding categories, the original paper was referenced for example activities within their assessment to help in the decision making. For example, if a study categorized a cluster of activities as "experiential", the paper was referenced for whether these activities were intended to assess underlying social, physical, or cognitive activities, and if this was unclear, the individual activities were evaluated and categorized based on the categorization of other studies included in the meta-analysis.

Cognitive Domain

Cognitive performance domain assessed was another moderator of interest. Because studies varied in the cognitive areas assessed, we decided to code these areas into broader measures of fluid or crystallized abilities in separate columns. Again, we used the original categorizations and assessments provided by the studies whenever possible. For any area or assessment serving as a measure of vocabulary or general knowledge, we coded these as crystallized. For any area or assessment serving as a measure of working memory, learning, reasoning, or other fluid cognitive abilities were coded as fluid (Blair, 2006).

Statistical Analysis

Analyses were conducted within R utilizing the metafor and ClubSandwich packages (Pustejovsky, 2023; R Core Team, 2020; Viechtbauer, 2010). Because we collected multiple effect sizes within each study, we chose to use a correlated and hierarchical effects model (multivariate model) to account for within study dependence (Pastor & Lazowski, 2018; Pustejovsky & Tipton, 2022). We first fitted our multivariate model with metafor by using the restricted maximum likelihood estimation method (REML). We assumed a correlation of rho = 0.6 for effect sizes within studies. Then we used the robust variance estimation (RVE) method implemented in ClubSandwich to correct our estimation for potential misspecification. We ran several sensitivity analyses with varying values of the assumed correlation (rho) between 0.2 and 0.8. To address research question 1, we first estimated the average effect size between activity engagement and cognitive performance. To address our second research question, separate meta-regressions were used for moderation analyses with each moderator category of interest serving as the predictors. Age and education were treated as continuous variables and all other moderators were treated as categorical variables.

Data, R script, and supplementary materials (e.g., full list of all studies included) are available on the Open Science Framework (https://osf.io/8pu24/?view_only=d3bdae7e23484638a2ae871e32b8618e)

Results

Overall Model

The RVE model included 42 unique samples and 484 effect sizes. Correlations ranged from r = -.5 to r = .53. The results from the CHE model were as follows (r = .16 95% CI = [0.12, 0.20], p < .001). Sensitivity analyses in adjusting the assumed correlations within studies revealed similar results [provide these sensitivity analyses / data here]. Thus, the results suggest that activity engagement has a small but significant association with cognitive performance amongst healthy older adults. The 95% prediction interval for the potential distribution of effect sizes across studies is [-0.14, 0.45], suggesting that there is considerable heterogeneity in the results across studies. As such, we proceeded with conducting moderation analyses to identify if the effect sizes between studies would differ by our variables of interest (i.e., age, activity category, timeframe of retrospective assessment, cognitive area index, and cognitive performance area).

Moderators

Age

The magnitude of the relation between activity engagement and cognitive performance differed as a function of mean age (b = .01, 95% CI = [0.01, 0.02], p < .01). For exploratory purposes, we wanted to see how the overall effect size would change was by subsetting the data by mean age lower and higher age groups. To do so, age was divided into two categories, “younger old” ≤ 71.90 and “older old” >71.90 using the median of the data as a cut off to be placed in either category. The overall effect for younger old was (b = 0.13, 95% CI = [0.07, 0.19], p < .01) and the overall effect for older old was (b = 0.18, 95% CI = [0.13, 0.23], p < .001). Subsetting the data into "younger old" and "older old" did not change the overall effect size drastically, however, the older old subset resulted in a slightly larger effect size.

Education

Years of education was not found to moderate the relation between activity engagement and cognitive performance (b = -0.01, 95% CI = [-0.03, 0.01], p = .21).

Activity type

Activity type was treated as a categorical variable and dummy codes were created for social, physical, cognitive, combined, and other. The dummy codes created were put into a meta-regression model except for social activities which served as the reference category (see Table 2). Social activities were selected as the reference group for ease of interpretation. Overall, activity type was found to moderate the relation between activity engagement and cognitive performance ($F_{4, 479}$ = 14.92, p < .001). Cognitive and combined activities were found to be significantly different from social activities (b = .13, 95% CI [0.06, 0.20]; b = .12, 95% CI [0.02, 0.21]). Specifically, cognitive and combined activities are associated with .13 and .12 increase in cognitive performance in comparison to social activities. However, physical and other activities were not found to be significantly different from social activities (b = .05, 95% CI [-0.07, 0.16]; b = .08, 95% CI [-0.06, 0.21]).

Time of retrospective assessment

We used the activity engagement questionnaire provided by the studies included to code the time frame in which participants were asked to recollect their overall engagement. Studies were grouped into hours/day/week, days, weeks, months, years and not specified. In the meta-regression model, hours was used as the reference category for ease of interpretation. Time of retrospective assessment was found to moderate the relation between activity engagement and cognitive performance ($F_{5, 461} = 7.03$, $p < .001$). Months was found to be the largest contributor ($b = .17$) in comparison with hours. However, a cluster analysis to account for dependencies revealed no significant differences between categories (see Table 3).

Performance index

We coded the type of dependent variable, performance index, into categories of accuracy/correct responses, reaction time/time, adjusted scores, other, and missing. We referred to the original study's assessments used to determine these categorizations. Accuracy served as the reference category in the meta-regression mode. Overall, performance index was not found to moderate the relation between activity engagement and cognitive performance ($F_{3, 462} = 1.17$, $p = .32$) and adjusted scores were dropped from the model (see Table 4).

Cognitive domain

We coded the cognitive domains into fluid and crystallized. We referred to the original study's assessments and intended cognitive areas measured to determine these categorizations. Measures of working memory, overall executive functioning, and learning were coded as fluid abilities. Measures of vocabulary and generalized knowledge were coded as crystallized. Assessments were coded as "mixed" if any global cognitive measure was not specified or contained both fluid and crystalized assessments, or if the measures used were unclear. In the meta-regression model, fluid abilities served as the reference category. Overall, cognitive domain was not found to moderate the relation between activity engagement and cognitive performance ($F_{2\ 481} = 0.70$, $p = .50$) (see Table 5).

Exploratory Analyses

Comparing similarities and differences

For exploratory purposes, we were interested to see if there were any systematic similarities or differences between studies with the largest and smallest effect sizes to evaluate what factors may be most likely drivers of the relationship. To do so, we organized the effect sizes from smallest to largest (r = -.5 to r = .53) and split the data into quartiles (cf. Table 1). We chose to split the data in this manner to have a fairly equal of number of effect sizes for comparison as there were more positive effect sizes in the sample in comparison to negative (371 effect sizes > 0 and 113 effect sizes ≤ 0). We compared 113 larger effect sizes (25 different studies) with 129 smaller effect sizes (18 different studies). Nine studies were shared between both extremes, meaning they shared both larger and smaller effect sizes that were included in the upper and lower quartiles. Amongst the larger effects sizes, most were represented by cognitive activities (e.g., reading, playing games, learning languages), primarily assessed fluid abilities, had an overall median age of 72.5 years, and were from studies with participant samples of individuals in countries outside of the United States (such as Spain, Sweden, Netherlands, and Canada; 16 out of 24) (see Figure 2). Amongst the smaller effect sizes, most were associated with social and physical activities (e.g., attending church, volunteering, and sitting activities), primarily assessed fluid abilities, had an overall median age of 71.9 years, and were from studies with participant samples of individual in the United States (8 studies) and other countries (10 studies) (cf. Figure 3).

Publication Bias

Studies reporting null findings are less likely to be published in comparison to those reporting statistically significant findings (Franco et al., 2014). As such, studies included in systematic reviews and meta-analyses have the potential to be positively biased. Funnel plots are one method of assessing bias (Lin & Chu, 2018). We first used a funnel plot of the distribution of effect sizes as a visual of publication bias and can be seen on Figure 4. In this figure, effect sizes were plotted against standard error and the vertical line in the center of the funnel is the location of the estimated overall effect. In the absence of bias, effect sizes should be symmetrical across the funnel shape. An indication of possible bias is observed when there is asymmetry of the effect size distribution. Examining our funnel plot, there was some asymmetry observed, as such, we proceeded to assess publication bias quantitatively utilizing the egger sandwich test for funnel plot asymmetry with dependent effects (Rodgers & Pustejovsky, 2020). This is done by RVE meta-regression where the z-transformed effect size is regressed on its standard error. This model did not reach statistical significance, suggesting no evidence of publication bias, $z = -.28$, $p = .65$.

Discussion

The goal of the present study was to determine the extent to which activity engagement and cognitive performance are related amongst healthy older adults and to identify potential moderators using a systematic review and meta-analysis. Our final sample consisted of 35 studies with 42 unique samples and 484 effect sizes included in our analyses.

Our meta-analysis revealed that there was a small, but significant relation between activity engagement and cognitive performance. Age was found to moderate this relation in that the effects were more pronounced in relatively older populations, and in addition, activity type and time of retrospective assessment were significant moderators, with most pronounced effects observed in cognitive, and combined activities (as compared to social and physical activities) and for recalling engagement within months (vs. recollecting engagement over the past few days or years).

It is well documented that cognitive performance declines with age (Murman, 2015; Salthouse, 2009). Thus, it was not surprising that age moderated the relation between activity engagement and cognitive performance in our analyses, and the finding is also consistent with suggestions from other studies that more specifically examine the relation between physical activity and cognitive performance in aging (Etnier & Labban, 2012; Leckie et al., 2012; Stenling et al., 2021). There are likely a couple of reasons why we found a larger effect size for adults categorized as “older old” in our data. Although our sample consisted of “healthy” individuals, it is likely that there is more variability in cognition as individuals become older given the general age-related cognitive decline, and because other health issues are also likely to increase, such as hearing loss, resulting in different rates of decline (Lin et al., 2013; Paganini-Hill et al., 2023; Rapp et al., 2005). This increase in variability could have resulted in a larger effect size for “older old” adults in our analysis. Alternatively, this age range is considered well within typical retirement years, and engaging in more leisure type activities becomes the primary form of cognitive engagement as opposed to one’s occupation (Y. Lee & Jean Yeung, 2019). Additionally, previous work has found that various types of activity engagement, more specifically social engagement, is particularly beneficial for older adults such as those that are roughly 80 years old and above (Krueger et al., 2009). This hypothesis would align with the cognitive reserve theory which suggests that cognition is strengthened with engagement (Stern, 2002). For example, in a study by Lee and colleagues, they found that individuals assessed on areas of cognitive functioning and activity engagement at baseline and after 10 years, those who adopted greater activity diversity were associated with higher cognitive functioning at the 10-

year follow up (Lee, S., et al., 2020). It is possible that individuals categorized as "older old" in our data have had more time to build up their reserve as well as diversify their activity engagement.

Activity type was found to moderate the relation between activity engagement and cognitive performance, but only cognitive, and combined activities were found to be significantly different from social activities, not physical or other activities. This is in line with various studies that generally find a relation between activity engagement and cognitive performance (Bielak et al., 2012; S. Lee et al., 2020). It is important to note that in our data, cognitive activities contribute the most effect sizes numerically (142 total) in comparison with the other activity categories and combined the least (55). Although physical or other activities were not significantly different from the other categories, the activity category "combined" encompassed various individual activities that were also shared with the "physical" and "other" categories. This is suggestive of the importance of engaging in a variety of activities and is in line with other work that has found this relation. For example, Jeon and colleagues found that activity variety was associated with higher cognitive functioning beyond frequency of engagement, especially for activities that included a social component (Jeon et al., 2022). However, they expressed those social activities in their study shared physical and cognitive attributes.

We found the moderating effect of activity type on cognitive performance to be interesting as it suggests that activity type may differentially influence cognitive performance. In our moderation analyses, we found that in comparison to social activities, cognitive activities were (b = .13) larger and was the largest estimate in comparison to the other activity categories. We originally hypothesized that physical activities would drive this association because this activity is more representative in the literature in comparison to cognitive and social activities, especially experimental studies. In addition, physical activities were also well represented in our data (101 effect sizes). Upon closer examination of the individual studies with our exploratory analyses, we found that the strongest effect sizes were most associated with cognitive activities such as reading, playing games, and learning languages. This is consistent with other studies that find this relation (Iizuka et al., 2021). Further, most of the studies included in our sample were suggestive of light physical activity and low energy expenditure such as walking or housework related movement, rather than vigorous exercise. It is possible that individuals in our sample were not reaching an optimal dose of physical activity in order to experience more significant improvements in cognitive performance (Gallardo-Gómez et al., 2022). Further, moderate to vigorous physical activity has been found to be a better predictor of longevity compared with less vigorous physical activity (Lee, I. M., & Paffenbarger, 2000; Paganini-Hill et al., 2011). In our analysis, we only included studies with typically healthy older adults who may generally be more active, and thus, may require more vigorous physical activity in comparison to other populations where light physical activity is beneficial. For example, in a meta-analysis by Groot and colleagues examining physical activity interventions amongst patients with dementia, they found a significant overall effect size of 0.42 (Groot et al., 2016). It is not uncommon in physical activity intervention studies to work with initially sedentary individuals who then engage in much more movement as a result of participating in the intervention. This may result in much larger outcomes with these populations in comparison to individuals who are already regularly active in their everyday lives. This also applies to cognitive activities. It is possible that amongst a typically healthy population, we may not see as strong of an effect size in relation to cognitive performance as cognitive activities may be a regular occurrence in their daily lives in comparison to other populations. For example, a met-analysis of computerized cognitive training amongst adults with mild cognitive impairment by Hill and colleagues found an overall effect size of (Hedge’s *g* = 0.35) (Hill et al., 2017). Although activity engagement types of interventions have been found to be particularly beneficial amongst individuals with mild cognitive impairment or dementia, a variety of these interventions utilize activities that may be considered more sedentary in nature (e.g., individuals begin doing light reading or walking) (Billington et al., 2013; Groot et al., 2016). The cognitive reserve theory would suggest that engagement in activities must require effort and challenge in order to maintain and build the cognitive reserve. These more “sedentary” activities amongst a typically healthy populations do not require the same level of effort as it may for individuals with cognitive impairments, potentially leading to smaller effect sizes.

In contrast to our expectations, we did not find that education moderated the relation between activity engagement and cognitive performance, even though there is an abundance of evidence highlighting it’s relation to cognition as well as its influence on other factors that may impact cognition such as income, health, and health-related behaviors (S. Park et al., 2019; Schneeweis et al., 2014; Stern, 2009). At the same time, our findings are in line with more recent work that has argued that education might not necessarily have a direct effect on cognitive performance in older age or reducing risk of dementia, but rather, it might impact early life individual differences in cognitive skills that carry on into older adulthood (Berggren et al., 2018; Lövdén et al., 2020; Seblova et al., 2021). For example, Lövdén and colleagues propose that although there is strong evidence that education may influence fluid and crystallized abilities, there are various factors that contribute to one’s selection into seeking more education such as existing cognitive abilities and social factors. These factors may lead to individual differences in abilities that are maintained with aging (Lövdén et al., 2020). Additionally, they propose that an individual's environment or life conditions, play a larger role, such as complexity of occupation, where educational experience is leveraged, but not the primary contributor to maintained cognitive functioning in older adulthood. Environments that encourage the regular maintenance and use of cognitive skills that were developed in early adulthood. It is possible that there are additional variables not captured in our analysis indirectly related to education that would have served as better moderators such as occupational complexity or SES. Unfortunately, we were unable to included SES as many studies did not report this information. Given that education quantity and quality can vary greatly, future studies investigating activity engagement should consider assessing additional factors that may be related with maintained cognitive functions, i.e., occupational complexity and SES.

Time of retrospective assessment was found to moderate the relation between activity engagement and cognitive performance, however, none of the categories were significantly different from one another. Although not significantly different from one another, assessing engagement over months produced the largest estimate in comparison to hours ($b = .17$) and the other categories. We assume that the activities participants reported engaging with, in general, for months, were suggestive of more long-term engagement rather than being activities that they may have recently started. This hypothesis would align with the idea that regular engagement with the same activity over time to build the required skills for that activity facilitates brain plasticity and in turn, contributes to one's cognitive reserve which has been found to be associated with higher cognitive performance (Scarmeas & Stern, 2003; Stern, 2002). However, assessing previous engagement in correlational studies relies heavily on retrospective self-reporting, which has its limitations. It has been suggested that individuals may over or under report their overall time spent engaging in activities, and that individuals with higher cognitive ability may more accurately recall their engagement (Parisi et al., 2009). Although there is no way to account for this in our analysis, it is likely that recalling how often one engages with activities over a longer period may be less precise.

Although we did not have a specific hypothesis for performance index as a moderator, this finding is not surprising as accuracy/correct responses was the most frequent in our analytic sample and is a common outcome used amongst certain cognitive assessments (e.g., number of correctly recalled items/words, etc.).

Somewhat surprisingly, cognitive domain was not found to moderate the relation between activity engagement and cognitive performance, however, it was interesting to see in our exploratory analyses that fluid abilities were most associated with the largest and smallest effect sizes in our sample as fluid abilities are age sensitive (Bugg et al., 2006). Our finding is relatively consistent with other work that has found a relation between fluid and crystallized abilities and different categories of activity engagement (i.e., social, physical, and cognitive activities) suggesting that different types of activities recruit different areas of fluid and crystallized abilities (Borgeest et al., 2020). Because fluid abilities are relatively malleable and have the potential to be improved such as working memory or processing speed (Jaeggi et al., 2020), it is possible that one's activity engagement keeps these abilities sharp and vice versa if not utilized often or at all (Hultsch et al., 1999).

Limitations

We note several limitations to our study. First, our goal for this study was to estimate the magnitude of the relation between activity engagement and cognitive performance, not to identify causality. Although there is likely a bidirectional relation, we cannot conclude activity engagement leads to improvements in cognitive performance in our study. However, interventional studies such as those done with physical activities have found improvements to cognitive performance and memory in their training groups in comparison to their control groups (Erickson et al., 2011), which provide compelling evidence for causality. Similarly, targeted cognitive and social activity types of interventions have been found to improve cognitive performance amongst the older adult population (Diaz Abrahan et al., 2021; Otake-Matsuura et al., 2021).

Second, our categorization of activities into the social, cognitive, and physical categories relied primarily on the authors' intended categorization if they were specified at all, and if they were not specified, we categorized them based on the most common categorizations from previous studies. As such, our results should be interpreted with caution. Currently, there is no universally agreed upon way to categorize activities which results in lots of variation across studies. Our chosen categories are intended to be broad for analysis purposes, but we acknowledge that there is overlap across categories for individual activities such as dancing which can easily fit into all three categories (social, cognitive, and physical). Future studies should aim to establish a validated and universally acceptable assessment of activity engagement for older adult populations.

Third, we were unable to examine socioeconomic status as a moderator given that very few studies reported this information. Although education is sometimes seen as a proxy for SES, we did not find education to influence the relation between activity engagement and cognitive performance. Future work in this area should consider reporting socioeconomic status as well as other closely related factors associated with quality of life such as occupation. These factors have been shown to be associated with cognitive performance, and quality of life, and may have an impact on one's activity engagement throughout their lifetime (Bielderman et al., 2015; Lövdén et al., 2020; Migeot et al., 2022; M. Zhang et al., 2015).

Lastly, were various studies on activity engagement and cognitive performance, but we were not able to include them all due to some of our exclusion criteria. For example, we did not include studies that used MMSE or IADL as the measure of cognitive performance or studies that used interclass correlations rather than bivariate correlations. Future studies should examine the overall effect of this relation amongst non-zero-order correlational studies.

Conclusion

Our study provides evidence supporting that there is a small positive relation between activity engagement and cognitive performance among health older adults. Moreover, age, activity category, and time of retrospective assessment can moderate this relation in that cognitive performance increased as participants grow older, was greatest for cognitive activities, with a larger estimate for recalling engagement over months (vs. hours or years). Although the overall effect size was small given the relatively large body of work that is suggestive of a larger relation, there are countless other factors that contribute to optimal aging such as sleep, nutrition, cardiovascular health, and more (Kawas, 2006; Paganini-Hill et al., 2016). Thus, activity engagement is just one piece of a much larger picture of what can contribute to optimal aging. Given that even a small significant effect was found amongst a typically healthy population, the types of modifiable lifestyle factors included in this review may have the potential to impact many individuals. Additionally, as suggested by others, engagement alone may not be enough, but also the variety of activities one engages with as well as greater mental stimulation and effort overall to contribute to higher and maintained cognitive function in later life (Lee, S. et al., 2020; Marquié et al., 2010). Our findings are relevant in guiding future studies that aim to better understand the effects of the activities one engages with over a lifetime and how they may support one of many critical areas of optimal aging. Additionally, we hope these findings will aid in the development and future interventional work.

Appendix B

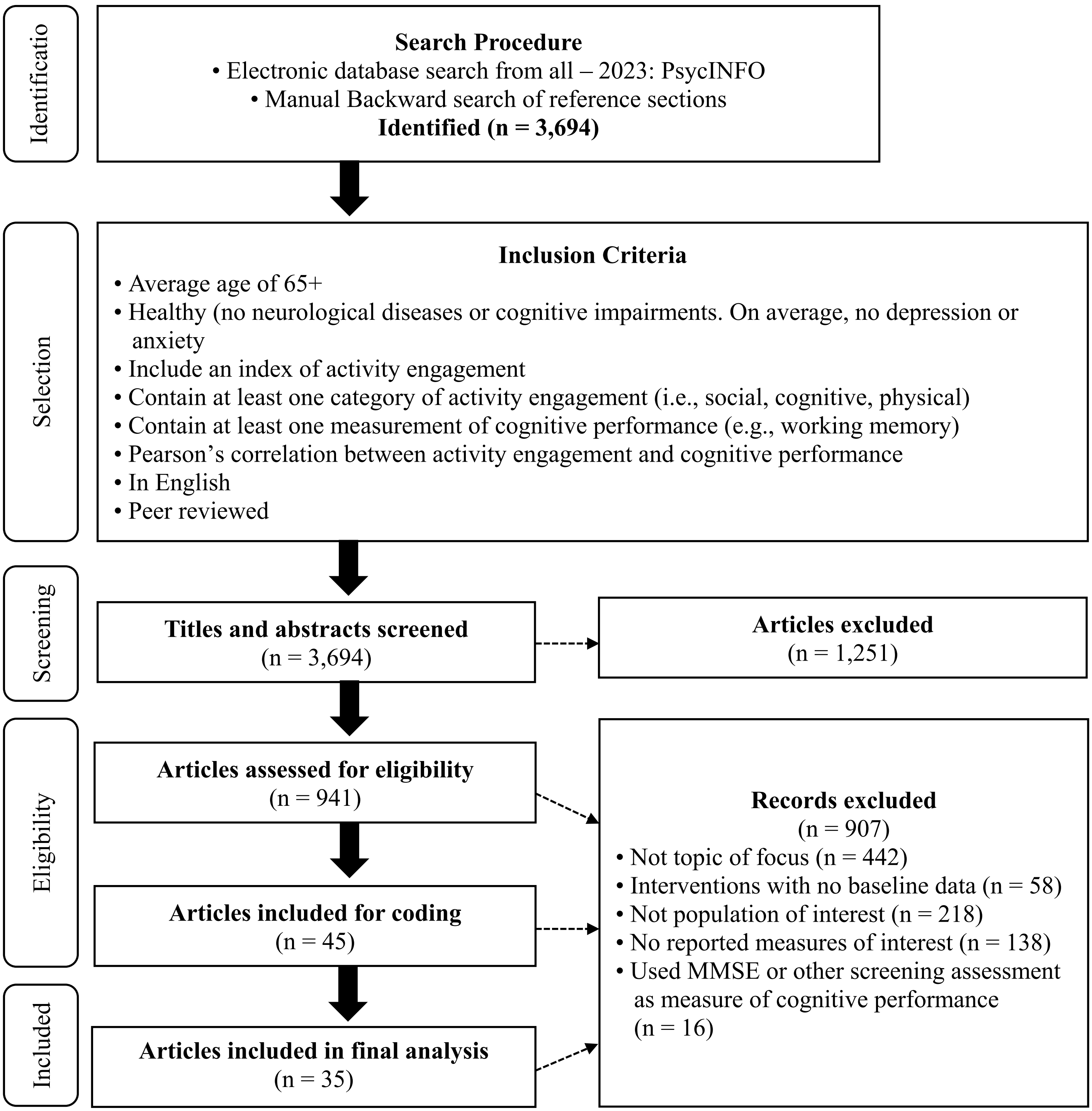

Figure 2.1
Study Selection Flow Chart

Activity Category	Examples of most common activities reported within each activity category
Cognitive	Playing games (e.g., board, word, cards), reading, educational (e.g., learning languages, self-study, activity), arts (e.g., making art, playing music, crafts)
Combined	Unspecified leisure activities
Other	Watching TV, listening to radio, travel, housework
Physical	Any physical activity that raises heart rate, moderate or vigorous activity, sports, heavy housework
Social	Organization or club participation, visiting sports matches or institutions (e.g., museums, cinemas)

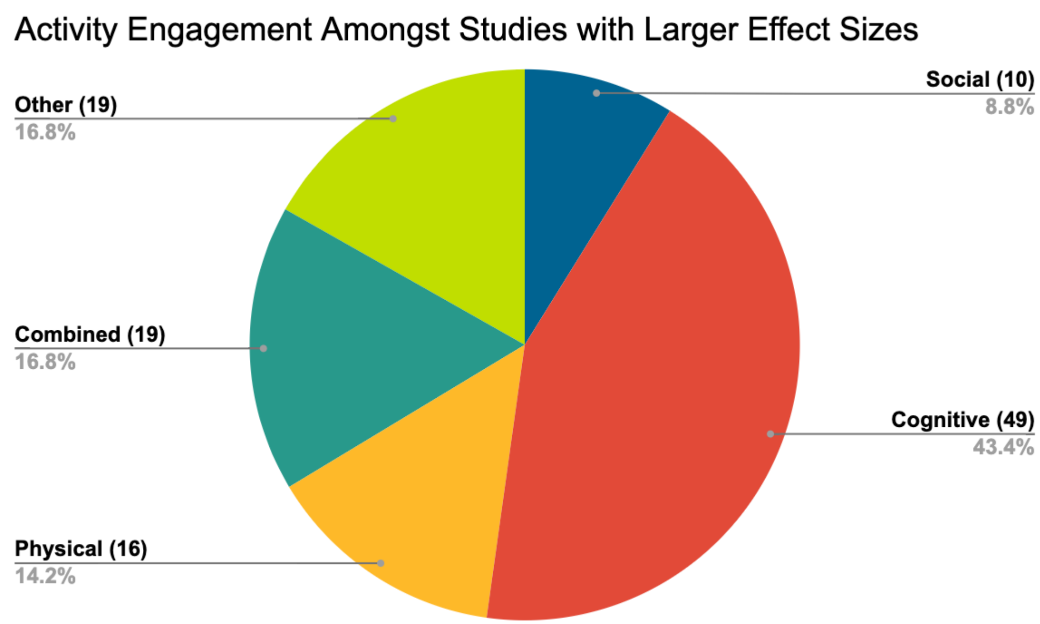

Figure 2.2
Activity Engagement Amongst Studies with Larger Effect Sizes
Note. Activity categories in the table on the left are ordered from most to least representative effect sizes in this quartile. The number in parentheses in the pie chart is the number of effect sizes of that activity category that contributed to this section.

Activity Category	Examples of most common activities reported within each activity category
social	Attending church, meetings, volunteer work
physical	Sitting activities, recreational activities, exercise, low or moderate level of energy activities such as gardening, housework/cleaning, and walking
other	Watching TV, listening to radio/music, looking at art
cognitive	Playing games, writing, reading, & art
combined	Unspecified leisure activities

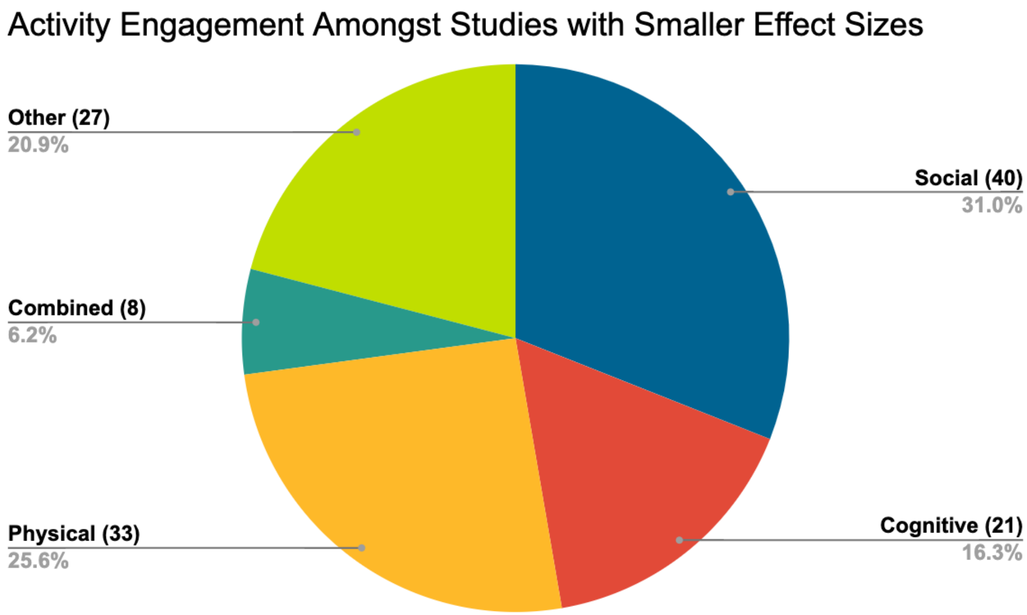

Figure 2.3
Activity Engagement Amongst Studies with Smaller Effect Sizes
Note. Activity categories in the table on the left are ordered from most to least representative effect sizes in this quartile. The number in parentheses in the pie chart is the number of effect sizes of that activity category that contributed to this section.

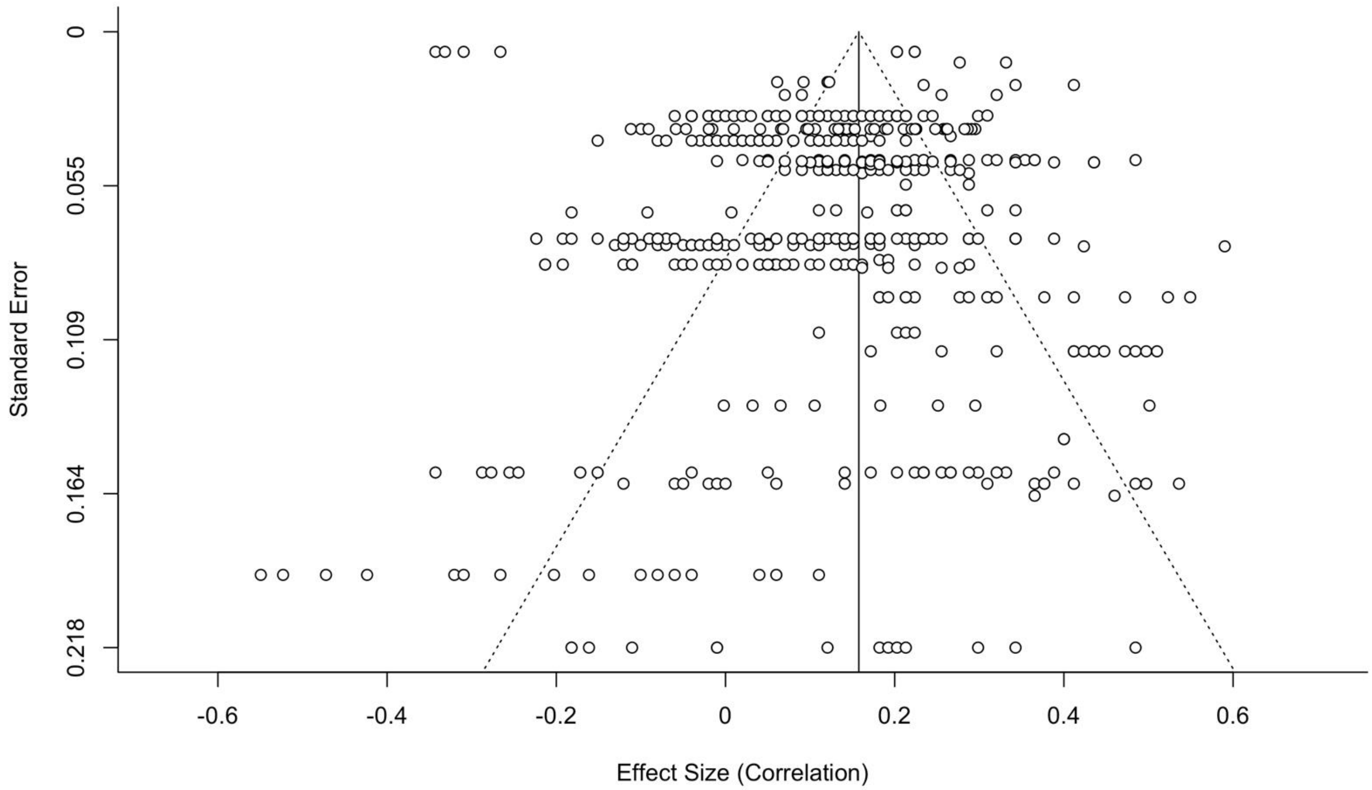

Figure 2.4
Funnel Plot

Table 2.1

Contrasting studies with smallest and largest correlations

Smaller Effect Sizes		Larger Effect Sizes	
Median age	71.9	Median age	72.5
Range	-.50 – .02	Range	.22 – .53
Citation	**Country/Region**	**Citation**	**Country/Region**
Aartsen et al., 2002*	The Netherlands	Aartsen et al., 2002*	The Netherlands
Anstey & Smith, 1999	Australia	Calero-Garcia et al., 2007	Spain
Bernsetin et al., 2022	U.S.	Eskes et al., 2010*	Canada
Bernstein et al., 2023	U.S.	Gajewski & Falkenstein, 2015	Germany
Bourassa et al., 2017	19 European Union countries and Israel	Gow et al., 2012	Denmark
Burzynska et al, 2020	U.S.	Gow et al., 2014	Denmark
Eskes et al., 2010*	Canada	Gray & Gow, 2020*	U.K.
Gray & Gow, 2020*	U.K.	Guiney et al., 2019	New Zealand
Heisz et al., 2014	Canada	Hill et al., 1995	Sweden
Hultsch et al., 1999*	Canada	Hultsch et al., 1999*	Canada
Jeon, Lee, & Charles, 2022*	U.S.	Ihle et al., 2018	Finland
Köhncke et al., 2018	Sweden	Jackson et al., 2019	U.S.
Luo et al., 2023*	Switzerland	James et al., 2011	U.S.
Mueller, Raymond, & Yochim, 2013*	U.S.	Jeon, Lee, & Charles, 2022*	U.S.
Parisi et al., 2009*	U.S.	Krell-Roesch et al., 2019	U.S.
Parisi et al., 2012	U.S.	Luo et al., 2023*	Switzerland
Rebok & Pludge, 2010*	U.S.	Marquine et al., 2012	U.S.
Stumm & Deary, 2011	Scotland	Memel et al., 2016	Eurozone & Israel
		Mueller, Raymond, & Yochim, 2013*	U.S.
		Parisi et al., 2009*	U.S.
		Rebok & Pludge, 2010*	U.S.
		Robitaille et al., 2014	Sweden
		Smits et al., 1995	Netherlands
		Wahl et al., 2013	Germany & Israel

Note. * Denotes study contributed to both smaller and larger effect sizes

Table 2.2

Activity Type Moderating Activity Engagement and Cognitive Performance

Moderator	*b*	*SE*	*t*	95% CI	*p* value
Activity Type (reference group: social activities)	.08	.02	2.43	[.04, .12]	< .05
Physical activities	.05	.05	2.19	[-.07, .16]	.37
Cognitive activities	.13	.03	4.43	[.06, .20]	< .01
Combined activities	.12	.04	2.68	[.02, .21]	< .05
Other activities	.08	.06	1.34	[-.06, .21]	.22

Note. *SE* = standard error, CI = confidence interval. Moderators were dummy coded and entered in one model.

Table 2.3
Time of Retrospective Assessment Moderating Activity Engagement and Cognitive Performance

Moderator	*b*	*SE*	*t*	95% CI	*p* value
Retrospective assessment (reference group: hours)	.11	.08	1.32	[-.15, .37]	.19
Days	.13	.13	.99	[-.24, .50]	.38
Weeks	.01	.10	.21	[-.58, .60]	.96
Months	.17	.09	1.95	[-.07, .41]	.12
Years	.07	.11	.80	[-.16, .30]	.47
Not specified	.02	.09	.21	[-.26, .29]	.85

Note. *SE* = standard error, CI = confidence interval. Moderators were dummy coded and entered in one model.

Table 2.4

Performance Index Moderating Activity Engagement and Cognitive Performance

Moderator	*b*	*SE*	*t*	95% CI	*p* value
Performance index (reference category: accuracy)	.15	.02	7.38	[.11, .20]	< .001
Reaction time	.03	.009	3.57	[.01, .05]	< .01
Other	.004	.02	.18	[-.05, .06]	.86
Missing	.03	.004	6.25	[.02, .04]	< .001

Note. *SE* = standard error, CI = confidence interval. Moderators were dummy coded and entered in one model.

Table 2.5
Cognitive Domain Moderating Activity Engagement and Cognitive Performance

Moderator	*b*	*SE*	*t*	95% CI	*p* value
Cognitive domain (reference category: fluid abilities)	.16	.02	7.81	[.12, .20]	< .001
Crystallized abilities	-.03	.01	-2.04	[-.06, .01]	.11
Mixed abilities	-.01	.08	-.13	[-.20, .18]	.90

Note. *SE* = standard error, CI = confidence interval. Moderators were dummy coded and entered in one model.

Study 3

Following the Sound of Music - Comparing the Effects of Music vs Non-Music Based Interventions on Auditory and Cognitive Processing in Older Adults

Speech in Competition and Musical Engagement

Hearing speech in competition, commonly referred to as speech-in-noise, refers to the ability to extract a target voice from a soundscape of competing voices or sounds (Song et al., 2011). This perceptual ability is critical to communication and is often a common challenge reported largely by older adults. Difficulties understanding speech in competition and its associated frustrations often lead to decreased social interaction, which can ultimately lead to loneliness (Loughrey et al., 2018). Amongst older adults between the ages of 65-71, approximately one in three individuals experience hearing loss, which is among the early indications of Alzheimer's disease and related dementias (ADRD) (Bakhos et al., 2015). Further, hearing loss is frustrating and may lead individuals to stop engaging in activities they may normally enjoy such as socializing with loved ones. Not only does a decrease in social interaction and engagement lead to feelings of loneliness, but it may also lead to less cognitive engagement which can have detrimental long-term effects on one's functional independence, cognitive abilities, and overall quality of life (Lin et al., 2013). For example, in a recent Lancet study, it was reported that mid-life hearing loss accounted for greater variance in development of late life dementia compared to any other factor in their analysis (Orgeta et al., 2019). Given the prevalence of age-related cognitive decline and hearing loss, there is a need for rehabilitation approaches targeting both domains.

Although hearing aids are a common assistance for hearing loss, they do not directly rehabilitate auditory processing abilities. While simply prescribing a hearing aid could be beneficial amongst older adults, however, many individuals with hearing loss, even those with severe hearing impairment, never acquire a hearing aid (Gallun et al., 2013). Further, peripheral hearing is only one factor responsible for success in complex acoustical environments (Bernstein et al., 2013; Gallun et al., 2013; Mehraei et al., 2014). Cognitive functions, such as executive functions and those involved with language processing, also play a role in speech in competition abilities and may be particularly important for older adults to serve as compensation mechanisms (Anderson et al., 2013; P. C. M. Wong et al., 2010).

Music is well documented in its ability to impact mood (Rigg, 1964; Saarikallio, 2008; Sarkamo et al., 2008). Not only has music been found to provide positive therapeutic benefits related to mood, emotion regulation, and memory, but also improved speech-in-competition abilities amongst older adult musicians (Coffey et al., 2017; Fleming et al., 2019; Sixsmith & Gibson, 2007). Musical engagement and exposure appear to have a positive impact across various domains of human experience and over the previous decade, there has been a growing interest in the extent to which musical training and experience may lead to enhancements in related and unrelated skills. For example, various studies have reported music training advantages in areas of executive functioning such as attention, working memory, and inhibitory control (Bugos, 2010; Holochwost et al., 2017; Moreno et al., 2011). Additionally, there is abundant evidence found amongst school-aged children suggesting a positive relationship between musical engagement and academic achievement (Holochwost et al., 2017; Sala & Gobet, 2020).

Studies examining the potential cognitive benefits of musical training and engagement amongst older adults have found musician advantages in auditory processing and auditory working memory capacities when compared with non-musicians, suggesting long-term impacts of musical training (Coffey et al., 2017; Grassi et al., 2017; Slater, 2015; White-Schwoch et al., 2013). For example, correlational studies have found preserved speech in competition abilities in older adult musicians compared with their non-musician counterparts (Parbery-Clark et al., 2009), as well as auditory working memory abilities (Parbery-Clark et al., 2011). These studies suggest that lifelong music engagement may offset some the effects of aging in relation to hearing and highlight the potential compensational role cognitive processes may play.

The current evidence of music-related advantages raises debates regarding underlying mechanisms and the extent to which effects are truly attributable to the music itself. Experimental findings suggest a tentative causal link between music training and increased cognitive performance, however, there have been some controversies around the strength and validity of these effects (Sala & Gobet, 2020). In addition, most studies have been conducted amongst school-aged children (Alemán et al., 2017; Habibi et al., 2018) and it is unclear whether and how the effects observed in children translate to older adults.

Several studies reporting a potential relationship between musical engagement and increased cognitive/perceptual abilities suggest that it may be due to increased attentional demand (Bugos, 2010; Sachs et al., 2017; Sarkamo et al., 2008). It has been argued that music listening instruction may provide similar benefits as instrumental instruction amongst healthy older adults (Bugos, 2010). Currently, there is limited work on music listening amongst older adult, however, a few studies have found that it aids in cognitive recovery amongst stroke patients and dementia (Sarkamo et al., 2008; Särkämö & Sihvonen, 2018; Sihvonen et al., 2017). It is important to note that previous music listening interventions have largely been structured as music appreciation courses or have relied on participant self-selection of music for passive listening.

Although one might argue that training with instruments may provide optimal benefits for improving cognitive and auditory abilities, the needed musical instruments and instructors may not be feasible or accessible to everyone due to restrictions such as physical ones, especially amongst older adults. Further, the mechanisms underlying the cognitive benefits of engaging with music remain to be clarified. Thus, there is a need for alternative ways of engaging with music that are not a result of instrumental training that aid in the development of auditory processing and cognitive abilities and as well as a need to experimentally address what core aspects of engagement with music are potentially driving beneficial outcomes.

Study 3 is the development of early prototypes and usability testing of a music-based intervention and assessments targeting auditory processing and cognition with the goal of improving speech in competition abilities amongst older adults. Materials and results from Study 3 were completed in preparation for larger scale implementation of this music-based intervention as a randomized-controlled trial. The overall goal of Study 3 was to gain insights with our target population of healthy older adults ages 65+ in regards to usability and difficulty of tasks, participants being able/willing to complete study procedures, have positive perceptions/enjoyment ratings of the stimuli intended for the experimental group, and provide any feedback they have about their experience that could guide in the prioritization of features to be implemented in the application designed to serve as the medium to carry out the intervention. Although the final intervention will have participants complete all study procedures from their homes, the below usability testing groups used a combination of remote and in person methods to collect data in a manner that would provide the most applicable data. This RCT will allow us to explore potential underlying mechanisms of the beneficial effects of music and further elucidate the contributions of auditory and cognitive domains to speech-in-competition. For this RCT, 216 healthy older adult participants will be newly recruited using the same inclusion criteria as the usability testing groups. See Figure 5 for design of the RCT. This RCT is anticipated to take place during 2024-2025.

The three usability groups tested in study 3 are as follows: Sound of music plus attention (SOM+A), this is the primary experimental group that aims to train auditory and cognitive abilities. In this group, participants listen to instrumental music and are given instructions/tasks to complete that aim to essentially teach individuals how to listen like a musician; Sound of the environment plus attention (SOE+A), in this active control group, participants complete similar training to the SOM+A group, but rather than listening to music they will listen to environmental sounds. The overall goal of this group was to serve as an active listening condition without the music component and will be one of the comparison groups in the intervention to help us identify if there are any training related differences; The last usability group is the paper prototype group. The overall goal of this group was to observe participants interactions with tasks and get live feedback that will assist with application development.

Method

Participants and Procedure

A total of 14 individuals were recruited to participate in a variety of prototyping and usability type studies. Three participants took part in two usability studies. Individuals were eligible to participate if they were 65 years of age or older, had no diagnosis of neurological disorders, reported no severe hearing loss that required the use of hearing aids or cochlear implants, and who were non-musicians which we defined as an individual that has not taken more than two years of formal music training in childhood or the past 20 years from the screening date. Additionally, participants were screened for depression and generalized anxiety using the Geriatric Depression Scale (GDS $\leq$4; Yesavage, 1988), and Generalized Anxiety Depression Questionnaire (GAD $\leq$4 ; (Spitzer et al., 2006); only participants in SOM+A, SOE+A, and Assessments Prototypes usability groups completed the GDS and GAD screenings.

For Study 3, we held four different rounds of usability testing to gain insight from participants on various aspects of stimuli development such as how much they enjoyed the stimuli, difficulty of tasks, likelihood to complete more sessions over a longer period, and to identify any problems or pain points to address.

Music stimuli for this study have been created by a musician (Ales Mauric) with expertise in music composition and technology in collaboration and upon specification provided by me and our junior specialist, Giancarlo Arzu. We made the decision to create original instrumental pieces to prevent familiarity with the songs as well as to have control over individual instruments, volume, where and when participants need to direct their attention, etc. A total of five instrumental pieces were created in various genres for the larger scale intervention, however, only one musical piece was used to create prototypes (a classical music piece). The development of each musical piece was composed to include 4-6 different instruments that could be easily distinguished, with each piece lastly roughly 10-15 minutes in length. Participants in all usability testing groups were compensated in the form of an online Amazon gift card as a token of our appreciation for their valuable insights.

Usability Testing Groups

SOM+A (Sound of Music Plus Attention) Prototype

A total of five participants were recruited for and completed this usability test. For this group, participants were mailed Amazon Fire tablets and headphones to complete their usability testing. See Figure 2 for an image of materials used. Please see the link here for to try out an early prototype (https://uci.co1.qualtrics.com/jfe/form/SV_0eydOv1c7n6NmJw). Graduate student ANW met with the participants over Zoom once they received their materials to discuss the study procedures, how to use the equipment, and how to return the materials. The prototype itself was created on the Qualtrics platform to embed survey questions before and after each session. At the end of this usability test, participants met over Zoom for a 2-hour semi-structured focus group to discuss their experience in more detail.

For this group, the overall goal was for participants to provide feedback about their enjoyment of the musical stimuli, perceptions of the progression of difficulty across sessions, thoughts about the duration of different sessions, and their mood/attention throughout sessions. Participants completed five sessions lasting roughly 10-25 minutes in length composed of a classical music piece. Guided verbal instructions were recorded over the music stimuli that periodically told participants what aspect of the music to pay attention to. For example, participants would hear instructions such as “pay attention to the melody of the piano, ignore all other instruments” or “switch your attention to the rhythm of the drums”. Verbal instructions were developed to target the use of focused and sustained attention, inhibition, attention switching, and updating working memory. To record if participants were attending to the appropriate aspect of the music, they were presented with 10 attention check questions total roughly every two minutes. The attention check questions provided multiple-choice options to choose from. To avoid the use of process of elimination strategy, they were presented with the same multiple choice list each time. At the end of each session, participants were asked to rate how much they enjoyed the music they listened to during that session on a 5-point Likert scale ranging from “I did not enjoy the music at all” to “I enjoyed the music very much”. In addition, they were asked how often they were distracted while listening to the session using a slider to respond from “never” to “almost constantly” ranging from 0-100 as well as attempt to quantify how many times they were distracted with a numeric value using a text box response. Lastly, participants answered questions about the difficulty of the sessions and any comments or suggestions they had using a variety of liker, text box, and multiple-choice response forms.

Difficulty across sessions was manipulated in a variety of ways including increasing the complexity of the instrumentation, the type of instructions on what aspect of the music to attend to, use to stereo location, and the spacing between the instructions.

A script was created for the focus group to cover four domains: Access/working with the materials, wording/visual interaction, thoughts about auditory stimuli, and general questions. The focus group was in a semi-structured format and intended to be conversational in nature. The focus group facilitator used the questions as a guide to ensure the desired domains were discussed, however, participants were encouraged to lead the discussion and were encouraged by the facilitator to be detailed in their responses and feedback. See Table 1 for examples questions.

SOE+A (Sound of Environment + Attention) Prototype

The SOE+A group is intended to serve as one of the active control groups for the larger intervention. Four participants were recruited and completed this usability test. Participants in this group completed five sessions of a similar task to the SOM+A group (i.e., they were given written instructions on what to attend to), but they listened to environmental sounds such as a beach and heard sounds commonly associated with those scenes. For example, at a beach, it is common to hear ocean waves, a breeze, or a volleyball being tossed back and forth. For these sessions, participants listened to the following environmental "scenes": Beach, kitchen, a campground with a river, a work office, and the inside of a home during a rainstorm.

Each session was approximately 10-25 minutes in length from start to finish. This goal for this group was also to gain insights on participants' enjoyment of the environmental stimuli, perceptions of the progression of difficulty across sessions, thoughts about the duration of different sessions, and their mood/attention throughout sessions. This group was also given the same materials as the SOM+A group, but because participants were local, they were given the option to have their materials personally delivered and picked up and given set-up instructions in person. In addition, this group also participated in a 2-hour focus group over Zoom utilizing the same script from the SOM+A group, with some alterations to answer questions specific to the environmental stimuli.

SOM+A Paper Prototype

A total of three participants took part in this usability test. Participants were invited individually to the lab for a three-hour usability test of a paper prototype we created. The overall goal of this usability test was to gain insights on interacting with “buttons”, testing out how to express correct and incorrect responses for participants, clarity of instructions, testing out various tasks that we were unable to complete with Qualtrics due the limiting nature of response types, and monitoring responses in person to help inform the design of the app that participants would eventually complete on a tablet.

To create the materials for this, a cardboard cut-out was used to cut into the shape of a tablet. Google Slides was used to create page by page “screens” to mimic what participants might see on a real tablet and for them to engage with. In addition, images such as buttons to interact with, pictures of the instruments heard in the musical piece, and other objects intended to “move” were printed and cut out. After participants completed the prototype, they debriefed with the researchers present to discuss their experience and provide feedback. See Figure 3 for an example of some of the “screens” participants saw.

Two researchers were present for paper prototyping. One researcher took observational notes as well as notes during the debriefing, and the other research was responsible for engaging with the participant during the usability test. To conduct the usability test, the researcher played the auditory stimuli on a speaker, sat across a table from the participant, and moved the "screens" and objects by hand to mimic the interaction the participant may have with the tablet. See Figure 4 for an example of one of our participants engaging with the paper prototype.

Assessments Prototype

The below assessments described were embedded into a system called Portable Adaptive Rapid Testing (PART; Gallun et al, 2018). PART is a high-fidelity psychoacoustical testing tool that uses affordable technology (can be downloaded as an app onto a tablet) that allow individuals to test their hearing and was developed by Aaron Seitz and Frederick Gallun. These assessments are intended to be administered during pretest and posttest for the larger intervention. In this group, we had five participants come into the lab individually for approximately three hours to go through the entire battery of auditory processing and cognitive assessments. The overall goal of this group was to gather participants' feedback about usability, i.e., the clarity of test instructions and procedures, legibility of the text (e.g., font size, contrast), ease of navigation, responsiveness of the buttons, self-perceptions of test fatigue, and their thought on completing these assessments at home. Throughout the usability test, participants given five optional 3-minute breaks (roughly after every 2-3 assessments) and one optional 30-minute break after completing half of the assessments.

Speech in Competition

Digit-in-Noise Test. In this task, participants were presented trials of three sequential spoken digits against a broad-band speech-shaped masker. Signal/noise ratio varied adaptively to track 50% correct responses. Participants performed an active version of this task delivered conjointly in each ear. The outcome measure is the threshold noise tolerance in dB (Gallun et al., 2018).

Spatial Release from Masking. This assessment tests the ability to distinguish speech from competing speech using spatial locations. The task used co-located conditions, with a target and two competing maskers all located directly in front of the listener, and spatially separated conditions, with two masking sentences sent from 45 degrees to the left and right of the center. The outcome is the threshold target-to-masker ratio as estimated based on the number of sentences correctly identified as part series of 20 test trials in which the target-to-masker ratio progressively reduced every two trials (Gallun et al., 2018).

Dichotic Sentence Identification. In this task, two nonsense sentences were presented simultaneously, one to each ear. Participants indicated two sentences heard from a list of 10 alternatives. The outcome is the percentage of sentences correctly identified (Gallun et al., 2018).

Cognitive Assessments

Attention

Sustained, Divided and Selective Attention. Participants were presented with auditory sequences of spoken digits and visual sequences of written letters and were instructed to recall a particular sequence either in advance (assessing selective attention) or only afterwards (assessing divided attention) (Cowan et al., 2005).

Paced Auditory Serial Addition Task (PASAT). In this task, participants were presented with a list of single digit numbers, and are required to add each number to the preceding number. The results must be selected from a list of answer alternatives on the tablet. The speed of presentation was varied starting from an interstimulus interval of 2.5 seconds. The total number of correct responses served as the dependent measure (Tombaugh, 2006).

Working Memory

Auditory and Visual Working Memory Recall. The same auditory sequences of spoken digits and visual sequences of written letters described for the attention measure was used to probe working memory. Participants were asked to recall increasingly long sequences of stimuli either in the order presented or in alphabetical or numerical order. The dependent variable was the total number of correct trials (Jaeggi et al., 2020).

Letter-Number Sequencing. Participants were presented with a mixed order of letters and numbers and had to remember and sort them numerically and alphabetically. For example, the sequence 'H8T3K5' would be sorted into '358' and 'HKT'. The set size started at 2 and increased until the participants failed to recall both trials at a given set size. The dependent variables were span (the highest set size achieved where at least 1 trial is correct) and score (the total number of correct trials) (Stepankova et al., 2014).

Auditory N-Back. Participants were presented with a consecutive stream of items through headphones (e.g., spoken letters or tones), and were asked to tap on their tablet screen every time the currently presented item matched the one presented N items earlier. All participants completed 1-back, 2-back, and 3-back (in that order). The outcome measure consists of accuracy on each of the levels calculated as hits/(hits+misses+false alarms). The stimuli was presented for 2500 ms with an ISI of 500 ms (Jaeggi et al., 2020; Stepankova et al., 2014).

Musical ability

Only participants that took part in the SOME+A, SOE+A, and Assessments Prototype usability tests completed the below assessment on musical ability.

The Goldsmith Musical Sophistication Index (Gold-MSI). This self-report inventory measures individual differences in musical sophistication and is intended to measure the ability to engage with music in a flexible manner. This index assessed five different domains (active musical engagement, self-reported perceptual abilities, musical training, self-reported singing abilities, and sophisticated emotional engagement with music) (Müllensiefen et al., 2014).

Results

Enjoyment Engaging with the Prototypes

Across all usability groups, all participants completed all required sessions for testing. To get an understanding of participants' overall enjoyment of the stimuli they were listening to as well as the tasks they were completing, they were asked questions about their experience through survey questions, focus groups, and discussing their opinions with the researchers. In general, participants provided positive feedback regarding their experience with the stimuli and overall engagement with the prototypes in the SOM+A, SOE+A, and paper prototype groups.

Across all five sessions in the SOM+A group, the average score for enjoyment of the music was rated 4.4 out of 5 (higher = more enjoyable). In the SOE+A group, the average score for enjoyment of the stimuli was rated 3.91 out of 5. Additionally, participants in the paper prototype group also expressed that the music they listened to was pleasant. Participants in this group did not complete questionnaires, they were verbally asked questions regarding their perceptions of the stimuli. For the SOM+A group, comments left at the end of the sessions as well as discussed in the focus group expressed that overall, the music listened to was enjoyable, simple to listen to, and that the tasks were challenging but fun.

Difficulty, Duration, and Attention

Across all five sessions in the SOM+A group, the average score for difficulty was rated 3.5 out of 5 (higher = easier). The SOE+A group rated their sessions on average 4.02 out of 5. During the focus groups as well as in some of the comments at the end of sessions, participants expressed confusion/desire for more clarity on some of the instructions. For example, while listening during the sessions, participants were asked “Please firmly tap the screen every time your attention switches to a different sound”. Some participants were confused if this meant to tap the screen if their attention switched to an environmental distraction, by a new instrument or sound that would arise in the session, or to tap the screen when they got distracted by not being able to follow along with the auditory instructions.

Participants that completed the paper prototype were not asked to rate their perception of the difficulty of the tasks on a scale, just to estimate how easy or difficult each task felt alone and in comparison, to the others they completed prior. All participants found most of the tasks challenging but doable with a few we called “mini games” that they found relatively easy. This was observed by correct/incorrect responses during tasks as well as during debriefing with participants after the session. We noticed during paper prototyping that often, there were incorrect responses due to changes in timbre for instruments as well as confusing instruments that were similar in sound. For example, one of the tasks required participants to listen to two short sound clips of individual instruments playing and identify if they were the same or different. Participants struggled a bit more differentiating between an oboe and flute. Although participants did not enjoy responding incorrectly, this was a helpful indication of an area for us to provide further training.

Regarding attention, we were curious to know how often participants may be getting distracted for the SOM+A and SOE+A groups in particular as these groups were completing tasks at home just like participants in the full intervention would be. In the SOM+A group, participants noted they were distracted an average of 4 times per session (i.e., their attention drifted from the task). In the SOE+A group, participants were distracted an average of 3.8 times per session. Responses from one participant were removed from the scoring of this question due to extremely high numbers in comparison with other values. Because the overall goal of the paper protype test was more to assess enjoyment with the stimuli and participants' interactions, we did not ask attention specific questions to this group. Similarly, the assessments group was not asked attention specific questions.

General Feedback

Overall, participants stated that the duration of the sessions were just right and could have completed longer sessions. However, there was one participant in the SOM+A group as well as the SOE+A group that more often stated they would have liked shorter sessions. Participants completing the paper prototype completed short samples of sessions intended to be completed over a week, but they also expressed that a longer duration (15-20 minutes) of each of the samples they completed could be helpful for their learning and comfort with the tasks over time.

At the end of the focus groups and debriefing with paper prototyping participants, everyone was asked about their likelihood to complete 40 sessions at home of whatever prototype they were testing. Participants in all groups stated they would be willing to complete 40 sessions, however, they would like some flexibility in terms of how often they could complete them. For example, if they were given a timeframe of 2-3 months and they can complete them during that time (no more than one per day), they would be more likely to complete all sessions. The SOM+A and paper prototype groups stated that roughly 20 minutes per session would be doable. The SOE+A group unanimously stated that if they were to complete 40 sessions of these tasks, they would be more willing to complete them all if they were 10 minutes per session. This is not surprising as the stimuli for this group could be considered a little less engaging.

Assessments Prototype

Overall, participants took roughly and hour and a half to complete all the assessments. Regarding the instruction, only one assessment had instructions that were found to confusing by participants and was recommended to revise. In terms of duration, most participants did not use up the total duration of their 3-minute breaks or the 30-minute break and reported no serious fatigue. All participants reported the battery to be doable in one sitting. When asked about their thoughts completing these assessments at home, all participants stated that they liked the idea of completing the battery at home and had no preference for completing it in one session vs. two or more.

Limitations, Conclusion and Next Steps

There are a few limitations that I would like to note about our usability tests. The first being the use of Qualtrics for our platform for the SOM+A and SOE+A groups. Although this was an affordable and quick way to have participants engage with the prototypes in a way that most closely mimicked our desired final product (a gamified app), we were unable to provide participants with visual feedback whenever they tapped the tablet screen or provide a summary of their scores at the end of each session. Additionally, Qualtrics does not provide a great user experience for continuous engagement with auditory and visual stimuli that would be expected from a game app such as stored login information (most participants expressed annoyance with having to remember or go back and find their participant ID), stored performance progress per session and overall, visual feedback when touching objects, and other visual attributes we would have liked to include for responses such as visual feedback for correct/incorrect responses. During the focus groups, a large portion of the feedback and suggestions provided were regarding the user experience with Qualtrics. Although we will be able to remedy these during app development, feelings of frustration with interacting with the materials through Qualtrics may have had an influence on perceptions of the stimuli itself as well as confusion completing some of the tasks.

The most notable limitation for the paper prototyping group was the administration of the tasks using paper. Although this was an affordable, fast, and convenient way for us test out some of the tasks, see how participants navigated the tasks, and make immediate changes, it took some time for participants to get comfortable interacting on a fake tablet. However, one of the biggest benefits to using this method was we were able to see how and when participants would respond and we were able to ask questions immediately when we saw something notable, and revisit tasks quickly and answer questions when debriefing.

Overall, triangulating data through surveys, focus groups, and in person testing, we were able to collect sufficient evidence to suggest we are on the right track with stimuli development for SOM+A and SOE+A groups. In addition, we received helpful suggestions from our target population that will aid in the app development. One of the challenges we face with this project is making the control groups enjoyable while still maintaining their primary functions to help us identify training related changes in the experimental group. By doing usability testing while we are developing materials for all groups, we are able to quickly test out ideas and pursue the ones that align best with the project goals to create a delightful research experience for participants.

A few things I have learned throughout this process are in regard to the importance of addressing our users' (participants) experiences. Although research products often look different than everyday consumer products, for example video games used for interventions for educational purposes vs. video games for leisure which are more often designed for a target audience, the experience our participants have with our research products can have a great impact on our overall results. In addition, having a delightful experience (from visual design, the tasks themselves, navigation, and more) can be valuable to our participants and has the potential to evoke feelings we may not anticipate being associated with our research product such as annoyance, satisfaction, nostalgia, and may impact their motivation and performance. For example, ease of use and navigation may sound simple, but these are often factors that may lead to participant drop out due to feelings of frustration even before starting training that requires effort and often accompanied by training related frustrations. We learned from this study and from our target population that fewer steps to access their training is ideal. Additionally, sometimes less is more. During our team brainstorming sessions, we've spent lots of time discussing many creative ideas to implement in the final research product. Through discussing some of these ideas with our participants in the focus groups and paper prototyping, it appears that a few game-like aspects we thought would add value to motivation may be ignored or be distracting. For example, we have played around with creating an underlying story to the training to keep this game-like aspect that comes with in-app types of rewards (equivalent to points or something similar). Participants have expressed that this is a nice feature, but regarding their motivation, they are more motivated by the study goal itself to improve their hearing abilities. This is helpful information that can be easily addressed in the next steps of this project and has helped us refine how much information we disclose about the goals of the overall intervention during other usability tests. In addition, as a team, we also discussed including more educational features into the training as a form of "reward" such as learning about the history of certain genres of music or instruments and have evidence from conversations with our participants to suggest that this is an avenue worth pursuing and developing further.

The next steps for this project are to pilot 20 sessions for the SOM+A group lasting 20 minutes in length to gather feedback about enjoyment and engagement of the musical stimuli and tasks for 5 musical pieces total. A few of the genres include, rock, classical, and jazz. This pilot study is to take place during the summer of 2023. In addition, we will be piloting 20 sessions for another control group, SOT+A (sound of tones plus attention). This pilot test will serve as the specific go-no-go criteria to allow for transition to the next phase of this project.

The overall goal of the next study phase is to test the efficacy of the attention-based music intervention to improve performance in speech-in-competition, and to uncover the separate and/or additive contributions of music and attention using active controls that target either music or attention separately (SOM, SOE+A, SOT+A).

In summary, our usability tests and focus groups have provided valuable information that has helped us refine ongoing usability tests and will help inform the design of the app used for the final intervention. Our focus groups and paper prototyping helped us learn from our participants what their pain points were with our prototypes, what they liked/disliked, and allowed us to discuss their overall experience in greater detail in comparison with our questionnaires. We look forward to implementing their feedback into the next stages of this project.

Appendix C

Access/Materials	Wording/Visuals	Auditory Stimuli	General Questions
Tell me about your experience accessing the materials.	Tell me about your experience reading the instructions on the tablet. For example, font size, too little or too many instructions.	What are your thoughts about the sound calibration at the start of each session?	Would you participate in this study if you had to do 40 sessions of listening to stimuli like this? If not, how many would you be willing to do?
Do you like being emailed sessions daily, or would you prefer access to all sessions at once?	Tell me about your experience completing the tasks. How did you feel about the quality of the instructions?	What are your thoughts about the duration of each session? Were they too long, too short, just right?	What is the likelihood that you would participate in hearing training at home if it was gamified and you could download it as an app?
Tell me about your experience with the tablet. For example, ease or difficulty with tapping.		How much did you like or dislike the music throughout each session?	Based on your experience with this prototype, why would you recommend this training (or not) to a friend?

Figure 3.1
Example Questions for Focus Group of SOM+A Prototype
Note. This is not a comprehensive list.

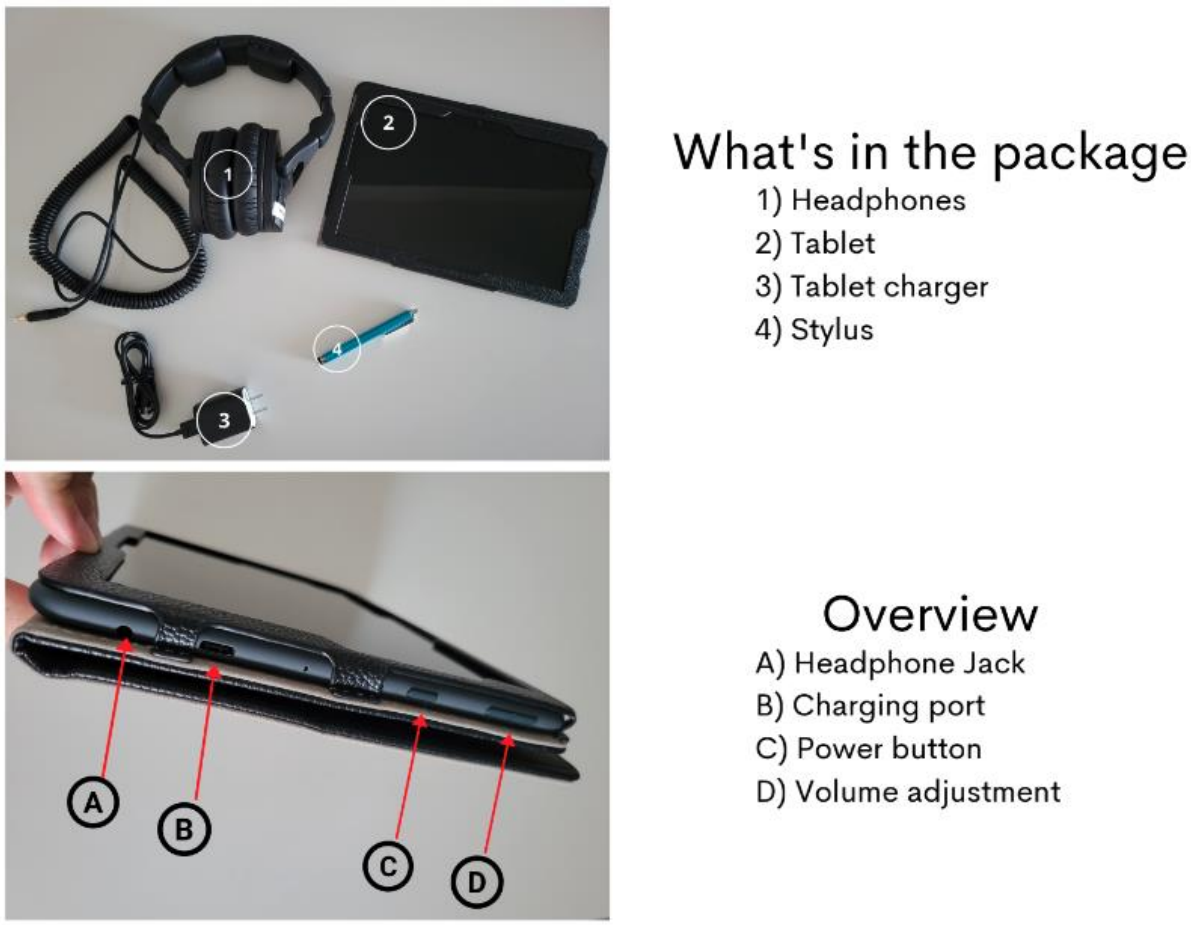

Figure 3.2
Materials used for SOM+A, SOE+A, and assessments prototype

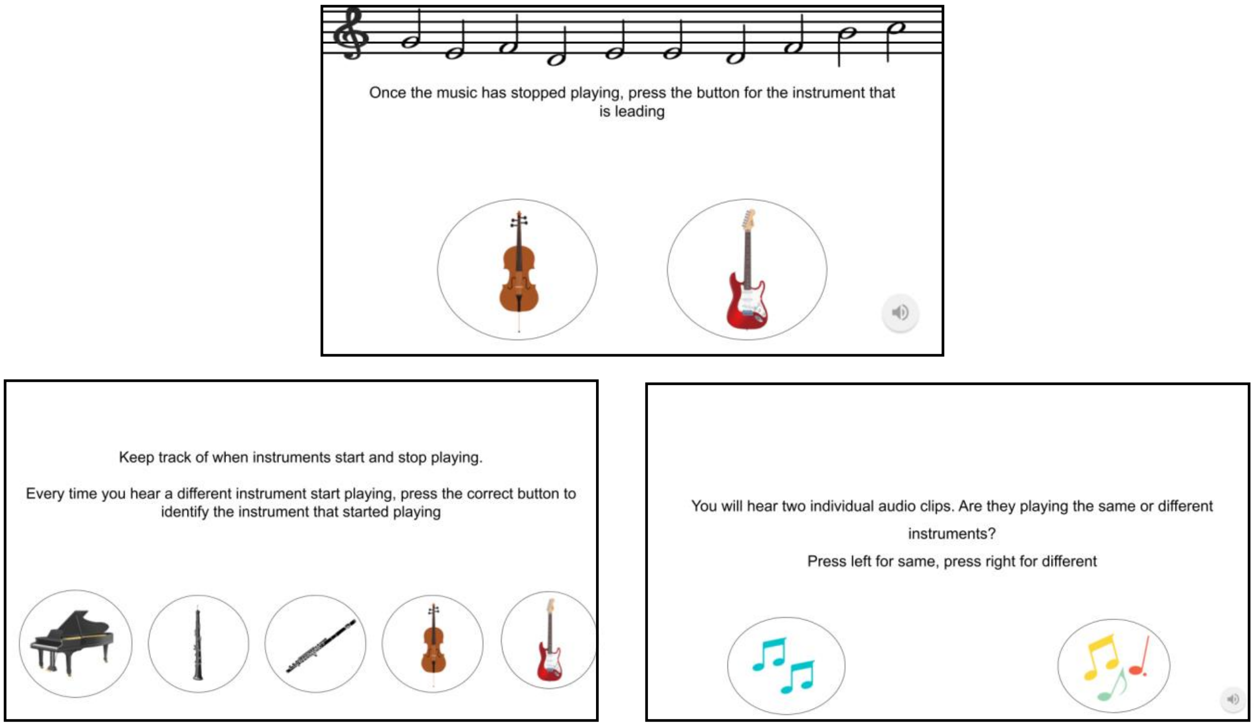

Figure 3.3
Example Screens Participants Saw During Usability Test with Paper Prototype

Figure 3.4
Example of Participant Engaging with Paper Prototype

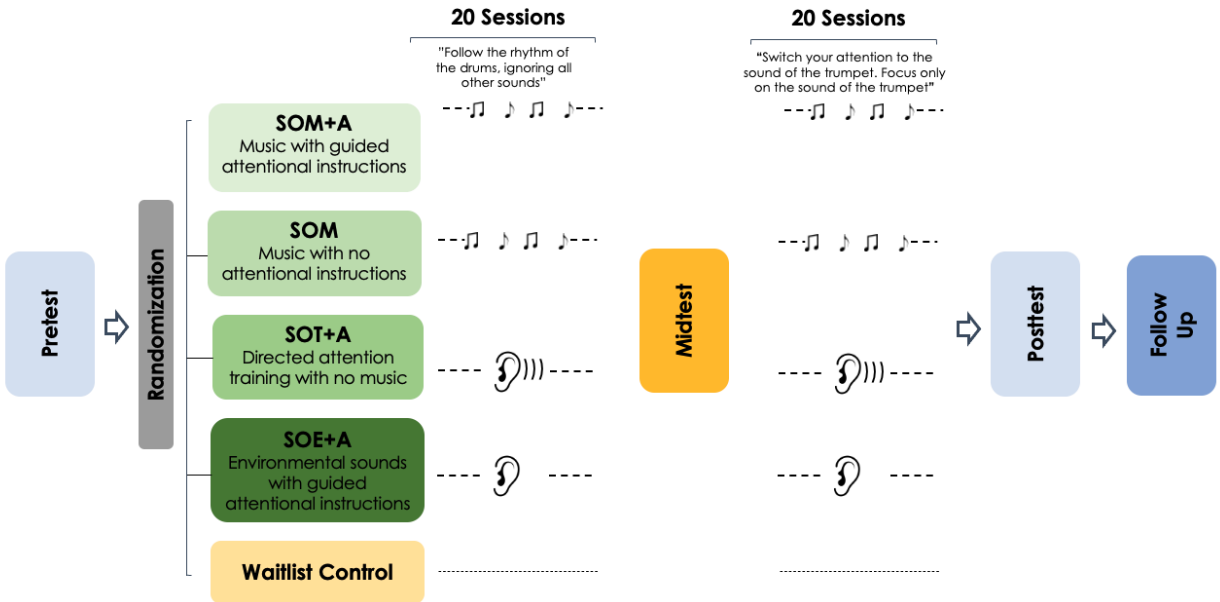

Figure 3.5

Experimental design and illustration of conditions (R33 phase)

SUMMARY AND CONCLUSIONS

This dissertation examined the relation between activity engagement and cognitive performance amongst healthy older adults through two studies and took a deeper look at the impact of one specific activity (music engagement) on areas affected by aging in the third study. Study 1 examined cognitive, social, and physical activities and whether they would predict cognitive performance in a healthy older adult population, as well as frequency of engagement and variety of activities. Study 2 investigated the overall magnitude of this relationship by conducting a systematic review and meta-analysis of 35 studies and 484 effect sizes as well as potential moderators. Study 3 discussed the impact of music engagement on hearing and cognitive performance, its potential to mitigate age-related declines, and reports the results of usability testing of prototypes intended serve a larger scale intervention investigating training related changes. Overall, this dissertation contributes to the field in activity engagement, cognitive performance, and aging. Study 1 and Study 2 investigate the correlational relation between engagement in a variety of activities and cognitive performance and provide insights into why the strength of this association may differ for a typically healthy population and the various factors that contribute to optimal aging. Lastly, this dissertation has aided in the development of an innovative study that will contribute insights to the field on mechanisms underlying music and cognitive performance and has the potential to benefit millions of induvial experiencing age-related hearing loss and influence future related studies and products.

Throughout the process of the studies in this dissertation, I have interrogated if, how, and why the activities we do keep our cognition sharp as we age as well as how strongly activity engagement may be contributing to preserved abilities. Although Study 1 and Study 2 do not provide overwhelmingly strong evidence to support that this is the case for a direct relationship, the activities we engage with provide a multitude of other benefits that go beyond our cognition that may contribute to optimal aging through a variety of other avenues. Additionally, Study 2 demonstrates that the types of activities one engages with seems to matter. As we saw when comparing studies at the most extreme ends of effect sizes, those with the strongest positive effect sizes were comprised of activities one would consider to be more active and engaging such as games and puzzles. In contrast, studies with the strongest negative correlations were comprised of activities one would consider to be more passive such as watching TV. The underlying theme I see consistently amongst studies of activity engagement and cognitive performance are that active engagement, challenge, and effort are crucial for maintaining cognitive abilities in older age. Further, one's motivation, beliefs about their own abilities, and self-efficacy also play an important role. For example, adopting a growth mindset can make a world of difference when faced with challenges, especially challenges in abilities that may have previously been effortless such as remembering the names of someone new or even what you need to pick up at the grocery store because you remembered you've ran out of a few items at home. Additionally, a growth mindset in the face of challenges can make the difference in whether one chooses to continue to engage in certain activities, a decision that can have major positive or negative consequences over time.

During my graduate training, I have often been asked by friends and family what specific activity I recommend they take on to stay sharp such as learning a new language or playing daily sudoku. While I would love to give a straightforward and satisfying answer, this field of work highlights how intricate aging is with the brain being incredibly resilient and forgiving with certain experiences while also being sensitive to others. Although maintaining intact cognitive abilities is a key factor in optimal aging, activity engagement is only one piece of the puzzle.

When there is a choice, most importantly, engaging in activities that one truly enjoys has the potential to provide so much more than one benefit alone.

REFERENCES

Aartsen, M. J., Smits, C. H. M., van Tilburg, T., Knipscheer, K. C. P. M., and Deeg, D. J. H. (2002). Activity in older adults: cause or consequence of cognitive functioning? A longitudinal study on everyday activities and cognitive performance in older adults. J. Gerontol. Ser. B Psychol. Sci. Soc. Sci. 57, 153–162. doi: 10.1093/geronb/57.2.P153

Adler, N. E., Epel, E. S., Castellazzo, G., and Ickovics, J. R. (2000). Relationship of subjective and objective social status with psychological and physiological functioning: preliminary data in healthy, White women. Health Psychol. 19, 586–592. doi: 10.1037//0278-6133.19.6.586

Agahi, N., & Parker, M. G. (2005). Are today's older people more active than their predecessors? Participation in leisure-time activities in Sweden in 1992 and 2002. Ageing & Society, 25(6), 925–941. https://doi.org/10.1017/S0144686X05004058

Alemán, X., Duryea, S., Guerra, N. G., McEwan, P. J., Muñoz, R., Stampini, M., & Williamson, A. A. (2017). The Effects of Musical Training on Child Development: A Randomized Trial of El Sistema in Venezuela. Prevention Science, 18(7), 865–878. https://doi.org/10.1007/s11121-016-0727-3

Anderson, S., White-Schwoch, T., Parbery-Clark, A., & Kraus, N. (2013). Reversal of age-related neural timing delays with training. Proceedings of the National Academy of Sciences, 110(11), 4357–4362. https://doi.org/10.1073/pnas.1213555110

Andridge, R. R., and Little, R. J. A. (2010). A review of hot deck imputation for survey non-response. Int. Stat. Rev. 78, 40–64. doi: 10.1111/j.1751-5823.2010.00 103.x

Arab, A., Christie, G. J., Mansouri, M., Ahmadzadeh, M., Sixsmith, A., Ester, M., & Moreno, S. (2021). Moderate-Intensity Physical Activity, Music and Art Activities Preserved

Cognitive Health in Older Adults: An Argument for Social Prescribing Solution. Frontiers in Aging Neuroscience, 13, 463. https://doi.org/10.3389/fnagi.2021.693791

Baker, L. A., Cahalin, L. P., Gerst, K., and Burr, J. A. (2005). Productive activities and subjective well-being among older adults: the influence of number of activities and time commitment. Soc. Indic. Res. 73, 431–458. doi: 10.1007/ s11205-005-0805-6

Bakhos, D., Villeuneuve, A., Kim, S., Hammoudi, K., & Hommet, C. (2015). Hearing loss and Alzheimer's disease. Gériatrie et Psychologie Neuropsychiatrie du Viellissement, 13(2), 195–204. https://doi.org/10.1684/pnv.2015.0539

Baldivia, B., Andrade, V. M., and Bueno, O. F. A. (2008). Contribution of education, occupation and cognitively stimulating activities to the formation of cognitive reserve. Dement. Neuropsychol. 2, 173–182. doi: 10.1590/S1980- 57642009DN20300003

Barnett, J. H., Salmond, C. H., Jones, P. B., and Sahakian, B. J. (2006). Cognitive reserve in neuropsychiatry. Psychol. Med. 36, 1053–1064. doi: 10. 1017/S0033291706007501

Barulli, D., and Stern, Y. (2013). Efficiency, capacity, compensation, maintenance, plasticity: emerging concepts in cognitive reserve. Trends Cogn. Sci. 17, 502–509. doi: 10.1016/j.tics.2013.08.012

Berggren, R., Nilsson, J., & Lövdén, M. (2018). Education Does Not Affect Cognitive Decline in Aging: A Bayesian Assessment of the Association Between Education and Change in Cognitive Performance. Frontiers in Psychology, 9, 1138. https://doi.org/10.3389/fpsyg.2018.01138

Bernstein, J. G. W., Mehraei, G., Shamma, S., Gallun, F. J., Theodoroff, S. M., & Leek, M. R. (2013). Spectrotemporal modulation sensitivity as a predictor of speech intelligibility for hearing-impaired listeners. Journal of the American Academy of Audiology, 24(4), 293–306. https://doi.org/10.3766/jaaa.24.4.5

Bielak, A. A. M. (2010). How Can We Not 'Lose It' if We Still Don't Understand How to 'Use It'? Unanswered Questions about the Influence of Activity Participation on Cognitive Performance in Older Age – A Mini-Review. Gerontology, 56(5), 507–519. https://doi.org/10.1159/000264918

Bielak, A. A. M. (2017). Different perspectives on measuring lifestyle engagement: a comparison of activity measures and their relation with cognitive performance in older adults. Aging Neuropsychol. Cogn. 24, 435–452. doi: 10.1080/13825585. 2016.1221378

Bielak, A. A. M., Anstey, K. J., Christensen, H., & Windsor, T. D. (2012). Activity engagement is related to level, but not change in cognitive ability across adulthood. Psychology and Aging, 27(1), 219–228. https://doi.org/10.1037/a0024667

Bielak, A. A. M., Mogle, J. A., and Sliwinski, M. J. (2019). Two sides of the same coin? Association of variety and frequency of activity with cognition. Psychol. Aging 34, 457–466. doi: 10.1037/pag0000350

Bielderman, A., de Greef, M. H. G., Krijnen, W. P., & van der Schans, C. P. (2015). Relationship between socioeconomic status and quality of life in older adults: A path analysis. Quality of Life Research, 24(7), 1697–1705. https://doi.org/10.1007/s11136-014-0898-y

Bierre, K. L., Lucas, S. J., Guiney, H., Cotter, J. D., and Machado, L. (2017). Cognitive difficulty intensifies age-related changes in anterior frontal hemodynamics: novel evidence from near-infrared spectroscopy. J. Gerontol. Ser. A Biol. Sci. Med. Sci. 72, 181–188. doi: 10.1093/gerona/glw061

Billington, J., Carroll, J., Davis, P., Healey, C., & Kinderman, P. (2013). A literature-based intervention for older people living with dementia. Perspectives in Public Health, 133(3), 165–173. https://doi.org/10.1177/1757913912470052

Blair, C. (2006). How similar are fluid cognition and general intelligence? A developmental neuroscience perspective on fluid cognition as an aspect of human cognitive ability. The Behavioral and Brain Sciences, 29(2), 109–125; discussion 125-160. https://doi.org/10.1017/S0140525X06009034

Borgeest, G. S., Henson, R. N., Shafto, M., Samu, D., *Cam-CAN, & Kievit, R. A. (2020). Greater lifestyle engagement is associated with better age-adjusted cognitive abilities. PLOS ONE, 15(5), e0230077. https://doi.org/10.1371/journal.pone.0230077

Böttcher, A., Zarucha, A., Köbe, T., Gaubert, M., Höppner, A., Fabel, K., Altenstein, S., Bartels, C., Buerger, K., Dechent, P., Dobisch, L., Ewers, M., Fliessbach, K., Freiesleben, S. D., Frommann, I., Haynes, J. D., Janowitz, D., Kilimann, I., Kleineidam, L., … Group, for the D. study. (2021). Lifelong musical activity is associated with multi-domain cognitive and brain benefits in older adults (p. 2021.09.15.460202). https://doi.org/10.1101/2021.09.15.460202

Brickenkamp, R. (2002). Test d2. The d2 test of attention, 9th Edn. Goettingen: Hogrefe.

Brown, C. L., Gibbons, L. E., Kennison, R. F., Robitaille, A., Lindwall, M., Mitchell, M. B., Shirk, S. D., Atri, A., Cimino, C. R., Benitez, A., MacDonald, S. W. S., Zelinski, E. M., Willis, S. L., Schaie, K. W., Johansson, B., Dixon, R. A., Mungas, D. M., Hofer, S. M., & Piccinin, A. M. (2012). Social Activity and Cognitive Functioning Over Time: A Coordinated Analysis of Four Longitudinal Studies. Journal of Aging Research, 2012, 287438. https://doi.org/10.1155/2012/287438

Buchman, A. S., Yu, L., Wilson, R. S., Lim, A., Dawe, R. J., Gaiteri, C., et al. (2019). Physical activity, common brain pathologies, and cognition in community-dwelling older adults. Neurology 92:e811. doi: 10.1212/WNL. 0000000000006954

Buchner, D. M. (2009). Physical activity and prevention of cardiovascular disease in older adults. Clinics in Geriatric Medicine, 25(4), 661–675, viii. https://doi.org/10.1016/j.cger.2009.08.002

Bugg, J. M., Zook, N. A., DeLosh, E. L., Davalos, D. B., & Davis, H. P. (2006). Age differences in fluid intelligence: Contributions of general slowing and frontal decline. Brain and Cognition, 62(1), 9–16. https://doi.org/10.1016/j.bandc.2006.02.006

Bugos, J. A. (2010). The Benefits of Music Instruction on Processing Speed, Verbal Fluency, and Cognitive Control in Aging. 4, 9.

Cabeza, R., Albert, M., Belleville, S., Craik, F. I. M., Duarte, A., Grady, C. L., et al. (2018). Maintenance, reserve and compensation: the cognitive neuroscience of healthy ageing. Nat. Rev. Neurosci. 19, 701–710. doi: 10.1038/s41583-018-0068-2

Carlson, M. C., Parisi, J. M., Xia, J., Xue, Q.-L., Rebok, G. W., Bandeen-Roche, K., et al. (2012). Lifestyle activities and memory: variety may be the spice of life. The women's health and aging study II. J. Int. Neuropsychol. Soc. 18, 286–294. doi: 10.1017/S135561771100169X

Chan, D., Shafto, M., Kievit, R., Matthews, F., Spink, M., Valenzuela, M., et al. (2018). Lifestyle activities in mid-life contribute to cognitive reserve in late-life, independent of education, occupation and late-life activities. Neurobiol. Aging 70, 180–183. doi: 10.1016/j.neurobiolaging.2018.06.012

Chang, M., Jonsson, P. V., Snaedal, J., Bjornsson, S., Saczynski, J. S., Aspelund, T., et al. (2010). The effect of midlife physical activity on cognitive function among older adults: AGES–Reykjavik Study. J. Gerontol. Ser. A Biol. Sci. Med. Sci. 65, 1369–1374. doi: 10.1093/gerona/glq152

Chang, Y. K., Labban, J. D., Gapin, J. I., & Etnier, J. L. (2012). The effects of acute exercise on cognitive performance: A meta-analysis. Brain Research, 1453, 87–101. https://doi.org/10.1016/j.brainres.2012.02.068

Cheng, S.-T. (2016). Cognitive reserve and the prevention of dementia: the role of physical and cognitive activities. Curr. Psychiatry Rep. 18:85. doi: 10.1007/ s11920-016-0721-2

Coffey, E. B. J., Mogilever, N. B., & Zatorre, R. J. (2017). Speech-in-noise perception in musicians: A review. Hearing Research, 352, 49–69. https://doi.org/10.1016/j.heares.2017.02.006

Cohen, J. (1977). Statistical Power Analysis for the Behavioral Sciences, Revised Edition. San Diego, CA: Academic Press.

Cohen, S., and Herbert, T. B. (1996). Health Psychology: psychological factors and physical disease from the perspective of human psychoneuroimmunology. Ann. Rev. Psychol. 47, 113–142. doi: 10.1146/annurev.psych.47.1. 113

Colcombe, S. J., Erickson, K. I., Scalf, P. E., Kim, J. S., Prakash, R., McAuley, E., Elavsky, S., Marquez, D. X., Hu, L., & Kramer, A. F. (2006). Aerobic Exercise Training Increases Brain Volume in Aging Humans. The Journals of Gerontology: Series A, 61(11), 1166–1170. https://doi.org/10.1093/gerona/61.11.1166

Corrêa, J. C., Ávila, M. P. W., Lucchetti, A. L. G., & Lucchetti, G. (2020). Altruism, Volunteering and Cognitive Performance Among Older Adults: A 2-Year Longitudinal

Study. Journal of Geriatric Psychiatry and Neurology, 0891988720964260. https://doi.org/10.1177/0891988720964260

Cowan, N., Elliott, E. M., Scott Saults, J., Morey, C. C., Mattox, S., Hismjatullina, A., & Conway, A. R. A. (2005). On the capacity of attention: Its estimation and its role in working memory and cognitive aptitudes. Cognitive Psychology, 51(1), 42–100. https://doi.org/10.1016/j.cogpsych.2004.12.001

de Ribaupierre, A., and Lecerf, T. (2006). Relationships between working memory and intelligence from a developmental perspective: convergent evidence from a neo-Piagetian and a psychometric approach. Eur. J. Cogn. Psychol. 18, 109–137. doi: 10.1080/09541440500216127

Diaz Abrahan, V., Shifres, F., & Justel, N. (2021). Impact of music-based intervention on verbal memory: An experimental behavioral study with older adults. Cognitive Processing, 22(1), 117–130. https://doi.org/10.1007/s10339-020-00993-5

Dodge, H. H., Kita, Y., Takechi, H., Hayakawa, T., Ganguli, M., & Ueshima, H. (2008). Healthy Cognitive Aging and Leisure Activities Among the Oldest Old in Japan: Takashima Study. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 63(11), 1193–1200. https://doi.org/10.1093/gerona/63.11.1193

Erickson, K. I., Voss, M. W., Prakash, R. S., Basak, C., Szabo, A., Chaddock, L., Kim, J. S., Heo, S., Alves, H., White, S. M., Wojcicki, T. R., Mailey, E., Vieira, V. J., Martin, S. A., Pence, B. D., Woods, J. A., McAuley, E., & Kramer, A. F. (2011). Exercise training increases size of hippocampus and improves memory. Proceedings of the National Academy of Sciences, 108(7), 3017–3022. https://doi.org/10.1073/pnas.1015950108

Etnier, J. L., & Labban, J. D. (2012, May 11). Physical Activity and Cognitive Function: Theoretical Bases, Mechanisms, and Moderators. The Oxford Handbook of Exercise Psychology. https://doi.org/10.1093/oxfordhb/9780195394313.013.0005

Fang, J., Power, M., Lin, Y., Zhang, J., Hao, Y., and Chatterji, S. (2012). Development of short versions for the WHOQOL-OLD module. Gerontol. 52, 66–78. doi: 10.1093/geront/gnr085

Farfel, J. M., Nitrini, R., Suemoto, C. K., Grinberg, L. T., Ferretti, R. E. L., Leite, R. E. P., et al. (2013). Very low levels of education and cognitive reserve: a clinicopathologic study. Neurology 81, 650–657. doi: 10.1212/WNL. 0b013e3182a08f1b

Faul, F., Erdfelder, E., Lang, A.-G., and Buchner, A. (2007). G∗Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav. Res. Methods 39, 175–191. doi: 10.3758/BF0319 3146

Fleming, D., Belleville, S., Peretz, I., West, G., & Zendel, B. R. (2019). The effects of short-term musical training on the neural processing of speech-in-noise in older adults. Brain and Cognition, 136, 103592. https://doi.org/10.1016/j.bandc.2019.103592

Folstein, M. F., Folstein, S. E., and McHugh, P. R. (1975). “Mini-mental state”: a practical method for grading the cognitive state of patients for the clinician. J. Psychiatr. Res. 12, 189–198. doi: 10.1016/0022-3956(75)90 026-6

Fong, T. G., Gleason, L. J., Wong, B., Habtemariam, D., Jones, R. N., Schmitt, E. M., et al. (2015). Cognitive and physical demands of activities of daily living in older adults: validation of expert panel ratings. PM R 7, 727–735. doi: 10.1016/j.pmrj.2015.01.018

Franco, A., Malhotra, N., & Simonovits, G. (2014). Publication bias in the social sciences: Unlocking the file drawer. Science, 345(6203), 1502–1505. https://doi.org/10.1126/science.1255484

Gallardo-Gómez, D., del Pozo-Cruz, J., Noetel, M., Álvarez-Barbosa, F., Alfonso-Rosa, R. M., & del Pozo Cruz, B. (2022). Optimal dose and type of exercise to improve cognitive function in older adults: A systematic review and bayesian model-based network meta-analysis of RCTs. Ageing Research Reviews, 76, 101591. https://doi.org/10.1016/j.arr.2022.101591

Gallun, F. J., Diedesch, A. C., Kampel, S. D., & Jakien, K. M. (2013). Independent impacts of age and hearing loss on spatial release in a complex auditory environment. Frontiers in Neuroscience, 7, 252. https://doi.org/10.3389/fnins.2013.00252

Gallun, F. J., Seitz, A., Eddins, D. A., Molis, M. R., Stavropoulos, T., Jakien, K. M., Kampel, S. D., Diedesch, A. C., Hoover, E. C., Bell, K., Souza, P. E., Sherman, M., Calandruccio, L., Xue, G., Taleb, N., Sebena, R., & Srinivasan, N. (2018). Development and validation of Portable Automated Rapid Testing (PART) measures for auditory research. Proceedings of Meetings on Acoustics. Acoustical Society of America, 33(1). https://doi.org/10.1121/2.0000878

Grassi, M., Meneghetti, C., Toffalini, E., & Borella, E. (2017). Auditory and cognitive performance in elderly musicians and nonmusicians. PLOS ONE, 12(11), e0187881. https://doi.org/10.1371/journal.pone.0187881

Groot, C., Hooghiemstra, A. M., Raijmakers, P. G. H. M., van Berckel, B. N. M., Scheltens, P., Scherder, E. J. A., van der Flier, W. M., & Ossenkoppele, R. (2016). The effect of physical activity on cognitive function in patients with dementia: A meta-analysis of randomized control trials. Ageing Research Reviews, 25, 13–23. https://doi.org/10.1016/j.arr.2015.11.005

Guiney, H., and Machado, L. (2018). Volunteering in the community: potential benefits for cognitive aging. J. Gerontol. Ser. B Psychol. Sci. Soc. Sci. 73, 399–408. doi: 10.1093/geronb/gbx134

Guiney, H., Keall, M., and Machado, L. (2021). Volunteering in older adulthood is associated with activity engagement and cognitive functioning. Aging Neuropsychol. Cogn. 28, 253–269. doi: 10.1080/13825585.2020.174 3230

Habibi, A., Damasio, A., Ilari, B., Elliott Sachs, M., & Damasio, H. (2018). Music training and child development: A review of recent findings from a longitudinal study: Music training and child development: a review. Annals of the New York Academy of Sciences, 1423(1), 73–81. https://doi.org/10.1111/nyas.13606

Hartshorne, J. K., & Germine, L. T. (2015). When Does Cognitive Functioning Peak? The Asynchronous Rise and Fall of Different Cognitive Abilities Across the Life Span. Psychological Science, 26(4), 433–443. https://doi.org/10.1177/0956797614567339

He, W., Goodkind, D., and Kowal, P. (2016). An aging World: 2015. International Population Reports. Available online at: https://www.census.gov/content/dam/ Census/library/publications/2016/demo/p95-16-1.pdf (accessed October 1, 2020).

Hekler, E. B., Buman, M. P., Haskell, W. L., Conway, T. L., Cain, K. L., Sallis, J. F., et al. (2012). Reliability and validity of CHAMPS self-reported sedentary- to-vigorous intensity physical activity in older adults. J. Phys. Activ. Health 9, 225–236. doi: 10.1123/jpah.9.2.225

Hill, N. T. M., Mowszowski, L., Naismith, S. L., Chadwick, V. L., Valenzuela, M., & Lampit, A. (2017). Computerized Cognitive Training in Older Adults With Mild Cognitive Impairment or Dementia: A Systematic Review and Meta-Analysis. American Journal of Psychiatry, 174(4), 329–340. https://doi.org/10.1176/appi.ajp.2016.16030360

Holochwost, S. J., Propper, C. B., Wolf, D. P., Willoughby, M. T., Fisher, K. R., Kolacz, J., Volpe, V. V., & Jaffee, S. R. (2017). Music education, academic achievement, and executive functions. Psychology of Aesthetics, Creativity, and the Arts, 11(2), 147–166. https://doi.org/10.1037/aca0000112

Hooren, S. A. H., van Valentijn, A. M., Bosma, H., Ponds, R. W. H. M., Boxtel, M. P. J., van, et al. (2007). Cognitive functioning in healthy older adults Aged 64–81: a cohort study into the effects of age, sex, and education. Aging Neuropsychol. Cogn. 14, 40–54. doi: 10.1080/13825589096 9483

Hultsch, D. F., Hertzog, C., Small, B. J., & Dixon, R. A. (1999). Use it or lose it: Engaged lifestyle as a buffer of cognitive decline in aging? Psychology and Aging, 14(2), 245–263. https://doi.org/10.1037/0882-7974.14.2.245

Huxhold, O., Miche, M., & Schüz, B. (2014). Benefits of Having Friends in Older Ages: Differential Effects of Informal Social Activities on Well-Being in Middle-Aged and Older Adults. The Journals of Gerontology: Series B, 69(3), 366–375. https://doi.org/10.1093/geronb/gbt029

Hwang, J., Brothers, R. M., Castelli, D. M., Glowacki, E. M., Chen, Y. T., Salinas, M. M., et al. (2016). Acute high-intensity exercise-induced cognitive enhancement and brain-derived neurotrophic factor in young, healthy adults. Neurosci. Lett. 630, 247–253. doi: 10.1016/j.neulet.2016. 07.033

Ihle, A., Gouveia, ÉR., Gouveia, B. R., Freitas, D. L., Jurema, J., Odim, A. P., et al. (2017). The relation of education, occupation, and cognitive activity to cognitive status in old age: the role of physical frailty. Int. Psychogeriatr. 29, 1469–1474. doi: 10.1017/S1041610217000795

Iizuka, A., Suzuki, H., Ogawa, S., Takahashi, T., Murayama, S., Kobayashi, M., & Fujiwara, Y. (2021). Association between the frequency of daily intellectual activities and cognitive domains: A cross-sectional study in older adults with complaints of forgetfulness. Brain and Behavior, 11(1), e01923. https://doi.org/10.1002/brb3.1923

Iordan, A. D., Cooke, K. A., Moored, K. D., Katz, B., Buschkuehl, M., Jaeggi, S. M., et al. (2018). Aging and Network Properties: Stability Over Time and Links with Learning during Working Memory Training. Front. Aging Neurosci. 9:419. doi: 10.3389/fnagi.2017.00419

Jaeggi, S. M., Buschkuehl, M., Parlett-Pelleriti, C. M., Moon, S. M., Evans, M., Kritzmacher, A., Reuter-Lorenz, P. A., Shah, P., & Jonides, J. (2020). Investigating the Effects of Spacing on Working Memory Training Outcome: A Randomized, Controlled, Multisite Trial in Older Adults. The Journals of Gerontology: Series B, 75(6), 1181–1192. https://doi.org/10.1093/geronb/gbz090

Jagger, C., Matthews, F. E., Wohland, P., Fouweather, T., Stephan, B. C. M., Robinson, L., Arthur, A., & Brayne, C. (2016). A comparison of health expectancies over two decades in England: Results of the Cognitive Function and Ageing Study I and II. The Lancet, 387(10020), 779–786. https://doi.org/10.1016/S0140-6736(15)00947-2

James, B. D., Wilson, R. S., Barnes, L. L., & Bennett, D. A. (2011). Late-Life Social Activity and Cognitive Decline in Old Age. Journal of the International Neuropsychological Society, 17(6), 998–1005. https://doi.org/10.1017/S1355617711000531

Jeon, S., Lee, S., & Charles, S. T. (2022). Not Just How Much, But How Many: Overall and Domain-Specific Activity Variety and Cognitive Functioning in Adulthood. The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences, 77(7), 1229–1239. https://doi.org/10.1093/geronb/gbac053

Jivraj, S., Goodman, A., Pongiglione, B., & Ploubidis, G. B. (2020). Living longer but not necessarily healthier: The joint progress of health and mortality in the working-age population of England. Population Studies, 74(3), 399–414. https://doi.org/10.1080/00324728.2020.1767297

Kawas, C. H. (2006). Medications and Diet Protective Factors for AD? Alzheimer Disease and Associated Disorders, 20(3 Suppl 2), S89–S96.

Kawas, C. H. (2008). The oldest old and the 90+ Study. Alzheimers Dement. 4, S56–S59. doi: 10.1016/j.jalz.2007.11.007

Kesse-Guyot, E., Charreire, H., Andreeva, V. A., Touvier, M., Hercberg, S., Galan, P., & Oppert, J.-M. (2012). Cross-Sectional and Longitudinal Associations of Different Sedentary Behaviors with Cognitive Performance in Older Adults. PLOS ONE, 7(10), e47831. https://doi.org/10.1371/journal.pone.0047831

Köhncke, Y., Laukka, E. J., Brehmer, Y., Kalpouzos, G., Li, T.-Q., Fratiglioni, L., Bäckman, L., & Lövdén, M. (2016). Three-year changes in leisure activities are associated with concurrent changes in white matter microstructure and perceptual speed in individuals aged 80 years and older. Neurobiology of Aging, 41, 173–186. https://doi.org/10.1016/j.neurobiolaging.2016.02.013

Kramer, A. F., & Erickson, K. I. (2007). Capitalizing on cortical plasticity: Influence of physical activity on cognition and brain function. Trends in Cognitive Sciences, 11(8), 342–348. https://doi.org/10.1016/j.tics.2007.06.009

Krell-Roesch, J., Syrjanen, J. A., Vassilaki, M., Machulda, M. M., Mielke, M. M., Knopman, D. S., et al. (2019). Quantity and quality of mental activities and the risk of incident mild cognitive impairment. Neurology 93, e548–e558. doi: 10.1212/WNL.0000000000007897

Krueger, K. R., Wilson, R. S., Kamenetsky, J. M., Barnes, L. L., Bienias, J. L., & Bennett, D. A. (2009). Social Engagement and Cognitive Function in Old Age. Experimental Aging Research, 35(1), 45–60. https://doi.org/10.1080/03610730802545028

Ku, P.-W., Stevinson, C., and Chen, L.-J. (2012). Prospective associations between leisure-time physical activity and cognitive performance among older adults across an 11-year Period. J. Epidemiol. 22, 230–237. doi: 10.2188/jea. JE20110084

Lappe, C., Herholz, S. C., Trainor, L. J., & Pantev, C. (2008). Cortical Plasticity Induced by Short-Term Unimodal and Multimodal Musical Training. Journal of Neuroscience, 28(39), 9632–9639. https://doi.org/10.1523/JNEUROSCI.2254-08.2008

Leckie, R. L., Weinstein, A. M., Hodzic, J. C., & Erickson, K. I. (2012). Potential Moderators of Physical Activity on Brain Health. Journal of Aging Research, 2012, e948981. https://doi.org/10.1155/2012/948981

Lee, I. M., & Paffenbarger, R. S. (2000). Associations of light, moderate, and vigorous intensity physical activity with longevity. The Harvard Alumni Health Study. *American Journal of Epidemiology*, *151*(3), 293–299. https://doi.org/10.1093/oxfordjournals.aje.a010205

Lee, S., Charles, S. T., & Almeida, D. M. (2020). Change is Good for the Brain: Activity Diversity and Cognitive Functioning Across Adulthood. The Journals of Gerontology: Series B, gbaa020. https://doi.org/10.1093/geronb/gbaa020

Lee, Y., & Jean Yeung, W.-J. (2019). Gender matters: Productive social engagement and the subsequent cognitive changes among older adults. Social Science & Medicine, 229, 87–95. https://doi.org/10.1016/j.socscimed.2018.08.024

Lee, Y., Chi, I., and Palinkas, L. A. (2019). Retirement, leisure activity engagement, and cognition among older adults in the united states. J. Aging Health 31, 1212–1234. doi: 10.1177/0898264318767030

Lin, F. R., Yaffe, K., Xia, J., Xue, Q.-L., Harris, T. B., Purchase-Helzner, E., Satterfield, S., Ayonayon, H. N., Ferrucci, L., Simonsick, E. M., & Group, for the H. A. S. (2013). Hearing Loss and Cognitive Decline in Older Adults. JAMA Internal Medicine, 173(4), 293–299. https://doi.org/10.1001/jamainternmed.2013.1868

Lin, L., & Chu, H. (2018). Quantifying publication bias in meta-analysis. Biometrics, 74(3), 785–794. https://doi.org/10.1111/biom.12817

Loughrey, D. G., Kelly, M. E., Kelley, G. A., Brennan, S., & Lawlor, B. A. (2018). Association of Age-Related Hearing Loss With Cognitive Function, Cognitive Impairment, and Dementia: A Systematic Review and Meta-analysis. JAMA Otolaryngology–Head & Neck Surgery, 144(2), 115–126. https://doi.org/10.1001/jamaoto.2017.2513

Lövdén, M., Fratiglioni, L., Glymour, M. M., Lindenberger, U., & Tucker-Drob, E. M. (2020). Education and Cognitive Functioning Across the Life Span. Psychological Science in the Public Interest, 21(1), 6–41. https://doi.org/10.1177/1529100620920576

Mandolesi, L., Polverino, A., Montuori, S., Foti, F., Ferraioli, G., Sorrentino, P., & Sorrentino, G. (2018). Effects of Physical Exercise on Cognitive Functioning and Wellbeing: Biological and Psychological Benefits. Frontiers in Psychology, 9, 509. https://doi.org/10.3389/fpsyg.2018.00509

Manini, T. M., Everhart, J. E., Patel, K. V., Schoeller, D. A., Colbert, L. H., Visser, M., et al. (2006). Daily activity energy expenditure and mortality among older adults. JAMA 296, 171–179. doi: 10.1001/jama.296.2.171

Marquié, J. C., Duarte, L. R., Bessières, P., Dalm, C., Gentil, C., & Ruidavets, J. B. (2010). Higher mental stimulation at work is associated with improved cognitive functioning in both young and older workers. Ergonomics, 53(11), 1287–1301. https://doi.org/10.1080/00140139.2010.519125

Marquine, M. J., Segawa, E., Wilson, R. S., Bennett, D. A., and Barnes, L. L. (2012). Association between cognitive activity and cognitive function in older hispanics. J. Int. Neuropsychol. Soc. 18, 1041–1051. doi: 10.1017/ S135561771200080X

Mata, J., Thompson, R. J., Jaeggi, S. M., Buschkuehl, M., Jonides, J., and Gotlib, I. H. (2012). Walk on the bright side: physical activity and affect in major depressive disorder. J. Abnorm. Psychol. 121, 297–308. doi: 10.1037/a0023 533

McGillivray, S., and Castel, A. D. (2011). Betting on memory leads to metacognitive improvement by younger and older adults. Psychol. Aging 26, 137–142. doi: 10.1037/a0022681

Mehraei, G., Gallun, F. J., Leek, M. R., & Bernstein, J. G. W. (2014). Spectrotemporal modulation sensitivity for hearing-impaired listeners: Dependence on carrier center frequency and the relationship to speech intelligibility. The Journal of the Acoustical Society of America, 136(1), 301–316. https://doi.org/10.1121/1.4881918

Menec, V. H. (2003). The relation between everyday activities and successful aging: a 6-year longitudinal study. J. Gerontol. Ser. B Psychol. Sci. Soc. Sci. 58, S74–S82. doi: 10.1093/geronb/58.2.S74

Migeot, J., Calivar, M., Granchetti, H., Ibáñez, A., & Fittipaldi, S. (2022). Socioeconomic status impacts cognitive and socioemotional processes in healthy ageing. Scientific Reports, 12(1), Article 1. https://doi.org/10.1038/s41598-022-09580-4

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. Annals of Internal Medicine, 151(4), 264–269. https://doi.org/10.7326/0003-4819-151-4-200908180-00135

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

Müllensiefen, D., Gingras, B., Musil, J., & Stewart, L. (2014). The Musicality of Non-Musicians: An Index for Assessing Musical Sophistication in the General Population. PLOS ONE, 9(2), e89642. https://doi.org/10.1371/journal.pone.0089642

Murman, D. L. (2015). The Impact of Age on Cognition. Seminars in Hearing, 36(3), 111–121. https://doi.org/10.1055/s-0035-1555115

Newson, R. S., & Kemps, E. B. (2006). The influence of physical and cognitive activities on simple and complex cognitive tasks in older adults. Experimental Aging Research, 32(3), 341–362.

Nyberg, L. (2017). Functional brain imaging of episodic memory decline in ageing. Journal of Internal Medicine, 281(1), 65–74. https://doi.org/10.1111/joim.12533

Opdebeeck, C., Martyr, A., and Clare, L. (2016). Cognitive reserve and cognitive function in healthy older people: a meta-analysis. Aging Neuropsychol. Cogn. 23, 40–60. doi: 10.1080/13825585.2015.1041450

Orgeta, V., Mukadam, N., Sommerlad, A., & Livingston, G. (2019). The Lancet Commission on Dementia Prevention, Intervention, and Care: A call for action. Irish Journal of Psychological Medicine, 36(2), 85–88. https://doi.org/10.1017/ipm.2018.4

Otake-Matsuura, M., Tokunaga, S., Watanabe, K., Abe, M. S., Sekiguchi, T., Sugimoto, H., Kishimoto, T., & Kudo, T. (2021). Cognitive Intervention Through Photo-Integrated Conversation Moderated by Robots (PICMOR) Program: A Randomized Controlled Trial. Frontiers in Robotics and AI, 8. https://www.frontiersin.org/article/10.3389/frobt.2021.633076

Paganini-Hill, A., Kawas, C. H., & Corrada, M. M. (2011). Activities and mortality in the elderly: The Leisure World cohort study. The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 66(5), 559–567. https://doi.org/10.1093/gerona/glq237

Paganini-Hill, A., Kawas, C. H., & Corrada, M. M. (2016). Lifestyle factors and dementia in the oldest-old: The 90+ Study. Alzheimer Disease and Associated Disorders, 30(1), 21–26. https://doi.org/10.1097/WAD.0000000000000087

Paganini-Hill, A., Montine, T. J., Bukhari, S. A., Corrada, M. M., Kawas, C. H., & Sajjadi, S. A. (2023). LATE and potential estrogen-related risk factors collected 30 years earlier: The

90+ Study. Journal of Neuropathology & Experimental Neurology, 82(2), 120–126. https://doi.org/10.1093/jnen/nlac119

Pahor, A., Collins, C., Smith, R. N., Moon, A., Stavropoulos, T., Silva, I., Peng, E., Jaeggi, S. M., & Seitz, A. R. (2021). Multisensory Facilitation of Working Memory Training. Journal of Cognitive Enhancement: Towards the Integration of Theory and Practice, 5(3), 386–395. https://doi.org/10.1007/s41465-020-00196-y

Palta, P., Sharrett, A. R., Deal, J. A., Evenson, K. R., Gabriel, K. P., Folsom, A. R., et al. (2019). Leisure-time physical activity sustained since midlife and preservation of cognitive function: the atherosclerosis risk in communities study. Alzheimers Dement. 15, 273–281. doi: 10.1016/j.jalz.2018.08.008

Panza, G. A., Taylor, B. A., MacDonald, H. V., Johnson, B. T., Zaleski, A. L., Livingston, J., Thompson, P. D., & Pescatello, L. S. (2018). Can Exercise Improve Cognitive Symptoms of Alzheimer's Disease? Journal of the American Geriatrics Society, 66(3), 487–495. https://doi.org/10.1111/jgs.15241

Parbery-Clark, A., Skoe, E., & Kraus, N. (2009). Musical experience limits the degradative effects of background noise on the neural processing of sound. The Journal of Neuroscience, 29(45), 14100–14107. http://dx.doi.org/10.1523/JNEUROSCI.3256-09.2009

Parbery-Clark, A., Strait, D. L., Anderson, S., Hittner, E., & Kraus, N. (2011). Musical Experience and the Aging Auditory System: Implications for Cognitive Abilities and Hearing Speech in Noise. PLoS One; San Francisco, 6(5), e18082. http://dx.doi.org/10.1371/journal.pone.0018082

Parisi, J. M., Stine-Morrow, E. A. L., Noh, S. R., & Morrow, D. G. (2009). Predispositional Engagement, Activity Engagement, and Cognition among Older Adults. Aging, Neuropsychology, and Cognition, 16(4), 485–504. https://doi.org/10.1080/13825580902866653

Park, D. C., Lodi-Smith, J., Drew, L., Haber, S., Hebrank, A., Bischof, G. N., & Aamodt, W. (2014). The Impact of Sustained Engagement on Cognitive Function in Older Adults: The Synapse Project. Psychological Science, 25(1), 103–112. https://doi.org/10.1177/0956797613499592

Park, S., Choi, B., Choi, C., Kang, J. M., & Lee, J.-Y. (2018). Relationship between education, leisure activities, and cognitive functions in older adults. Aging & Mental Health. https://www.tandfonline.com/doi/abs/10.1080/13607863.2018.1512083

Park, S., Choi, B., Choi, C., Kang, J. M., & Lee, J.-Y. (2019). Relationship between education, leisure activities, and cognitive functions in older adults. Aging & Mental Health, 23(12), 1651–1660. http://dx.doi.org/10.1080/13607863.2018.1512083

Parlett-Pelleriti, C., Lin, G. C., Jones, M. R., Linstead, E., and Jaeggi, S. M. (2019). Exploring age-related metamemory differences using modified brier scores and hierarchical clustering. Open Psychol. 1, 215–238. doi: 10.1515/psych-2018-0015

Pastor, D. A., & Lazowski, R. A. (2018). On the Multilevel Nature of Meta-Analysis: A Tutorial, Comparison of Software Programs, and Discussion of Analytic Choices. Multivariate Behavioral Research, 53(1), 74–89. https://doi.org/10.1080/00273171.2017.1365684

Perissinotto, C., Holt-Lunstad, J., Periyakoil, V. S., and Covinsky, K. (2019). A practical approach to assessing and mitigating loneliness and isolation in older adults. J. Am. Geriatr. Soc. 67, 657–662. doi: 10.1111/jgs.15 746

Perrig, W. J., Etienne, A., Jaeggi, S. M., Blaser, D., Meier, B., Hofer, D., et al. (2006). Computerunterstuützter Gedächtnis- Funktion-Test (C-GFT) (Version 3.1). Bern: Universitat Bern.

Phillips, C. (2017). Lifestyle modulators of neuroplasticity: how physical activity, mental engagement, and diet promote cognitive health during aging. Neural Plastic. 2017, 1–22. doi: 10.1155/2017/3589271

Poelke, G., Ventura, M. I., Byers, A. L., Yaffe, K., Sudore, R., and Barnes, D. E. (2016). Leisure activities and depressive symptoms in older adults with cognitive complaints. Int. Psychogeriatr. 28, 63–69. doi: 10.1017/ S1041610215001246

Power, R., Prado-Cabrero, A., Mulcahy, R., Howard, A., and Nolan, J. M. (2019). The role of nutrition for the aging population: implications for cognition and alzheimer's disease. Annu. Rev. Food Sci. Technol. 10, 619–639. doi: 10.1146/ annurev-food-030216-030125

Pustejovsky, J. (2023). clubSandwich: Cluster-Robust (Sandwich) Variance Estimators with Small-Sample Corrections. R package version 0.5.10.9999, http://jepusto.github.io/clubSandwich/.

Pustejovsky, J. E., & Tipton, E. (2022). Meta-analysis with Robust Variance Estimation: Expanding the Range of Working Models. Prevention Science, 23(3), 425–438. https://doi.org/10.1007/s11121-021-01246-3

R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Rapp, M. A., Schnaider-Beeri, M., Sano, M., Silverman, J. M., & Haroutunian, V. (2005). Cross-domain variability of cognitive performance in very old nursing home residents and community dwellers: Relationship to functional status. Gerontology, 51(3), 206–212. https://doi.org/10.1159/000083995

Redick, T. S., Broadway, J. M., Meier, M. E., Kuriakose, P. S., Unsworth, N., Kane, M. J., et al. (2012). Measuring working memory capacity with automated complex span tasks. Eur. J. Psychol. Assess. 28, 164–171. doi: 10.1027/15-5759/ A000123

Rigg, M. G. (1964). The Mood Effects of Music: A Comparison of Data from Four Investigators. The Journal of Psychology, 58(2), 427–438. https://doi.org/10.1080/00223980.1964.9916765

Rodgers, M. A., & Pustejovsky, J. E. (2020). Evaluating meta-analytic methods to detect selective reporting in the presence of dependent effect sizes. Psychological Methods. https://doi.org/10.1037/met0000300

Saarikallio, S. H. (2008). Music in Mood Regulation: Initial Scale Development. Musicae Scientiae, 12(2), 291–309. https://doi.org/10.1177/102986490801200206

Sachs, M., Kaplan, J., Der Sarkissian, A., & Habibi, A. (2017). Increased engagement of the cognitive control network associated with music training in children during an fMRI Stroop task. PLOS ONE, 12(10), e0187254. https://doi.org/10.1371/journal.pone.0187254

Sala, G., & Gobet, F. (2020). Cognitive and academic benefits of music training with children: A multilevel meta-analysis. https://doi.org/10.31234/osf.io/7s8wr

Salthouse, T. A. (2009). When does age-related cognitive decline begin? Neurobiology of Aging, 30(4), 507–514. https://doi.org/10.1016/j.neurobiolaging.2008.09.023

Salthouse, T. A., Berish, D. E., and Miles, J. D. (2002). The role of cognitive stimulation on the relations between age and cognitive functioning. Psychol. Aging 17, 548–557.

Särkämö, T., & Sihvonen, A. J. (2018). Golden oldies and silver brains: Deficits, preservation, learning, and rehabilitation effects of music in ageing-related neurological disorders. Cortex, 109, 104–123. https://doi.org/10.1016/j.cortex.2018.08.034

Sarkamo, T., Tervaniemi, M., Laitinen, S., Forsblom, A., Soinila, S., Mikkonen, M., Autti, T., Silvennoinen, H. M., Erkkila, J., Laine, M., Peretz, I., & Hietanen, M. (2008). Music listening enhances cognitive recovery and mood after middle cerebral artery stroke. Brain, 131(3), 866–876. https://doi.org/10.1093/brain/awn013

Sattelmair, J. R., Pertman, J. H., & Forman, D. E. (2009). Effects of Physical Activity on Cardiovascular and Noncardiovascular Outcomes in Older Adults. Clinics in Geriatric Medicine, 25(4), 677–702. https://doi.org/10.1016/j.cger.2009.07.004

Sattler, C., Toro, P., Schönknecht, P., and Schröder, J. (2012). Cognitive activity, education and socioeconomic status as preventive factors for mild cognitive impairment and alzheimer’s disease. Psychiatry Res. 196, 90–95. doi: 10.1016/ j.psychres.2011.11.012

Scarmeas, N., & Stern, Y. (2003). Cognitive Reserve and Lifestyle. Journal of Clinical and Experimental Neuropsychology, 25(5), 625–633. https://doi.org/10.1076/jcen.25.5.625.14576

Schmidt, A. F., and Finan, C. (2018). Linear regression and the normality assumption. J. Clini. Epidemiol. 98, 146–151. doi: 10.1016/j.jclinepi.2017.12. 006

Schneeweis, N., Skirbekk, V., & Winter-Ebmer, R. (2014). Does Education Improve Cognitive Performance Four Decades After School Completion? Demography, 51(2), 619–643. https://doi.org/10.1007/s13524-014-0281-1

Schuch, F. B., Vancampfort, D., Rosenbaum, S., Richards, J., Ward, P. B., Veronese, N., et al. (2016). Exercise for depression in older adults: a meta-analysis of randomized controlled trials adjusting for publication bias. Rev. Brasil. Psiquiatr. 38, 247–254. doi: 10.1590/1516-4446-2016- 1915

Seblova, D., Fischer, M., Fors, S., Johnell, K., Karlsson, M., Nilsson, T., Svensson, A. C., Lövdén, M., & Lager, A. (2021). Does Prolonged Education Causally Affect Dementia Risk When Adult Socioeconomic Status Is Not Altered? A Swedish Natural Experiment in 1.3 Million Individuals. American Journal of Epidemiology, 190(5), 817–826. https://doi.org/10.1093/aje/kwaa255

Seeman, T. E., Lusignolo, T. M., Albert, M., & Berkman, L. (2001). Social relationships, social support, and patterns of cognitive aging in healthy, high-functioning older adults: MacArthur Studies of Successful Aging. Health Psychology, 20(4), 243–255. https://doi.org/10.1037//0278-6133.20.4.243

Sihvonen, A. J., Särkämö, T., Leo, V., Tervaniemi, M., Altenmüller, E., & Soinila, S. (2017). Music-based interventions in neurological rehabilitation. The Lancet Neurology, 16(8), 648–660. https://doi.org/10.1016/S1474-4422(17)30168-0

Sims, R. C., Hosey, M., Levy, S.-A., Whitfield, K. E., Katzel, L. I., & Waldstein, S. R. (2014). Distinct Functions of Social Support and Cognitive Function Among Older Adults. Experimental Aging Research, 40(1), 40–59. https://doi.org/10.1080/0361073X.2014.857551

Singh-Manoux, A., Richards, M., Marmot, M. (2003). Leisure activities and cognitive function in middle age: evidence from the whitehall II study. J. Epidemiol. Commun. Health 57, 907–913. doi: 10.1136/jech.57. 11.907

Sixsmith, A., & Gibson, G. (2007). Music and the wellbeing of people with dementia. Ageing & Society, 27(1), 127–145. https://doi.org/10.1017/S0144686X06005228

Slater, J. (2015). Music training improves speech-in-noise perception: Longitudinal evidence from a community-based music program. Behavioural Brain Research, 9.

Small, B.J., Dixon, R.A., McArdle, J.J., Grimm, K.J. (2012). Do changes in lifestyle engagement moderate cognitive decline in normal aging? Evidence from the Victoria Longitudinal Study. Neuropsychology, 26(2), 144-55. https://doi.org/10.1037/a0026579

Snodgrass, J. G., and Vanderwart, M. (1980). A standardized set of 260 pictures: norms for name agreement, image agreement, familiarity, and visual complexity. J. Exp. Psychol. Hum. Learn. Mem. 6, 174–215. doi: 10.1037/0278- 7393.6.2.174

Song, J. H., Skoe, E., Banai, K., & Kraus, N. (2011). Perception of speech in noise: Neural correlates. Journal of Cognitive Neuroscience, 23(9), 2268–2279. http://dx.doi.org/10.1162/jocn.2010.21556

Spitzer, R. L., Kroenke, K., Williams, J. B., and Löwe, B. (2006). A brief measure for assessing generalized anxiety disorder: the GAD-7. Arch. Intern. Med. 166, 1092−1097. doi: 10.1001/archinte.166.10.1092

Sposito, G., Neri, A. L., & Yassuda, M. S. (2015). Cognitive performance and engagement in physical, social and intellectual activities in older adults: The FIBRA study. Dementia & Neuropsychologia, 9, 270–278. https://doi.org/10.1590/1980-57642015DN93000010

Stenling, A., Sörman, D. E., Lindwall, M., Hansson, P., Körning Ljungberg, J., & Machado, L. (2021). Physical activity and cognitive function: Between-person and within-person associations and moderators. Aging, Neuropsychology, and Cognition, 28(3), 392–417. https://doi.org/10.1080/13825585.2020.1779646

Stepankova, H., Lukavsky, J., Buschkuehl, M., Kopecek, M., Ripova, D., & Jaeggi, S. M. (2014). The malleability of working memory and visuospatial skills: A randomized controlled study in older adults. Developmental Psychology, 50(4), 1049–1059. https://doi.org/10.1037/a0034913

Stern, C., and Munn, Z. (2010). Cognitive leisure activities and their role in preventing dementia: a systematic review. Int. J. Evid. Based Healthc. 8, 2–17. doi: 10.1111/j.1744-1609.2010.00150.x

Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. Journal of the International Neuropsychological Society, 8(03), 448–460. https://doi.org/10.1017/S1355617702813248

Stern, Y. (2009). Cognitive reserve. Neuropsychologia, 47(10), 2015–2028. https://doi.org/10.1016/j.neuropsychologia.2009.03.004

Stern, Y. (2012). Cognitive reserve in ageing and Alzheimer's disease. Lancet Neurol. 11, 1006–1012. doi: 10.1016/S1474-4422(12)70191-6

Stewart, A. L., Mills, K. M., King, A. C., Haskell, W. L., Gillis, D., and Ritter, P. L. (2001). CHAMPS physical activity questionnaire for older adults: outcomes for interventions. Med. Sci. Sports Exerc. 33, 1126–1141. doi: 10.1097/00005768- 200107000-00010

Tan, E. J., Xue, Q.-L., Li, T., Carlson, M. C., & Fried, L. P. (2006). Volunteering: A Physical Activity Intervention for Older Adults—The Experience Corps® Program in Baltimore. Journal of Urban Health, 83(5), 954–969. https://doi.org/10.1007/s11524-006-9060-7

Taylor, A., Cable, N., Faulkner, G., Hillsdon, M., Narici, M., & Van Der Bij, A. (2004). Physical activity and older adults: A review of health benefits and the effectiveness of interventions. Journal of Sports Sciences, 22(8), 703–725. https://doi.org/10.1080/02640410410001712421

Thomas, K. R. (2015). Understanding Errors in Complex Everyday Cognitive Tasks in Older Adults. Doctoral dissertation, University of Florida.

Thow, M. E., Summers, M. J., Saunders, N. L., Summers, J. J., Ritchie, K., and Vickers, J. C. (2017). Further education improves cognitive reserve and triggers improvement in selective cognitive functions in older adults: the Tasmanian healthy brain project. Alzheimer's Dement. Diag. Assess. Disease Monitor. 10, 22–30. doi: 10.1016/j.dadm.2017.08.004

Tombaugh, T. N. (2006). A comprehensive review of the Paced Auditory Serial Addition Test (PASAT). Archives of Clinical Neuropsychology, 21(1), 53–76. https://doi.org/10.1016/j.acn.2005.07.006

Tombaugh, T. N., and McIntyre, N. J. (1992). The mini-mental state examination: a comprehensive review. J. Am. Geriatr. Soc. 40, 922–935. doi: 10.1111/j.1532-5415.1992.tb01992.x

Tucker-Drob, E. M., Johnson, K. E., and Jones, R. N. (2009). The cognitive reserve hypothesis: a longitudinal examination of age-associated declines in reasoning and processing speed. Dev. Psychol. 45, 431–446. doi: 10.1037/a0014012

United Nations. (2023). Leaving no one behind in an ageing world: World social report 2023. https://www.un.org/development/desa/dspd/world-social-report/2023-2.html

Valenzuela, M. J., and Sachdev, P. (2006). Brain reserve and cognitive decline: a non-parametric systematic review. Psychol. Med. 36, 1065–1073. doi: 10.1017/ S0033291706007744

Verghese, J., Lipton, R. B., Katz, M. J., Hall, C. B., Derby, C. A., Kuslansky, G., et al. (2003). Leisure activities and the risk of dementia in the elderly. N. Engl. J. Med. 348, 2508–2516. doi: 10.1056/NEJMoa022252

Viechtbauer, W. (2010). Conducting Meta-Analyses in R with the metafor Package. Journal of Statistical Software, 36(1), Article 1. https://doi.org/10.18637/jss.v036.i03

Vogel, T., Brechat, P.-H., Leprêtre, P.-M., Kaltenbach, G., Berthel, M., & Lonsdorfer, J. (2009). Health benefits of physical activity in older patients: A review. International Journal of Clinical Practice, 63(2), 303–320. https://doi.org/10.1111/j.1742-1241.2008.01957.x

Weaver, A. N., & Jaeggi, S. M. (2021). Activity Engagement and Cognitive Performance Amongst Older Adults. Frontiers in Psychology, 12. https://doi.org/10.3389/fpsyg.2021.620867

White-Schwoch, T., Carr, K. W., Anderson, S., Strait, D. L., & Kraus, N. (2013). Older Adults Benefit from Music Training Early in Life: Biological Evidence for Long-Term Training-Driven Plasticity. Journal of Neuroscience, 33(45), 17667–17674. https://doi.org/10.1523/JNEUROSCI.2560-13.2013

Wong, P. C. M., Ettlinger, M., Sheppard, J. P., Gunasekera, G. M., & Dhar, S. (2010). Neuroanatomical characteristics and speech perception in noise in older adults. Ear and Hearing, 31(4), 471–479. https://doi.org/10.1097/AUD.0b013e3181d709c2

Yaffe, K., Fiocco, A. J., Lindquist, K., Vittinghoff, E., Simonsick, E. M., Newman, A. B., Satterfield, S., Rosano, C., Rubin, S. M., Ayonayon, H. N., Harris, T. B., & Health ABC Study. (2009). Predictors of maintaining cognitive function in older adults: The Health ABC study. Neurology, 72(23), 2029–2035. https://doi.org/10.1212/WNL.0b013e3181a92c36

Yesavage, J. A. (1988). Geriatric depression scale. Psychopharmacol. Bull. 24, 709–711. doi: 10.1037/t01786-000

Zhang, M., Gale, S. D., Erickson, L. D., Brown, B. L., Woody, P., & Hedges, D. W. (2015). Cognitive function in older adults according to current socioeconomic status. Aging, Neuropsychology, and Cognition, 22(5), 534–543. https://doi.org/10.1080/13825585.2014.997663

Zhang, W., Tang, F., Chen, Y., Silverstein, M., Liu, S., & Dong, X. (2019). Education, Activity Engagement, and Cognitive Function in US Chinese Older Adults. Journal of the American Geriatrics Society, 67(S3), S525–S531. https://doi.org/10.1111/jgs.15560

Zheng, Y., Cheung, K. S. L., & Yip, P. S. F. (2020). Are We Living Longer and Healthier? Journal of Aging and Health, 32(10), 1645–1658. https://doi.org/10.1177/0898264320950067

Zunzunegui, M.-V., Alvarado, B. E., Del Ser, T., & Otero, A. (2003). Social Networks, Social Integration, and Social Engagement Determine Cognitive Decline in Community-Dwelling Spanish Older Adults. The Journals of Gerontology: Series B, 58(2), S93–S100. https://doi.org/10.1093/geronb/58.2.S93