THE ASSOCIATION BETWEEN LIGHT PHYSICAL ACTIVITY AND COGNITION AMONG ADULTS: A SCOPING REVIEW

BY

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THESIS

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ABSTRACT

Background. Regular physical activity (PA) engagement is a significant predictor of cognitive function across the lifespan. Traditionally, most of this research has focused on moderate-vigorous intensity physical activity (MVPA). With national and global health organizations issuing concrete recommendations for weekly MVPA engagement, this intensity has become the central focus for PA researchers. However, recently light physical activity (LPA) has become an area of interest. Historically treated as a "control" condition in exercise research, recent evidence suggests that LPA may exert its own health benefits, independent of MVPA engagement. These recent studies have primarily focused on the relationship between LPA and health outcomes such as morbidity and mortality risk and have not investigated a possible relationship with cognitive function. **Purpose:** The purpose of this scoping review is to catalog the existing evidence on the association between objectively measured LPA and cognition among adults, identify trends in the literature, and pinpoint future areas of research to optimize the use of PA, especially LPA, to promote healthy cognitive functioning. **Methods:** Among the six databases searched, 38 published studies met the inclusion criteria. Sample characteristics ranged from healthy to clinical populations and were primarily conducted with young and older adults. Among the 38 articles meeting the inclusion criteria 14 were acute exercise studies, four randomized control trials (RCTs), 16 cross-sectional studies, and four longitudinal studies. **Results:** 7/14 (50%) acute, 3/4 (75%) RCT, 8/16 (50%) cross-sectional, and 2/4 (50%) longitudinal studies reported a significant, positive relationship between LPA and one or more cognitive outcomes. These heterogeneous findings can largely be attributed to the diverse study designs and populations, as well as the numerous assessments used to test the cognitive domains. **Conclusion:** The collective findings among the reviewed studies indicate that LPA holds promise to have a positive, independent influence on cognitive functioning. However, the inconsistent approaches used among these studies suggests a more concerted, unified scientific approach is need to further understand the LPA-cognition relationship.

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CHAPTER 1: INTRODUCTION

Physical activity (PA) is a behavior which undisputedly enhances physical and mental health across the lifespan. Moderate-vigorous intensity physical activity (MVPA) has traditionally been promoted as the most effective intensity level to induce the greatest health benefits, with official global recommendations to achieve a minimum of 150 minutes per week of moderate-intensity, or 75 minutes per week of vigorous-intensity exercise (World Health Organization, 2010). However, 31.1% of adults across the globe do not meet these recommendations (Hallal et al., 2012), and individual states within the United States were reported to have between 17.3-47.7% of adults who were physically inactive (Centers for Disease Control and Prevention, 2020). Intrapersonal factors (such as lack of self-efficacy, motivation, or enjoyment) and environmental factors (such as decreases in occupational PA, increased availability of labor-saving technology and increased reliance on passive commuting) have largely contributed to the declines in MVPA engagement and increased sedentary time (Dunstan et al., 2009; Hallal et al., 2012; Lewis et al., 2016; McAuley & Blissmer, 2000; Ryan et al., 1997). Additionally, across the globe the number of adults ≥ 60 years of age is expected to compose of 22% of the total population by 2050 (World Health Organization, 2017), which will have vast implications of global health care systems. While PA engagement is largely promoted as a lifestyle behavior for healthy aging, this population often faces age-related functional and physical limitations preventing MVPA participation (Schutzer & Graves, 2004). Thus, the overall lack of MVPA engagement and across populations, either voluntary or forced due to health limitations, largely suggests that individuals are falling short of being their healthiest selves. However, it should be noted that traditionally, physical inactivity status has been primarily based on an individual's MVPA engagement (Booth et al., 2017). While the health benefits of MVPA are undisputed, characterizing an individual based on this dichotomous criteria can unintentionally limit the scope of the field by brushing aside potential benefits of other types of behaviors, such as light physical activity (LPA).

LPA, defined as any activity requiring an energy expenditure of 1.6-2.9 METs (Physical Activity Guidelines Advisory Committee, 2018), is an emerging area of interest for its independent contribution to physical health (Buman et al., 2010; Gando et al., 2010; Healy et al., 2007). After sedentary behavior, which makes up approximately 9.3 hours or 60% of waking hours, LPA is the most engaged in behavior by making up 6.5 hours or 35% of a waking hours (Dunstan et al., 2009), suggesting easy incorporation into most adults' everyday lifestyles. Currently no specific guidelines exist for LPA engagement, but broad recommendations of "move more, sit less" are promoted by the Centers for Disease Control and Prevention (CDC) among their official recommendations (Centers for Disease Control and Prevention, n.d.). More recently, researchers have begun studying the positive health contributions of LPA, especially in the context of cardio metabolic risk and mortality, independent of MVPA engagement (Ku et al., 2019; LaMonte et al., 2017). A systematic review of studies utilizing accelerometer data from the National Health and Nutrition Examination Survey (NHANES) observed LPA's favorable, significant associations with insulin sensitivity, triglyceride and high-density lipoprotein cholesterol levels, adiposity measures (i.e. body mass index, waist circumference, and triceps skinfold), diabetes, and mortality risk (Füzéki et al., 2017). However, the authors noted that of the 40 studies included in the review, only 18 adjusted for MVPA. A more recent systematic review by Amagasa et al. (2018) built on these previous findings by only including studies which adjusted for MVPA, and largely corroborated the findings by Füzéki et al (2017). Independent of MVPA participation, Amagasa et al. (2018) found LPA was inversely associated with metabolic syndrome, waist circumference, triglyceride levels, insulin and mortality. Notably, the research team included cognitive function as one of the reviewed health-related outcomes. Only two studies met their inclusion criteria and were reviewed, with inconsistent findings, indicating that the cognitive implications of LPA engagement are less clear and are in need of a more thorough investigation.

Therefore, the purpose of this review was to map out the current evidence regarding the association of LPA and cognition among adults. Given the vast number of research designs, populations studied, and cognitive outcomes investigated across the studies, a scoping review was identified as the most appropriate approach to examine the current status of research activity and catalog the existing evidence (Levac et al., 2010). The intention of this review was in line with the four reasons proposed by Arksey and O'Malley (2005) regarding the purpose of a scoping review. As the authors described, the first reason is to "examine the extent, range, and nature of research activity." Given the varying methodologies and parameters used when studying the cognitive outcomes associated with LPA, it is necessary to develop a comprehensive map of the field. This map will contribute to the second reason for the scoping review, which is "to determine the value of undertaking a full systematic review" (Arksey & O'Malley, 2005). Systematic reviews, by nature, are intended to provide a narrower focus and apply a rigorous review process on a defined research question. The third purpose for this scoping review is "to summarize and disseminate research findings" (Arksey & O'Malley, 2005), by cataloging the range of previous studies and their findings. This will ultimately fulfill the fourth and final purpose of this scoping review, which is "to identify research gaps in the existing literature" (Arksey & O'Malley, 2005). It is with this final purpose where the overarching objective of this present review lies - to consolidate the literature examining the efficacy of LPA to impact cognitive function and develop a foundation for future studies in this field.

CHAPTER 2: LITERATURE REVIEW

2.1 EXERCISE AND COGNITION

Physical activity (PA) engagement has been widely recognized for its cognitive benefits across the lifespan (Bherer et al., 2013; Cox et al., 2016; Physical Activity Guidelines Advisory Committee, 2018; Sibley & Etnier, 2003). Neuroimaging studies have found regular PA significantly contributes to the increase of gray matter volume within select regions in the brain, notably the hippocampus and prefrontal cortex (Erickson et al., 2011, 2014). Additionally, observational and intervention-based studies have reported consistent associations between PA and improvements in memory, attention, processing speed, and executive functioning (Smith et al., 2010). However, the underlying mechanisms of this PA-cognition relationship continue to spark debate among researchers. Various hypotheses have been proposed, including: the “neurotrophic hypothesis,” which suggests that the combination of upregulated neutrophin production and cerebral blood flow increase brain plasticity and neurogenesis (Stimpson et al., 2018); the “selective improvement hypothesis” which suggests that specific regions of the brain which are most sensitive aging will also be quite sensitive to exercise, and this is why only certain regions of the brain show significant associations with PA (Smiley-Oyen et al., 2008); the “cerebral circulation hypothesis,” which suggests that PA enhances cerebral blood flow, thereby improving the efficiency in which oxygen and nutrients are delivered to the brain (Marmeleira, 2013); and the “cardiovascular fitness hypothesis,” which suggests that improvements in aerobic fitness are the driving force in the PA-cognition relationship (Kramer & Colcombe, 2003). In fact, improvements and maintenance of optimal levels of aerobic fitness, which are largely attributable to exercise at higher intensities (Garber et al., 2011) have been consistently observed as predictive of cognitive functioning across the lifespan (Chaddock et al., 2011; Kramer et al., 2005). However, lower-intensity exercise modalities such as yoga (Gothe & McAuley, 2015) and tai-chi (Chang et al., 2010) have also shown notable, significant associations with cognitive functions, indicating that high-intensity physical exertion may not be a required element when using PA as a lifestyle intervention to improve cognition. Limited research has directly investigated the changes in brain structure which occur as a result of LPA engagement. An observational study by Varma et al. (2015) examined the association between low-intensity daily walking and hippocampal volume, and found that among older females higher levels of low-intensity walking was a positive predictor of hippocampal volume (the relationship among older males was insignificant). Another recent cross-sectional study by Spartano et al. (2019) observed that among both adults who did and not meet the recommend PA guidelines, LPA was significantly, incrementally associated with higher total brain volume. Notably, the study also found that after adjusting for LPA engagement in the regression models, MVPA was no longer significantly associated with brain volume. Other low-intensity mind-body exercises, such as yoga and tai-chi, have also shown to positively, significantly alter brain volume (Gothe et al., 2019; Tao et al., 2017). This emerging evidence suggests that higher-intensity exercise may not be a required component of PA to promote changes in brain structure and volume, which often lead to positive changes in cognitive functions.

2.2 HISTORICAL APPROACHES TO STUDYING LPA IN COGNITION RESEARCH

While engagement in MVPA is a well-established predictor of cognitive functioning, the current evidence for LPA’s influence on cognition is inconclusive. One reason may be due to the fact that LPA has historically been used as a control or comparison group within studies intentionally designed to examine MVPA effects. While this is not to suggest these research designs are biased against potential LPA associations, it does highlight that LPA has not been traditionally investigated as the main treatment arm. Thus, its dosage as the control/comparison group may not have been enough to produce an observable relationship. A second reason may be the lack of rigorous LPA-based RCTs designed to elucidate potential cognitive outcomes. Previous systematic reviews and meta-analyses examining the effects of exercise interventions have primarily only examined the effects of MVPA-based interventions. While these reviews did not include specific criteria to exclude non-MVPA interventions, the lack of LPA interventions present in the reviews highlights this shortcoming in the field. Additionally, there has been a consistent lack of intensity reporting across studies which utilize light-to-moderate intensity PA (Wayne et al., 2014), further complicating how such studies are accounted for in reviews and meta-analyses. For example, a widely-cited review article by Smith et al. (2010) of the effects of aerobic exercise RCTs on neurocognitive performance included 29 studies, 11 of which did not report the intensity of the intervention. While two included studies did report setting the intensity at a rating of perceived exertion (RPE) of 9-13 (a range of which ACSM defines as light to moderate) for the exercise arm, they did not objectively monitor or report the intensity of the interventions. Among studies included in two recent systematic reviews of exercise training interventions for older adults (Bouaziz et al., 2017; Chen et al., 2020), the included studies either reported the exercise dosage at moderate-vigorous intensity or did not report intensity. Another recent meta-analysis on the effects of exercise interventions for cognitive functioning among middle-aged to older adults found a non-significant effect size of 0.10 for low-intensity exercise (Northey et al., 2018). However, though the authors stated they coded their articles based on published intensity guidelines, it is unclear which articles they coded as “low-intensity,” given that all the included studies are either described as utilizing moderate-vigorous intensities or didn’t report them. Additionally, none of the three yoga or four tai chi studies included in the meta-analysis reported intensity. While the intensity of yoga and tai chi activities can vary, they are often performed at light intensity, especially among adults > 50 years (Larson-Meyer, 2016; Smith et al., 2015). Notably though, among Northey et al. (2018)'s meta-analysis, tai-chi was reported to have a significant effect size (SMD= 0.52).

2.3 LPA AND COGNITION- CURRENT STATE OF THE FIELD

Previous epidemiological studies (Krell-Roesch et al., 2018; Lee et al., 2013; Weuve et al., 2004; Willey et al., 2016) surveying participants on specific intensities of leisure-time PA behaviors across their lifespan have found mixed associations between self-report LPA engagement and cognitive outcomes. However, these inconsistent findings may be due to 1) the nature of self-report data, which is subject to recall and response biases (Baranowski, 1988; van de Mortel, 2008) leading to over- or under-reporting of actual PA engagement (Prince et al., 2008), 2) the numerous self-report PA measures employed across the studies and operational definitions used (Matthews et al., 2019), or 3) the various statistical approaches to model PA. For example, Willey et al. (2016) grouped LPA with physical inactivity to create a "no/light leisure-time physical activity" categorical variable and found individuals in this group had worse executive function, semantic memory, and processing speeds scores. While low- to no-PA engagement has been linked to lower cognitive scores (Hillman et al., 2006), pairing these behaviors with LPA in analyses may inaccurately overshadow any possible contributions of LPA. Unfortunately, the common practice of lionizing MVPA as the primary intensity to improve health outcomes, and subsequent practice of grouping of LPA with low to no-PA engagement categories (Aichberger et al., 2010; Vuillemin et al., 2005), has possibly lead to oversight in examining the independent effects of LPA towards various health outcomes, such as cognition.

2.4 PUBLIC HEALTH IMPLICATIONS FOR LPA-COGNITION RELATIONSHIP

Understanding if LPA is associated with improved cognitive functioning, independent of MVPA participation, would have two clinically meaningful implications. The first addresses the cognitive health benefits for older adults and clinical populations, who may experience functional limitations that prevent them from engaging in MVPA (Jefferis et al., 2014). By investigating if LPA confers cognitive benefits, future interventions and health care programs can be developed for these populations with a more targeted exercise prescription following the F.I.T.T principle (frequency, intensity, time and type of exercise; ACSM, 2018), specifically geared towards lower-intensity activities that may be easy to adopt and maintain in this age group. Secondly, sedentary behavior (SB) has become alarmingly prevalent in modern society (Yang et al., 2019), especially in the workplace (Thorp et al., 2012). In response, researchers have attempted to find novel, effective interventions to reduce sitting time (Shrestha et al., 2018). Many of these interventions involve displacing sedentary time with LPA, such as incorporating desk-based exercise equipment, where users can lightly move about while continuing with their work. However, the cost of work efficiency and productivity while engaged in LPA is potentially concerning, and thus a better understanding of the acute effects of LPA on cognition may aid in the design of interventions to reduce sedentary time. Additionally, understanding how the substitution of sedentary time with acute bouts LPA throughout the day may affect cognition would hold significant clinical value across age groups, who have shown increased prevalence in sedentary behaviors over recent years (Yang et al., 2019).

Despite the emerging interest into the potential of both acute and chronic LPA engagement to improve cognitive function, the lack of a concerted approach when investigating this relationship has hindered progression of the field. Furthermore, there has been no synthesized investigation into which, if any, specific cognitive domains may be most sensitive to

LPA. There are multiple considerations when investigating this relationship, from the specificity of doses (frequency, intensity, time, and type), populations (healthy vs clinical), age range (young adult vs elderly) and cognitive domains (i.e. executive functioning, memory, and attention). Thus, the purpose of the present scoping review is to address all these considerations and synthesize the existing research on the LPA-cognition relationship that can guide future research in this field.

CHAPTER 3: METHODS

The present review has been conducted following the five-stage methodological framework suggested by Arksey & O’Malley (2005) and updated by Levac et al. (2010).

3.1 IDENTIFY THE RESEARCH QUESTION

The guiding research question for this review was “what is the current evidence regarding the association between LPA and cognition among adults?” The intentional breadth of this question allows for a large scope of the field to be surveyed. Furthermore, given LPA is a health behavior which is widely engaged in by populations of all abilities, both clinical and non-clinical adult populations were included in an effort to avoid overlooking relevant studies which may hold clinically meaningful implications. The operational definition of “cognition” was defined by the primary domains of memory, executive function, and attention and processing speed (Smith et al., 2010), with the additional parameter of “overall cognitive function” to account for studies that assessed global cognitive status (primarily in aging studies).

3.2 IDENTIFY RELEVANT STUDIES

A search string was developed by the study author (EE), with the assistance of a health sciences librarian, and was based of previously published search strings (Amagasa et al., 2018; Donnelly et al., 2016). In an effort to broadly capture studies examining LPA as a concept, specific PA modalities which can performed at light intensities (such as yoga, walking, dance, tai chi, balance and flexibility training) were not intentionally included in the search string. However, if a study whose primary aim was to study the effects of LPA, and utilized one of these modalities in the design, it was eligible for inclusion. The working definition of cognition was “the set of mental processes that contribute to perception, memory, intellect and action”

(Donnelly et al., 2016). As such, the search parameters for cognition included broad terms (i.e. cognition, cognitive function, neurocognition, brain function) as well as specified functions (i.e. memory, executive function, attention, processing speed). The following medical subject headings were specified in the search string: exercise, executive function, cognition, mental processes, memory, attention, and problem solving. A sample search string can be found in the appendix (Appendix G). Databases searched included: CINHAL, PubMed, SPORTDiscus, Scopus, Web of Science, and PsycINFO. All citations were exported to Mendeley Desktop (Version 1.19.4) and Excel, where duplicates were identified and removed.

3.3 STUDY SELECTION

Original research studies using any research design (i.e. intervention or observational) were eligible for inclusion. The inclusion criteria were: 1) include an objective measure of LPA categorized by the one of the following ACSM definitions of "very light" or "light" relative intensity: <30-39 % HRR or % VO_2 reserve; <57-63 % HRR; <37-45 %VO2max; ≤11 RPE rating on 6-20 scale (American College of Sports Medicine, 2018) OR accelerometer-classified LPA, 2) include at least one validated behavioral cognitive performance measure, 3) directly examine an association between LPA and cognitive outcome, 4) use an adult (18+) sample.

Exclusion criteria included: 1) cognitive function was used as a screening measure and not an outcome variable, 2) structural or functional brain measures (measured via MRI, fMRI, ECG, PET scans, etc.) as the only outcomes reported, 3) self-report LPA using questionnaires as the exposure variable, 4) not a full peer reviewed article (i.e. conference abstract, thesis), 5) clinical psychological outcomes (i.e. depression, anxiety), 6) LPA designated as a control condition, and 7) use of animal models. Arksey and O'Malley (2005) suggested that search criteria in scoping reviews be amendable, to allow for additional criteria to be added once greater familiarity with the field was reached. Therefore, after the initial search was conducted, EE and NG consulted on common disparities which arose between search hits and the initial criteria. Once a consensus was reached if additional exclusion criteria was necessary, another search was conducted.

The first author (EE) ran the searches and, after duplicates were removed, eliminated articles based on irrelevance of titles and abstracts. After this, full texts were retrieved and read to determine basis for inclusion. The study selection process is detailed in the PRISMA flow, found in Figure 1.

3.4 CHARTING THE DATA

Data from all identified studies was extracted using Mendeley and Excel. The following data was extracted from each article: first author, year, study design, sample characteristics (mean sample age, gender percentage breakdown, and population characteristics), how LPA was monitored during study period, definition of LPA, cognitive domain(s) assessed, cognitive assessments used, and LPA-relevant study findings. Additionally, the following data was extracted from relevant studies: time point(s) of data collection (intervention, longitudinal); accelerometer data reduction details (cross-sectional, longitudinal), length/frequency of LPA bouts (acute, intervention); population metrics of LPA, MVPA, SB (cross-sectional, longitudinal). Reported covariates used in analysis were also recorded.

The fifth and final step of the five-stage methodological framework, “collating, summarizing, and reporting the results” (Arksey & O’Malley, 2005) is detailed in the following sections.

CHAPTER 4: RESULTS

4.1 ARTICLES RETRIEVED

All searches were conducted between January-May 2020 by EE. The initial search yielded 3,108 hits, with 2,808 titles remaining after duplicates were removed. Next, all titles and abstracts were examined for relevance. After removing 2,694 irrelevant hits, 114 articles were reviewed in their entity and screened for inclusion and exclusion criteria. 80 articles were excluded, for reasons listed in the PRISMA flow, found in Figure 1. After the search was completed, an additional exclusion criterion of “LPA assessed in experimental/extraordinary conditions” was added. This was to ensure that the only articles included in the review reflected LPA, which is engaged in upon normal, everyday life. The excluded articles (n=6) examined LPA’s relationship with cognitive outcomes in the context of normobaric hypoxia, heat, and hot-humid conditions. Additionally, two articles (derived from the same study) examined LPA in the context of highly experimental conditions of only a 10-meter walk. The reference lists of the remaining articles were scanned, yielding three more articles. A single, newly published article from our lab was also included, bringing the total number of articles included in this scoping review to n=38.

4.2 ARTICLE CHARACTERISTICS

Among the reviewed articles, study designs ranged from: n=14 acute LPA; n=4 randomized control trials (RCTs); n=16 cross-sectional; and n=4 longitudinal. Overall, 34% (n=13) studies examined LPA among young adults (age range 19.1-27.8 years), 26% (n=10) examined middle-aged adults (age range 35.7-64.78 years), and 42% (n=16) examined older adults (aged 65 and older). N=1 study was comprised of both young and older adults. N=30 (79%) studies utilized non-clinical, healthy populations. All studies examined either memory (episodic, semantic, and working subdomains), attention/processing speed, and/or executive functioning. Three longitudinal studies and four cross-sectional studies also included measures of global cognitive functioning, as assessed by the following measures: the Mini-Mental State Examination (MMSE), the Montreal Cognitive Assessment (MoCA), the Six-Item Screener, the Telephonic Assessment for Dementia, the Telephone Interview for Cognitive Status, and the Ascertain Dementia 8-Item Questionnaire. The wide variety of cognitive assessments used are listed in Table 5.

4.2.1 Acute Studies Examining LPA

Among the 14 acute studies (Table 1), 11 used young adult samples (mean age range of 20.01-27.8), two used middle-aged adults (mean age range 35.7-40.2), and one study included a sample of both young and older adults (mean age 21.8 and 65.5 years, respectively). The LPA dosage (i.e. frequency, intensity, time and type) among these studies was extremely varied. The most commonly used type of LPA was a cycle ergometer, with 10 (71%) of studies using this form of exercise. Intensities ranged from 60-90 revolutions per minute (RPM) at a fixed workload of 10 watts (n=1), 30% VO_{2peak} or VO_{2max} (n=3), target HR equivalent to an RPE of 11 (n=1), 30% peak power output (PPO) (n=1), 40% PPO (n=2), 40-60% heart rate reserve (HRR) (n=1), and power output of 50 watts (n=1). The remaining four (29%) studies had participants engage in treadmill walking at intensities ranging from walking at speeds between 0.5-2.5 mph (n=1), at 40-50% age-predicted HR_{max} (n=1), and at 30% HRR (n=2). The length of LPA bouts also varied across studies, ranging from 6.5-30 minutes. Two studies did not report the specific length of LPA bout, as the bout lasted as long as it took participants to complete the cognitive assessments. Cognitive assessments were administered at various time points, with six studies administering assessments during exercise, six studies administering pre- and following different durations post LPA, and two administering only at post-LPA exercise. Post-LPA exercise time points ranged from immediately after exercise cessation to 45 minutes after cessation. Seven (50%) of studies reported at least one significant outcome between the LPA condition and a cognitive measure. Among the four studies which measured cognitive performance *immediately after* the LPA bout, two found significant pre-post changes of reduced reaction times (RT) on the Flanker task, and reduced RT and multitasking costs on the CANTAB Multitasking assessment (both measures of attention and set-shifting). Notably, the two other studies with insignificant associations also administered assessments of attention and executive functioning, including the Stroop and Flanker Task. All four studies included LPA bouts between 20-30 minutes.

Among the five studies which administered cognitive assessments *after a delayed period,* four reported significant associations among the LPA groups. These significant associations among the domains of attention/processing speed, executive functioning, and memory included: a significant pre-post reduction of RT interference control and mean RT on the Flanker task five minutes after LPA cessation; a reduction of interference scores compared to a resting control group on the Stroop task five minutes after LPA cessation; significant pre-post improvements of inverse efficiency scores on the Stroop task 10 minutes after LPA cessation; and significant improvements in episodic memory performance on the Mnemonic Discrimination task 50 minutes after LPA cessation.

Among the six studies which administered cognitive assessments *during* the exercise bout, only one study reported significant associations of shorter average reaction times on both the Stroop Task and Rosvold Continuous performance test (measures of selective and sustained attention domains, respectively), compared to a seated control.

4.2.2 Randomized Control Trials (RCTs)

Four RCTs met the inclusion criteria for the present review and are listed in Table 2. All studies included adults, with mean age ranges between 60-64 years. Three studies included primarily healthy populations, and one study focused on sub-acute and chronic, deconditioned stroke patients. Frequency of sessions ranged from three to five sessions per week for four weeks to nine months, with session times ranging from 30 to 60 minutes. Prescribed intensity was rather consistent, from 30-40% HRR (n=3) and 30-40% HR and RPE assessed maximal exertion (n=1). Types of LPA included cycling on ergometers (n=2), gymnastics (n=1), and balance + flexibility exercises (n=1). The three studies which studied healthy, non-clinical populations included moderate-intensity (n=2) and high-intensity (n=1) comparison arms. The single study with stroke patients had a control arm of no exercise, physiotherapy-only sessions.

Three studies (75%) observed that the LPA experimental group significantly increased in at least one cognitive outcome score, including increased processing speed and working memory (assessed using the Symbol Coding, Symbol Search, and Verbal Digit Span-Forward tests). Additionally, one study found significant improvements among the attention/concentration, short-term memory and higher cognitive functioning subscales on the Strub and Black Mental status test. Notably, only two studies reported controlling for covariates in analyses, which included age, sex, marital status, years of education, and depression.

4.2.3 Cross-Sectional Studies

Sixteen cross-sectional studies were included in this scoping review (Table 3), varying in sample size from 72-7,098 participants. Twelve included healthy adult samples and five studied clinical populations (ranging from peripheral arterial disease patients, schizophrenic patients, older adults with cognitive impairments, and post-menopausal breast cancer survivors), with one study including both clinical and non-clinical populations. Only one study sampled young adults (mean age 19.1 years), with the remaining studies examining middle aged to older adult populations (mean age range 41.1-83.4). All studies used accelerometers, with devices and cut points varying from the Actical (n=1; 50-1065 cpm), Active Style Pro (n=2; 1.5- and 1.6-2.9 METs), Actigraph GT1M (n=1; 100-1,565 cpm), Actigraph GT3X+ (n=9; 100-1,041cpm; 101-1951 cpm; 51-1040 cpm; 101-2019 cpm; 251-1951 cpm; and <1,040-1951 cpm), Hookie AM20 (n=1, mean amplitude deviations converted to METs of 1.5-2.9), and Kenz Lifecorder (n=2; acceleration-classified intensity levels 1-3). Fourteen studies reported covariates incorporated into analyses, which included demographics (age, gender, race, education, employment, and living status), health behaviors (smoking, alcohol consumption, daily step count), health status (BMI, waist-hip ratio, medical history, co-morbidities, metabolic markers), and accelerometer wear time. Ten studies specifically included covariates of PA and/or cognitive status in their analyses.

All studies reported LPA and MVPA metrics obtained from accelerometers. The average amount of LPA was 270.56 (SD=124.89), and values ranged from 47.5-550.6 minutes per day. The average minutes of MVPA per day was 42.36 (35.68). Only eight studies reported sedentary time, which averaged 551.94 (SD=69.65) minutes per day. Analytic approaches utilized across studies included logistic and linear regression, isotemporal substitution, and bivariate correlations.

Overall, eight studies (50%) found LPA to be significantly associated with one or more cognitive outcomes. In summary, four studies found LPA to be significantly associated with better performance on Trail Making- Part B, one study found significant association with smaller global reaction time switch costs on a Task-Switching paradigm, and one study reported significant correlations with Stroop Task interference control and word fluency- all measures of executive functioning. Two studies also observed significant associations among LPA and Trail Making-Part A, which is an assessment of processing speed. One study reported positive associations of LPA with accuracy on the 1-back test- a measure of working memory. Only one study administered assessments of global cognitive status (via the Telephonic Assessment for Dementia and Telephone Interview for Cognitive status), among a twin cohort, and found LPA to be significantly associated with cognitive status via between-family regression models.

4.2.4 Longitudinal Studies

Four longitudinal studies were eligible for inclusion and were composed of sample sizes ranging from 15-6,452 participants (Table 4). Three studies included healthy, older adult populations (mean age range 66-74.52), and one study examined a small sample (n=15, mean age 78 years) of older adults with cerebrovascular disease. All studies administered assessments at baseline, with follow-up time points ranging from 4 months to 5 years. Accelerometers and cut points utilized included Actical (n=1; 50-1064 cpm), Actigraph GT1M (n=1; 100-1,565 cpm), and Actigraph GT3X-BT (n=2; 100-1951 cpm). Three studies reported accelerometer activity metrics. Only two studies administered accelerometers at both baseline and follow-up, with average baseline LPA engagement at 199.25 (SD= 104.16) minutes per day and average MVPA engagement at 15.75 (SD=18.17) minutes per day. Average LPA measured at final follow-up time points was 208.07 (SD= 44.14) minutes per day and average MVPA was 14.87 (SD=10.71) minutes per day. Only two studies reported daily sedentary time, with one of the studies including sleep time in this metric. Additionally, a single study also administered the Community Healthy Activities Model Programs for Seniors (CHAMPS) questionnaire. Three studies reported covariates used in their analyses, which included demographics (age, sex, race, education, living status, income, and acculturation), health status (co-morbidities, BMI) and health behaviors (smoking and alcohol consumption). In analyses, only one study included MVPA as a simultaneous predictor of cognitive outcomes. Studies used a variety of analytical approaches, including bivariate correlations, Spearman’s correlations, logistic regression and linear regression. Overall, two studies (50%) found significant associations between objectively-measured LPA and cognitive outcomes. One study reported that baseline LPA was predictive of reduced rate of cognitive decline (assessed using the Ascertain Dementia 8-Item Questionnaire) two years later. The second study reported LPA among its 15 participants, which was assessed every month for four months, was significantly correlated with Raven’s Matrices scores and Symbol Digit Modality test scores at each time point. Additionally, average LPA engaged in over the four month observation period was significantly correlated with Symbol Digit Modality test score at the final, 4th month assessment period.

CHAPTER 5: DISCUSSION

To our knowledge, this is the first review attempting to catalog the existing evidence from studies examining the direct associations between LPA and cognition, in an effort to draw a picture of the current state of the field. Overall, 50% (7 out of 14) acute studies, 75% (3 out of 4) RCTs, 50% (8 out of 16) cross-sectional studies, and 50% (2 out of 4) longitudinal studies showed significant associations between LPA and one or more cognitive outcomes. Among the 38 studies, twenty-two different assessments were administered to measure either semantic (n=2), episodic (n=11), or working (n=9) memory. Sixteen different assessments were used to measure attention and processing speed, with the Eriksen Flanker- congruent condition and Trail Making Part-A utilized the most frequently. Twenty-one different assessment were used to measure executive functioning, with Stroop- interference condition, Trail Making Part B and Eriksen Flanker- incongruent used most frequently. Lastly, six different assessments were used to assess global cognitive function including the MMSE, the MoCA, the Six-Item Screener, the Telephonic Assessment for Dementia, the Telephone Interview for Cognitive Status, and the Ascertain Dementia 8-Item Questionnaire.

5.1 ACUTE STUDIES

Half of the acute studies included in the present scoping review reported significant group differences among the light-intensity condition and measured cognitive outcomes. Acute exercise, defined as a single isolated bout of activity, has been widely recognized for its short-term improvements on cognitive performance (Audiffren, 2009). Study design parameters such as intensity, duration, mode of exercise, type and timing of cognitive task administration, may influence the results (Chang et al., 2012). The variety of moderating factors observed in the presently reviewed studies produces an inconclusive picture of acute LPA's influence of cognition. A previous meta-analysis (Chang et al., 2012) found that, when cognition is assessed *during* exercise, exercise intensity does not have a significant effect on performance. This was echoed in the current review, where 5 of the 6 studies which administered assessments during the LPA bout reported no significant associations with cognitive outcomes. However, among studies where cognition was tested *after* an acute LPA bout the findings were mixed. Chang et al. (2012)'s meta-analysis of the cognitive benefits of acute exercise suggested that lighter intensity exercise (which the authors notably grouped as very light, light and moderate intensity) may show cognitive associations when assessments are administered *immediately* after exercise. The authors suggested this may be due to activation of the "appropriate level of physiological mechanism[s]" to facilitate improved cognitive performance.

Chang et al. (2012)'s meta-analysis reported significant effect sizes for the effects of an acute bout of LPA on cognition during exercise (d=0.092), immediately after exercise (d=0.169) and after a delay (d= 0.245). These small effect sizes provide one possibility for the discrepancy among the results of our current studies, which is that some may have been underpowered. Many of the primary outcomes among these studies focused on neurological functioning under acute exercise conditions, and thus may not have been sufficiently powered to examine behavioral cognitive measures affected by LPA. Additionally, 12 of the 14 studies utilized healthy, young adult samples, and this lower age range is often recruited as a convenience sample of university student population. This limits the generalizability of the currently reported evidence to primarily young-adult populations.

5.2 RANDOMIZED CONTROL TRIALS

Only four RCTs were eligible for inclusion in present scoping review, as these studies reported the specific intensity set for their LPA-arm. Previous systematic reviews and meta-analyses of RCTs have noted a consistent lack of intensity dosage reporting among exercise RCTs (Falck et al., 2019; Kelly et al., 2014). Thus, it is likely more RCTs have been conducted utilizing LPA-based intervention arms. However, without consistently documenting the intensity of exercise, potential LPA effects may go undetected. Nevertheless, three out of the four reviewed studies reported significant associations between the LPA experimental arm and improved processing speed (Debreceni-Nagy et al., 2019), improved attention/concentration, short-term memory and higher cognitive functioning (Stevenson & Topp, 1990) and short-term memory (Tang et al., 2016). All study designs included at least three exercise sessions per week, with the interventions lasting from one to nine months.

While a majority (3 out of 4) of the reviewed studies reported positive, significant associations between the LPA arm and one or more cognitive outcomes, there were several significant shortcomings in the study designs. The first was, among the two studies which utilized healthy, older adult samples, neither controlled for fitness or prior PA engagement. Thus, it is unknown how active or aerobically fit participants were before commencement of the trial, which may have affected the results. Second, Rusheweyh et al. (2011)'s intensity classification was 30-40% and 50-60% of maximal exertion for the low-intensity and medium-intensity aerobic groups, respectively. It was left ambiguous as to what parameter the authors referred to as "maximum exertion" and how this intensity was monitored over the intervention period. Third, the small sample sizes of the studies (which ranged from 35 to 72 participants) allow for the possibility that the studies may have been underpowered to detect significant improvements in cognitive function.

The extremely limited number of LPA-based RCTs included in the present review is a testament that this is an understudied area of research. Historically, exercise interventions have been designed to study the impacts of moderate-to-vigorous intensity exercise on health outcomes (Bouaziz et al., 2017; Smith et al., 2010), given that MVPA has a strong foundation of evidence for its health-promoting efficacy. One meta-analysis (Scherder et al., 2014) did examine the effects of walking-based RCTs on executive functions among sedentary adults ≥ 50 years of age, and reported a small, significant effect of walking on set-shifting and inhibition functions among older adults without cognitive impairment. However, five out of the eight studies included in that analysis did not report the walking intensity (the remaining three studies set the walking intensity at moderate or vigorous). Low-intensity walking is the most common intensity engaged in by older adults (Varma et al., 2015), and has been shown to be associated with hippocampal volume in older women (Varma et al., 2015). Thus, by failing to directly monitor and report intensity, the distinct, independent effects of light- and moderate-vigorous PA cannot be distinguished. The same can also be said about other activities which can range in intensity, such as yoga, tai chi, dance and other mind-body exercises. While previous systematic reviews have examined effects of these modalities on cognition (Gothe & McAuley, 2015; Meng et al., 2020; Predovan et al., 2012; Wu et al., 2019), most RCTs included in those reviews did not report intensity.

5.3 CROSS-SECTIONAL STUDIES

Overall, eight out of the 16 cross-sectional studies reviewed reported significant associations between LPA engagement and executive functioning (Gothe, 2020; Johnson et al., 2016; Kerr et al., 2013; Lin et al., 2018; Umegaki et al., 2018), working memory (Gothe, 2020), attention and processing speed (Chen et al., 2016; Umegaki et al., 2018), and global cognitive functioning (Iso-Markku et al., 2018). In regard to sample size and measured daily-LPA engagement, there is no clear distinction between studies reporting significant findings and those who observed no significant associations. While there are likely multiple explanations for these inconsistent findings (which are addressed below), the nature of cross-sectional study designs likely contributes to the indeterminate conclusions. Cross-sectional studies, while useful for observing population-wide prevalence of certain health exposures and outcomes, have limitations including the inability to infer casual relationships and establish temporality between the outcome and exposure. Additionally, numerous inconsistent study designs and measurements are present among the studies, including health status of participants (four studies included clinical populations), sample size, activity levels of participants, cognitive assessments administered and outcomes reported, covariates included in analyses, and statistical approaches. Even though all studies used accelerometers, the variety of devices, cut points, data processing approaches and protocols used may affect the reported activity levels, as well as the possibility of measurement reactivity by participants (Burchartz et al., 2020). Thus, while accelerometers currently offer one of the best and most practical ways to measure free-living activity levels (Burchartz et al., 2020), inconsistent data collection and processing approaches make it difficult to compare data from different studies. This is particularly relevant to the current review, as the precise energy expenditure rates of physical activities cannot be directly measured with accelerometers. Without this information, classification of PA intensities relies on acceleration signals based on the wearer’s movements in the three spatial axes. However, the energy expenditure of an activity (and thus its intensity level) may differ between individuals of different ages, anthropomorphic characteristics, health status and fitness levels. Currently, most widely used cut-points have been validated for specific age groups (Migueles et al., 2017), but other nuances affecting intensity levels may go unaccounted for in these cut-point classifications.

Among the 15 cross-sectional studies, an extensive variety of cognitive assessments were used to measure memory, attention and processing speed, executive functioning and general cognitive functioning (Table 3). Interestingly, among the four studies which administered the Trail Making task, three found significant associations between minutes per day of LPA and performance on Part B (TMT-B) (Gothe, 2020; Johnson et al., 2016; Umegaki et al., 2018). Zlatar et al. (2019) combined TMT-B scores with other executive function task scores to create a composite executive function score, which bivariate Pearson correlations revealed no significant association with LPA. TMT-B has been found to be a strong predictor of executive functioning, specifically sub-domains of working memory and task-switching ability (Sánchez-Cubillo et al., 2009). However, the limited number of studies which administered the Trail Making task make it difficult to ascertain if any clinically meaningful trends do exist between LPA engagement and TMT-B performance. Additionally, other studies which administered assessments measuring overlapping cognitive domains with the TMT-B reported null findings. As previously mentioned, the nature of cross-sectional studies and the nuances of this study design limit any conclusions, especially conclusions regarding *causation*, between LPA engagement and cognition. Such limitations can only be overcome via more rigorous interventions and RCTs.

5.4 LONGITUDINAL STUDIES

Overall, two of the four included longitudinal studies observed positive, significant associations between LPA engagement (at one or more time points) and global cognitive status (Kojima & Nagano, 2019; Stubbs et al., 2017) and attention/processing speed (Kojima & Nagano, 2019) at follow up. Similar to the cross-sectional studies, no trends existed between sample size, measured activity levels and cognitive outcomes. Two studies collected PA data at multiple time points, with collection periods ranging from a monthly basis for four months

(Kojima & Nagano, 2019) to a five year follow-up period (Halloway et al., 2017). Given the extremely small number of included longitudinal studies, each with their own methodological limitations and differences in study design, it is difficult to draw any meaningful conclusions or identify trends. For example, Halloway (2017) noted a very high attrition rate, with 174 participants completing baseline assessments but only 59 participants completing follow up assessments. Kojima & Nagano (2019) had a small sample size of 15 adults with cerebrovascular disease. The researchers administered the same six cognitive tests four times over the 4-month study period, which may have introduced contamination due to practice effects. Additionally, it is possible that a 4-month time period may not have been long enough to observe changes in the test scores (the authors noted that scores on the Symbol Cancellation, Design Memory, and Mazes assessments did not significantly change across the four test periods). Stubbs et al. (2017) did not reported accelerometer-derived means for PA intensity levels. While the study authors did enter MVPA and LPA as continuous variables in their regression analyses (albeit using units of hours per day, compared to other studies which entered the intensities as minutes per day), this lack of reporting PA descriptive statistics can be problematic for future researchers seeking to study dosage effects of PA intensities on cognitive functions. Lastly, both Zhu et al. (2017) and Stubbs et al. (2017) only collected PA at baseline, and these PA levels were regressed onto changes in cognitive scores from baseline to follow-up. Thus, any changes in the PA levels of participants over time was not captured and appropriately analyzed.

CHAPTER 6: ISSUES AND CONSIDERATIONS AMONG THE LITERATURE

6.1 SIMULTANEOUS EFFECTS OF FITNESS AND MVPA ON COGNITION

Surprisingly, no study included in the present review included participants' cardiorespiratory fitness (CRF) as a covariate. This is a notable omission, as CRF is a significant predictor of cognitive function (Barnes et al., 2003; Kramer & Colcombe, 2003). However, 10 observational studies (nine cross-sectional and one longitudinal) included MVPA as a simultaneous predictor in their statistical models. While MVPA is not a validated direct proxy for CRF, this variable provides insight into LPA's association with cognition after controlling for engagement in higher intensity activities. Nevertheless, the fact that only 53% of the included observational studies accounted for MVPA engagement suggests that the current state of the field may not be fully capturing, and controlling for, all the significant PA and subsequent CRF predictors of cognition. These inconsistent statistical approaches may partly explain the heterogeneous findings of LPA's association with cognition. It is worth noting, however, that no clear trends emerge between studies who did control for MVPA and those that did not among their results. Thus, in an effort to provide clarity on how LPA may affect cognitive function among individuals of varying CRF status, future observational studies should measure and incorporate this variable in the statistical analyses.

Among the acute studies, maximal exertion tests were administered in nine studies as a means to set individualized intensity levels for the acute exercise bouts. However, given that the main effects of CRF on cognitive performance were not examined during analyses, from these current studies it is not possible to infer if higher fit individuals respond differently to acute bouts of LPA compared to their lower-fit counterparts. Previous acute studies (Chang et al., 2014, 2015) attempted to dissect the possible mediating role of CRF among the relationship between acute exercise and Stroop task performance among young adults (Chang et al., 2014) and older adults (Chang et al., 2015). Both studies found that, overall, task performance improved after the acute exercise bout regardless of fitness level; however, lower and moderately fit young adults performed marginally better on Stroop incongruent conditions (compared to the higher fit group), whereas higher fit older adults showed a larger improvement in performance post-exercise then their lower fit counterparts. It should be noted that, in both studies, the acute exercise bouts were performed at moderate intensity, as this intensity has been previously suggested to induce optimal arousal states and performance on cognitive tasks (Kashihara et al., 2009). A meta-analysis with 2,072 participants (mean age 28.51 years) found significant effects of cognitive task improvement during exercise for high fit individuals, no effects among moderate fit individuals, and reduced performance for low fit individuals; significant effects immediately post-exercise for low and high fit participants; and no effect of fitness on cognitive task performance after a delay following exercise (Chang et al., 2012). Given the current state of the evidence, it is uncertain if and how CRF status affects performance during or after acute exercise, let alone how it interacts with LPA bouts.

Among the four intervention studies included in the present review, Stevenson & Topp (1990) did not specify the PA engagement of their participants prior to study enrollment. However, they did assess participants' aerobic fitness status at baseline, halfway through the intervention (4.5 months) and at study completion (9 months). The authors observed that both the moderate- *and* low-intensity groups significantly increased CRF at 4.5 months and maintained these increases at 9 months. Additionally, both intensity groups experienced significant improvements in all measured cognitive outcomes (attention/concentration, short-term memory and higher cognitive functioning subscales of the Strub and Black mental status test); thus, it is difficult to ascertain what role, if any, CRF had in producing the observed changes. In the study conducted by Tang et al. (2016), the stroke survivor participants completed a graded maximal exercise test prior to the exercise intervention period, but this data was not incorporated in analyses. Debreceni-Nagy et al. (2019) studied deconditioned stroke patients and only administered a graded fitness assessment prior to the intervention. While the authors noted the patients had poor aerobic fitness before the study, it is uncertain to what extent their fitness may have changed over the intervention period. Previous studies among stroke survivors have found that aerobic fitness may be associated with improved cognitive performance post-stroke (Boss et al., 2017; Marzolini et al., 2013), which suggests CRF may be an important predictor among this population. Lastly, Ruscheweyh et al. (2011) studied a sample of sedentary older adults and administered a graded fitness assessment at baseline to screen for any CRF differences among the study groups. While CRF was not reassessed post-intervention, participants did complete a lactate step test both at baseline and post intervention, with insignificant changes in lactate threshold between pre- and post-testing.

6.2 HYPOTHESIZED UNDERLYING MECHANISMS

The acute and chronic physiological mechanisms underpinning LPA’s influence on cognitive function have not been widely investigated. Soya et al. (2007) previously found that rodents who ran at a “mild intensity” (defined as sub-lactic threshold) for 30 minutes exhibited greater activation in the CA1 and dentate gyrus (DG) regions of the hippocampus (measured via greater *c-fos* mRNA levels, which are markers of neural activity) and greater levels of brain-derived neurotrophic factor (BDNF) mRNA across hippocampal sub regions. The study authors hypothesized that due to the lower-stress nature of LPA, which didn’t trigger an increase in the stress hormone corticosterone, this allowed for higher levels of BDNF to accumulate in the hippocampus and remain at higher levels 60 minutes after cessation of exercise bout. BDNF plays a significant role in upregulating synaptic plasticity (Sendtner, 2005) and neurogenesis (Scharfman et al., 2005), especially in the hippocampal region, which can translate to improved cognitive functioning (Sendtner, 2005). Suwabe et al. (2018) found that healthy young adults who completed a 10 minute bout of light intensity (30% VO_{2peak}) cycling exhibited increased functional connectivity between hippocampal (DG/CA3 regions) and cortical (para-hippocampal, angular and fusiform gyri) regions, and this increase was predictive of increased episodic memory performance.

It is also possible LPA may indirectly affect cognition via upregulating peripheral metabolic pathways. For example, Butcher et al. (2008) found that an eight week low-intensity walking program improved plasma lipid metabolism. Impaired lipid metabolism has been associated with cognitive decline and increased risk for neurodegenerative diseases (Panza et al., 2006). LPA has also been suggested to help regulate blood glucose levels (Healy et al., 2007). Elevated blood glucose levels are linked to risk of Type 2 diabetes and cardiovascular disease, both which are also widely recognized as significant predictors of impaired cognitive function and risk of neurodegenerative diseases (Breteler et al., 1994; Stewart & Liolitsa, 1999)

LPA may also affect cognition via displacement of sedentary behavior (SB), which itself has been previously investigated for its detrimental cognitive associations (Falck et al., 2017). It has previously been hypothesized that high levels of prolonged SB may reduce cerebral blood flow (Carter et al., 2018), disrupt glucose and lipid metabolism (Wheeler et al., 2017; Zderic & Hamilton, 2006) and increase risk for metabolic syndrome (Edwardson et al., 2012)- all factors that have been associated with compromised cognitive functioning. However, no studies have applied rigorous protocols to examine the simultaneous, overlapping contributions of SB and PA on cognitive function and any potential mechanistic underpinnings (Voss et al., 2014). Nevertheless, Carter et al. (2018) found that disrupting prolonged (4 hours) sitting with short, frequent light-intensity walking breaks (2 minute breaks every 30 minutes) attenuated decreases in cerebral blood flow observed in the uninterrupted sitting group. Additional intervention studies have demonstrated physiological benefits of breaking up prolonged sitting with light-intensity walking breaks (Bailey & Locke, 2015; Dunstan, Kingwell, et al., 2012; Grace et al., 2019), albeit most have been conducted on overweight/obese participants.

Lastly, Iso-Markku et al. (2018) found significant, independent associations between both SB and LPA among a twin cohort. However, these associations were only observed in between-family linear analyses (i.e. between different sets of twins), leading the authors to hypothesize that the influence of LPA and SB on cognition may be due to “genetic selection and environmental similarity between siblings.”

6.3 LPA MEASUREMENT METHODOLOGIES AND REPORTING

Despite the formal classifications of LPA as activity with an energy expenditure between 1.6-2.9 METs, and methods of estimating this intensity recommended by ACSM, operationalization of the phrase “light-intensity” in PA research has widely varied (Norton et al., 2010). For example, a recent ‘proof of concept’ study was conducted to examine acute and training effects of aerobic exercise on memory and functional connectivity (Voss et al., 2020). The “light-intensity” exercise control condition in this study consisted of participants sitting on a cycle ergometer and having their legs moved by motorized pedals at a specific RPM. Ruscheweyh et al. (2011) conducted an RCT in which the “medium-intensity” aerobic exercise group was classified as 50-60% maximal exertion. While it is unclear what the authors used as a unit of “maximal exertion,” the authors asserted that at this intensity blood lactate values should range between 1.5-2.0 mmol/l during training. However, this is not an ideal way to assess intensity during an intervention, as blood lactate levels do not typically differ from resting levels during light and moderate exercise (Goodwin et al., 2007). It was also previously recommended that mind-body exercises, such as tai-chi and dance, exert the most beneficial cognitive effects among older adults when performed at “moderate intensity” (Wu et al., 2019). However, the authors’ defined moderate intensity as 60-120 minutes per week of exercise and had no reference to the actual *physical* intensity of the exercises.

Among cross-sectional and longitudinal studies which have utilized accelerometers, the varying data collection and processing methods vary greatly. When using accelerometers to assess free-living PA, many decisions must be made by the research team, including: monitor placement (thigh, waist, and wrist); measurement time frame (how long is the monitor worn each day and for how many days); raw acceleration data processing; and cutoffs used. It has been recently emphasized that due to the variety of decision points researchers face when using accelerometers and the frequent reliance on proprietary intensity-calculation algorithms produced by commercially available devices, the research community is limited in the extent to which accelerometer data can be compared and reproduced between studies (Burchartz et al., 2020).

While this section is not meant to be a comprehensive overview of ways in which PA intensities are classified and reported across the PA literature, it is intended to highlight the need for more rigid standards when reporting LPA in the literature. As greater interest continues to emerge regarding the overall independent health benefits of LPA, this inconsistent classification may lead to studies being incorrectly excluded or included in future analyses and reviews. It is quite possible that in the present review LPA studies have been overlooked and did not appear in our search due to inconsistent labeling. Norton et al. (2010) stated “there is…a need for greater consistency in terminology and consistent cutoffs for health professional and their clients,” and this need extends to the research community as well.

6.4 VARIETY OF COGNITIVE DOMAINS STUDIED AND ASSESSMENTS USED

Studies examining the effects of exercise on cognitive functions have largely focused on MVPA, as this intensity produces the most notable gains among physical and mental health. It is unknown if these trends which are observed in the MVPA-cognition literature are the same for LPA, and if so to what extent. Future interventions, as well as studies incorporating brain imaging techniques, should take a more focused approach in attempting to dissect any unique contributions LPA may exert on cognitive function, and if this differs from MVPA. This research goal may also be aided by future studies examining any physiological underpinnings which may accompany observed associations between LPA and cognition. By further understanding the peripheral and central physiological changes that occur during both acute and chronic LPA engagement, researchers can begin to better understand how LPA acts both on a neurological and cognitive level. Lastly, there currently exists a large discrepancy in the cognitive measures used in the present studies and the outcomes reported. While all the cognitive assessments listed in Appendix F have been well-validated, the variety of outcomes reported can reflect different domains, making it difficult to compare study outcomes.

6.5 CONSIDERATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

In order to continue progressing our understanding on the independent health contributions of LPA, especially in the context of cognitive function, the following considerations are recommended for future research studies:

1. More rigorous RCTs using LPA as the primary intervention arm. This also includes concrete parameters for LPA and fidelity checks during the interventions to assure participants are adhering to the intensity.
2. LPA-based RCTs incorporating neurological outcomes, such as MRI, fMRI or PET scans to help uncover potential neurological changes which may occur with increased LPA engagement.
3. Incorporate CRF levels as a covariate in analyses, to understand if individuals of varying aerobic fitness levels respond differently to LPA.
4. Examine the LPA-cognition relationship among populations who may experience functional limitations or health conditions preventing them from MVPA engagement. This includes older adults and clinical populations (such as stroke patients, individuals with neurocognitive deficits or disease, cancer survivors, and cardiovascular disease patients). Additionally, healthy but inactive individuals who may be averse to MVPA might be more receptive to higher engagement in LPA as a starting point to increase PA.
5. Design studies with greater power. Interest in LPA has evolved from paying little attention (with most research efforts directed towards MVPA), to being used as an "active control/comparison" condition in intervention studies, to more recently as mainstream intervention condition or primary independent predictor in observation studies. While LPA has seen a rise in attention for its physiological health impacts, its cognitive potential is still not understood. Nevertheless, there is a need for greater powered studies in order to observe the fully effect of LPA on cognition.

6. Examine if LPA can produce cognitive benefits above and beyond what may be gained via MVPA. Researchers should investigate if simultaneously increasing LPA *in addition to* increasing MVPA produces significantly greater gains.
7. Examine if displacing SB with LPA produces significant cognitive gains. While SB is being investigated as a unique detriment to cognitive function, it is important to examine if displacing this behavior with LPA can offset these detriments. This can have meaningful implications for highly sedentary populations, such as working adults.
8. Examine potential physiological pathways LPA may exert influence on cognitive function.

CHAPTER 7: CONCLUSION

Previous epidemiological research has shown that even individuals who meet the recommended PA guidelines still engage in high amounts of SB, and this trend has been referred to as the "active couch potato phenomena" (Dunstan et al., 2009; Owen et al., 2010). Public health messaging has evolved from purely focusing on MVPA promotion to the additional, global message of "move more, sit less." Accelerometer-based studies with adults have shown that, after SB, LPA is the second most commonly engaged in behavior (Dunstan et al., 2009; Dunstan, Howard, et al., 2012). Therefore, there is a growing trend focusing on promoting LPA as a means to displace excessive SB. As LPA continues to be given its due attention as an independent health predictor, it is important to understand if any cognitive implications accompany this behavior. Currently the research supporting this association remains equivocal and requires more rigorous studies. Throughout this scoping review, we have aimed catalog the existing evidence, identify gaps and issues that must be addressed in order to progress, and provide suggestions for future research. Given that LPA is an activity most individuals can easily engage in, it is worthy of further investigation into the plausibility of promoting this intensity as an independent behavior to maintain or improve cognitive functions.

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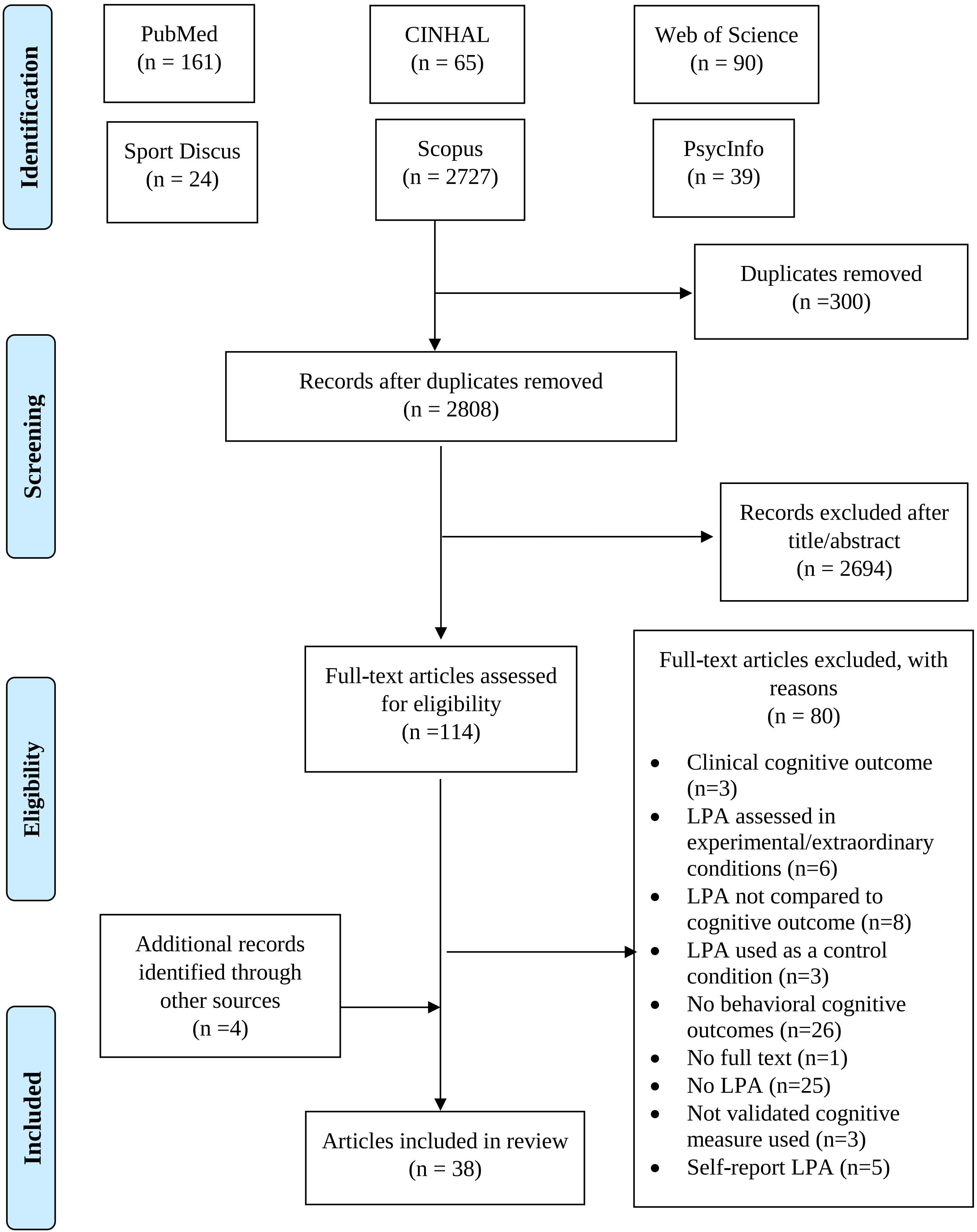
APPENDIX A: PRISMA FLOW DIAGRAM

Figure 1: PRISMA Flow Diagram of Study Selection



APPENDIX B: ACUTE STUDIES

Table 1: Acute LPA studies included in review

Author (Year)	**Participants**	**LPA Dosage (*Intensity, Time, Type)***	**Comparison/ Control Group**	**Time point(s) of cognitive assessment**	**Cognitive measure(s) used (outcomes reported)**	**Key findings among LPA group**
Alderman, Olson & Mattina (2014)	N= 66 healthy university students (59.09% F, M_{age}= 21.06)	"Low intensity" walking at speed between 0.5 – 2.5 mph Not reported Treadmill walking	No-exercise control *Seated*	During exercise	Stroop task (RT, ACC for neutral and interference trials) Flanker Task (RT, ACC for congruent and incongruent trials)	LPA bout not significantly associated with any outcomes
Brown & Bray (2018)	N=107 recreationally active university students (53.27% F; M_{age}= 20.01)	"Very light intensity" cycling at 60-90 RPM with fixed workload of 10W 20 minutes Cycling	High-intensity interval exercise *70% PPO/12.5% PPO; 20x1- minute intensity, 1-minute low-intensity bouts; cycling* High-intensity continuous exercise *80-90% HR_{max}; 20 minutes; cycling* Moderate-intensity continuous exercise *65-75% HR_{max}; 20 minutes; cycling*	Pre-exercise Immediately post exercise (Post-0) 10-minutes post exercise (Post-10)	Stroop task (Inverse efficiency score)	Significant pre to post-10 improvements in Inverse efficiency score Significant Post-0 to Post-10 improvements Inverse efficiency score

Table 1 (cont.)

			No-exercise control *Sitting on cycle ergometer; 25 minutes*			
Byun et al. (2014)	N=25 healthy young adults (48% F, M_{age}= 20.6)	“Light intensity” 30% VO_{2peak} 10 minutes Cycling	Resting control *Seated; 15 minutes*	Pre-exercise 5-minutes post exercise	Stroop task (RT, ACC, Stroop interference measured by RT)	Stroop interference scores significantly decreased after exercise; interference scores significantly more negative after exercise condition compared to after resting
Kamijo et al. (2007)	N= 12 healthy young adult males (0% F, M_{age}= 25.7)	“Fairly light to light” target HR equivalent to RPE=11[#] 20 minutes Cycling	Moderate-intensity exercise *Target HR equivalent to Borg RPE=13; 20 minutes; cycling* Hard-intensity exercise *Target HR equivalent to Borg RPE=15; 20 minutes; cycling*	Pre-exercise Immediately post exercise	Flanker task (RT & ACC for incongruent and congruent tasks)	Significant reduction in RT for both congruent and incongruent trials post LPA bout
Kamijo et al. (2009)	N= 12 older male adults (0% F, M_{age}= 65.5)	“Light-intensity exercise” 30% VO_{2max}	Moderate-intensity exercise *50% $VO2_{max}$; 20 minutes; cycling*	Pre-exercise Immediately post exercise	Flanker task (RT and ACC for congruent and incongruent conditions)	LPA bout not significantly associated with any outcomes.

Table 1 (cont.)

	N=12 young adult males (0% F, M_{age}= 21.8)	20 minutes Cycling				
Labelle et al. (2013)	N= 37 healthy young adults (48.64% F, M_{age}= 23.8)	“Light-intensity exercise” 40% PPO 6.5 minutes Cycling	Moderate-intensity exercise *60% PPO; 6.5 minutes; cycling* High-intensity exercise *80% PPO; 6.5 minutes; cycling*	During exercise bout	Stroop task (RT, ACC, intra-individual coefficient of variability in RT)	LPA bout not significantly associated with any outcomes.
Loprinzi & Kane (2015)	N=87 healthy young adults (41.3% F, M_{age}= 21.4)	“Light-intensity” 40-50% predicted HR_{max} 30 minutes Treadmill exercise	Moderate-intensity exercise *51-70% HR_{max}; 30 minutes; treadmill exercise* Vigorous-intensity exercise *71-85% HR_{max}; 30 minutes; treadmill exercise* No exercise control *Seated; 30 minutes*	Administered when post-exercise HR lowered within 10% baseline or 15 minutes after completion of exercise bout (whichever came first)	Trail Making task- Parts A and B* Spatial Span* Paired Associates* Grammatical Reasoning* Odd One Out* Polygon* Feature Match* Spatial Search* Spatial Slider*	LPA bout not significantly associated with any outcomes.
Loprinzi, Day & Deming (2019)	N=24 healthy young adults (66.7% F, M_{age}=20.9)	“Light-intensity exercise” 30% HRR 20 minutes	Moderate-intensity exercise *50% HRR; 20 minutes; treadmill exercise* High-intensity exercise	During exercise	Brown-Peterson task (number of letters recalled after delay of 0,9,18, & 36 seconds) Paired Associate Learning task (number of paired words recalled after	LPA bout not significantly associated with any outcomes.

Table 1 (cont.)

		Treadmill exercise	*80% HRR; 20 minutes; treadmill exercise* No exercise control *Seated*		immediate and long-term cued recall)	
Mekari et al. (2015)	N= 19 healthy young adults (63.16% F, M_{age}= 24.0)	“Low-intensity exercise” 40% PPO 9 minutes Cycling	Moderate-intensity exercise *60% PPO; 9 minutes; cycling* High-intensity exercise *85% PPO; 9 minutes; cycling*	During exercise	Stroop task (RT & ACC for neutral and interference trials)	LPA bout not significantly associated with any outcomes.
Morris et al. (2019)	N= 14 healthy adults (64.28% F, M_{age}= 26.0)	“Light-intensity exercise” 40-60% HRR 30 minutes Cycling	Resting control *Seated; 30 minutes*	Pre-exercise Immediately post exercise	Multitasking test (RT, ACC, multitasking cost) Stop-signal task (stop signal RT) Spatial Working memory task (errors, strategy utilization)	Significant, positive pre-post changes after LPA bout among multitasking test RT and cost.
Radel, Tempest & Brisswalter (2018)	N=12 trained male cyclists (0% F, M_{age}=27.8)	“Low intensity” Power output of 50 watts Not reported Cycling	Moderate intensity (Constant load) *At ventilatory threshold; cycling* Moderate Intensity (varied load) *Average intensity at ventilatory threshold, varied up to 15% around target intensity); cycling*	During exercise	Sustained Attention to Response Task (RT, coefficient of variation of RT, number of omissions of Go stimuli, number of errors for NoGo stimuli)	LPA bout not significantly associated with any outcomes.

Table 1 (cont.)

			Resting control *Seated on bike*			
Sandroff et al. (2016)	N= 24 adults with multiple sclerosis (95.8% F, M_{age}=40.2)	“Light-intensity exercise” 30% HRR 20 minutes Treadmill exercise	Moderate-intensity exercise *50% HRR; 20 minutes; treadmill exercise* Vigorous-intensity exercise *70% HRR; 20 minutes; treadmill exercise* Resting control *Seated; 30 minutes*	Pre-exercise 5 minutes post-exercise	Flanker task (RT and ACC for congruent and incongruent trails, interference control for RT and ACC)	LPA bout showed significantly greater pre-post reduction of interference control for RT and mean RT for congruent and incongruent conditions.
Suwabe et al. (2018)	N= 20 healthy young adults (40% F, M_{age}= 20.6)	“Mild exercise” 30% VO_{2peak} 10 minutes Cycling	Resting control *Seated; 10 minutes*	5 minutes post-exercise (encoding phase of task) 45 minutes post-exercise (retrieval phase of task)	Mnemonic discrimination task (Lure discrimination index)	LPA bout improved discrimination performance for high- and medium-similar lures
Torbeyns et al. (2016)	N=23 adults working at sedentary occupations (69.57% F, M_{age}=35.7)	“Low intensity” 30% PPO 30 minutes Cycling	Resting control *Seated; 30 minutes*	During exercise	Rey auditory verbal learning test (number of recalled words, amount correctly and incorrectly recalled) Stroop task (ACC and RT for neutral and interference trials)	Shorter RTs on averaged Stroop trials and RCPT during LPA bout.

Table 1 (cont.)

					Rosvold continuous performance test (ACC and RT)	

ACC, accuracy; HR, heart rate; HRR, heart rate reserve; LPA, light physical activity; M_{age}, mean age; mph, miles per hour; PPO, Peak Power Output; RPE, rating of perceived exertion; RT, reaction time; RPM, revolutions per minute; VO_{2peak}, peak oxygen uptake during maximal exercise test; VO_{2max}; maximal oxygen uptake during maximal exercise test

* Task outcomes not reported

[#] Based on the Borg RPE scale

APPENDIX C: RANDOMIZED CONTROL TRIALS

Table 2: Randomized Control Trials included in review

Author (Year)	**Participant sample**	**LPA Arm (Frequency, Intensity, Time, Type)**	**Comparison/ Control Arm(s)**	**Cognitive measure(s) used (outcomes reported)**	**Covariates used in analysis**	**Key findings corresponding to LPA engagement**
Debreceni-Nagy (2019)	N= 35 sub-acute and chronic, extremely deconditioned stroke patients* *N=19 in LPA +physiotherapy arm (31.57% F; $Median_{age}$= 59)* *N=16 in physiotherapy-only arm (31.25% F; $Median_{age}$ = 62)*	**Light physical activity arm:** 20 consecutive sessions over 4 weeks 30-40% HRR 30 minutes per session Cycling **In addition to 30 minutes of physiotherapy per session*	**Control arm:** 20 consecutive sessions over 4 weeks ------ 60 minutes per session Physiotherapy sessions	Digit Span Task (sum of number of digits recalled during forward, backward and sequencing subtasks) Symbol Search task (difference between correct and incorrect answers) Symbol Coding task (number of correctly drawn signs in 120 seconds)	No reported covariates	LPA arm showed significant increase in Symbol Coding and Symbol search scores.
Ruscheweyh et al. (2011)	N= 62 community-dwelling older adults (M_{age} = 60.2; 69.35% F) *N= 20 in moderate intensity exercise*	**Light-intensity arm:** 3 sessions per week for 6 months 30-40% maximal exertion (monitored by HR and RPE)	**Moderate-intensity arm** 3 sessions per week for 6 months 50-60% maximal exertion (monitored by HR and RPE)	Auditory Verbal Learning Test (total number of recalled words at end of 5 trials, after 1st presentation of the list, and after 30 min delay)	Age, sex, years of education, changes in Beck Depression Inventory scores	LPA arm did not significantly improve cognitive performance.

Table 2 (cont.)

	arm (70% F; M_{age} = 60.1) *N= 21 for light intensity exercise arm (62% F; M_{age} = 62.5)* *N= 21 control arm (no intervention received) (67% F; M_{age} = 58.1)*	50-minute sessions Gymnastics	50-minute sessions Nordic walking **Control arm** No-contact			
Stevenson & Topp (1990)	N= 72 healthy, community dwelling older adults (M_{age} = 63.9) *N= 39 in moderate-intensity exercise group (M_{age} = 63.1)* *N=33 in low-intensity exercise group (M_{age} = 64.5)*	**Low-intensity exercise arm:** 3 sessions per week for 9 months 30-40% HRR 30 minutes per session Cycling	**Moderate-intensity arm:** 3 sessions per week for 9 months 60-70% HRR 30 minutes per session Cycling	Strub and Black mental status test (Orientation, attention/concentration, short term memory and higher cognitive function subscale scores)	Age, sex, marital status	LPA arm showed improved attention/concentration, short-term memory, and higher cognitive function scores
Tang et al. (2016)	N= 50 community-dwelling adult stroke survivors* *N= 25 in low-intensity group (40% F, $Median_{age}$= 64)*	**Low-intensity arm:** 3 sessions per week for 6 months <40% HRR 60 minutes	**High-intensity aerobic arm** 3 sessions per week for 6 months Progressed from 40-80% HRR 60 minutes	Verbal Digit Span (number of correct sequences relayed in forward and reverse order) Trail Making test (time to completion on TMT-B)	Not reported	LPA arm showed significantly improved scores in Verbal Digit Span- Forward test

Table 2 (cont.)

	N=25 in high-intensity group (44% F, Median$_{age}$= 66)	Balance and flexibility exercises	Brisk walking, recumbent cycle ergometry, functional movement exercises	Color-word Stroop test (time to completion)		

LPA, light physical activity; HR, heart rate; HRR, heart rate reserve; M$_{age}$, mean age; RPE, rating of perceived exertion; TMT-B, Trail making test part B

*Mean age of entire sample not reported

APPENDIX D: CROSS-SECTIONAL STUDIES

Table 3: Cross-sectional studies included in review

Author (Year)	**Participant sample**	**Study design**	**LPA measurement (definition of LPA)**	**Sample activity metrics**	**Cognitive measure(s) used (outcomes reported)**	**Covariates used in analysis**	**Key findings corresponding to LPA engagement**
Amagasa et al. (2019)	N= 511 community dwelling older adults (53% F, M_{age}= 73.4)	Cohort (Neuron to Environmental Impact across Generations study)	Active style Pro (1.6-2.9 METs)	ST: 445.6 min/day LPA: 388.8 min/day MVPA: 52.4 min/day	Mini-Mental Sate Examination (score ≤ 23 indicates cognitive function decline)	Age, gender, living arrangement, residential area, working status, education, smoking status, alcohol use, medical history, BMI. ST and MVPA included as simultaneous predictors	Logistic regression analyses revealed proportion of time spent in LPA was not associated with cognitive function decline.
Cavalcante et al. (2018)	N= 130 adults with peripheral arterial disease (30.8% F, M_{age}= 67)	Cross-sectional	Actigraph GT3X+ (100-1041 cpm)[▲]	LPA: 275.9 min/day MVPA: 55.6 min/day	Montreal Cognitive Assessment (global score; visuospatial/executive plus attention and memory subscales)	Age, sex, educational status, ankle brachial index (measured of PAD severity), heart failure and CVD prevalence MVPA not included as simultaneous predictor	In fully adjusted linear regression model, LPA not significantly associated with cognitive outcomes
Chen et al. (2016)	N=199 adults with schizophrenia (38.7% F, M_{age}= 44)	Cross-sectional	Actigraph GT3X+ (101-1951 cpm)[$]	*Schizophrenia patients:* LPA: 158.6 min/day	Cognitrone test (number of responses made within 7 minutes)	*Among both groups:* Demographics (age, sex, education), health behavior (smoking and	Linear regression analyses revealed higher LPA among schizophrenic patients associated with better

Table 3 (cont.)

	N=60 healthy controls (43.3% F, M_{age}=41.1)			MVPA: 95.0 min/day *Healthy Controls:* LPA: 496.0 min/day MVPA: 154.5 min/day	Grooved Pegboard Test (total time to completion)	alcohol habits), metabolic parameters (waist circumference, blood pressure, serum triglycerides, HDL cholesterol, fasting glucose), accelerometer wear time, MVPA *Schizophrenia patients only:* Score of Positive and negative Syndrome scale, years since diagnosis, duration of hospitalization, medication use	performance on both cognitive assessments. Linear regression analyses revealed no significant associations between LPA and cognitive outcomes among healthy comparison group.
Fanning et al. (2017)	N= 247 low active, healthy older adults (68.4% F, M_{age}= 65.4)	Cross-sectional (Baseline data from RCT)	Actigraph GT3X+ (51-1040 cpm)[‡]	ST: 533.81 min/day LPA: 276.75 min/day MVPA: 46.45 min/day	Spatial working memory task (ACC and RT scores for 2, 3, and 4 dot conditions) Task-switching paradigm (global switch cost, local switch cost)	Age, gender, race MVPA, sleep time, and total daily activity time included as simultaneous predictors	Isotemporal substitution analyses revealed LPA to not be significantly associated with any cognitive outcomes.
Gothe (2020)	N= 110 community dwelling African American older adults	Cross-sectional	Actigraph GT3X-BT (101-2019 cpm)[a]	ST: 568.58 min/day LPA: 252.24 min/day	Trail Making test (time to completion for TMT-A and TMT- B; TMT-B minus TMT-A; TMT-B/TMT-A)	Age, education, cardiovascular fitness MVPA included as a simultaneous predictor	Multiple linear regression analyses revealed LPA was an independent, significant predictor of performance on the TMT-B task and accuracy on 1-back task.

Table 3 (cont.)

	(87.27% F; M_{age}= 64.78)			MVPA: 12.26 min/day	Flanker task (RT and ACC on congruent and incongruent conditions) N-back task (RT and ACC on 1- and 2-back conditions)		
Iso-Markku et al. (2018)	N= 726 same-sex Finnish twins (51.51% F, M_{age}= 72.9)	Cohort (Older Finnish Twin Cohort study)	Hookie AM20 accelerometer (1.5-2.9 METs)	ST: 537.0 min/day LPA: 175.0 min/day MVPA: 39.55 min/day	Combined Telephonic assessment for dementia & Telephone Interview for Cognitive Status (sum of orientation, serial subtraction, word recall, semantics, sentence repetition, linguistic skills, and attention subscale scores)	Age, sex, average daily accelerometer wear time, education level, BMI, living status (alone or with someone) ST and mean daily METs included as simultaneous predictors	Within-family linear regression analyses revealed LPA not a significant predictor of cognitive status Between-family linear regression analyses revealed, in fully adjusted model, LPA significantly, positively associated with cognitive status
Johnson et al. (2016)	N= 188 community dwelling older adults (53.7% F, M_{age}= 63.98)	Cohort (Tasmanian Older Adult Cohort Study)	Actigraph GT3X+ (251-1951 cpm)$^{\$}$	ST: 581.67 min/day LPA: 228.56 min/day MPA: 31.49 min/day VPA: 0.39 min/day	Trail Making Task (time to completion for TMT-A and TMT-B)	Age, gender, education, waist-hip ratio, smoking and alcohol consumption, leg muscle strength, total accelerometer wear time and present of MCI. ST, MPA and VPA included as	Multiple linear regression analyses revealed LPA as a significantly associated with TMT-B performance.

Table 3 (cont.)

						simultaneous predictors	
Kerr et al. (2013)	N= 215 older adults living in retirement communities (70.7% F, M_{age}= 83.4)	Cross-sectional	Actigraph GT3X+ (Low-intensity LPA: <1,040 cpm; High-intensity LPA: 1,040-1951 cpm) [ǂ$]	Low-LPA: 202.6 min/day High-LPA: 20.6 min/day MVPA: 10.6 min/day	Trail Making Task (time to completion for TMT-A and TMT-B; TMT-B time-TMT-A time)	Age, sex, education Low-LPA, high-LPA and MVPA included as simultaneous predictors	Multiple linear regression analyses revealed low-LPA engagement not significantly associated with trail making scores. High-LPA significantly associated with faster TMT-B and TMT-B-TMT-A scores only in unadjusted models.
Kimura, Yasunaga & Wang (2013)	N=72 elderly adults (47.22% F, M_{age}= 70.3)	Cross-sectional	Kenz Lifecorder accelerometer (Intensity levels 1-3, based on recorded acceleration)	*Easy Walking Activity* Intensity level 1: 85.6 min/day Intensity level 2: 177.6 min/day Intensity level 3: 25.8 min/day *Brisk Walking Activity* Intensity level 4: 28.5 min/day Intensity level 5: 9.5 min/day Intensity level 6: 8.6 min/day	Task-switching paradigm (intra-individual variability of switch RT)	Age, sex, daily step count, mean reaction time on task-switching paradigm All intensity levels (1-6) included as simultaneous predictors	Multiple linear regression analyses revealed daily duration of time spent in LPA (intensity levels 1-3) were not significant predictors of inter-individual variability scores.
Lin et al. (2018)	N= 162 university students (45.68% F, M_{age}= 19.0)	Cross-sectional	Actigraph GT3X+ (100-2,019 cpm) [a]	LPA: 142.9 min/day MVPA: 43.6 min/day	Task-switching paradigm (global switch cost and local switch cost for RT and accuracy)	Age, gender, accelerometer wear time	Multiple linear regression analyses revealed LPA was independently, significantly associated with smaller global

Table 3 (cont.)

						MVPA included as simultaneous predictor	reaction time switch costs.
Makizako et al. (2015)	N= 310 older adults with MCI (55.5% F, M_{age}=71.3)	Cohort (Obu Study of Health Promotion for the Elderly	Active style Pro (1.5-2.9 METs)	LPA: 347.3 min/day MPA: 22.6 min/day	Logical Memory subtest of WMS-R (sum score of immediate and delayed recall) Visual Memory subtest of WMS-R (delayed retention of geometric figures score) Rey Auditory Verbal Learning test (List A 30-minute delayed recall score)	Age MPA not included as a predictor	Multiple linear regression analyses revealed no significant associations between LPA engagements and memory performance score.
Marinac et al. (2015)	N= 135 post-menopausal breast cancer survivors (100% F, M_{age}= 62.6)	Cross-sectional (Data from RCTs- Reach for Health Study; Reach for Health memory study)	Actigraph GT3X (101-1,951 cpm) $^{\$}$	ST: 510.4 min/day LPA: 550.6 min/day MVPA: 21.1 min/day	Staged Information Processing Speed test (Domain score for information processing speed) Verbal and Non-verbal Memory Tests (Domain score for memory) Stroop Interference test; Go-No-Go Response Inhibition test;	Total accelerometer wear time, primary language spoken, chemotherapy history, BMI ST included as simultaneous predictor; MVPA not included as simultaneous predictor	Multiple linear regression models revealed no association between 10-minute bouts of LPA with any cognitive outcomes.

Table 3 (cont.)

					Catch Game (combined domain score for executive function)		
Umegaki et al. (2018)	N= 464 community dwelling older adults with cognitive complaints (46.4% F, M_{age}= 72.4)	Cross-sectional (baseline data from RCT-Toyota Preventional Intervention for Cognitive decline and Sarcopenia)	Kenz Lifecorder (Intensity levels 1-3 - based on recorded acceleration)	LPA: 47.5 min/day MPA: 18.4 min/day VPA: 1.3 min/day	Logical Memory I & II subtest of the WMS-R* Mini-Mental State Examination (total score) Visual Reproduction I and II subtests of WMS-R* Category and Letter Fluency test* Digit Span subtest of WMS-R* Visual Memory Span subtest of the WMS-R* Digit Symbol subtest of the Wechsler Adult Intelligence Scale-III (number of correct responses) Trail Making test (time to	Age, sex, education, apolipoprotein E4 status, insulin resistance, depression MVPA not include as simultaneous predictor	Multiple linear regression analyses revealed LPA was significantly associated with performance on TMT-A and TMT-B performance and Digit Symbol scores

Table 3 (cont.)

					completion for TMT-A and TMT-B)		
Wilbur et al. (2012)	N=174 Latino older adults (73.56% F, M_{age}= 66)	Cross-sectional	Actigraph GT1M (100-1,565 cpm)[♦]	LPA: 259.4 min/day MVPA: 31.2 min/day	East Boston memory test (mean of immediate and delayed recall) Color-word task of the Stroop Neuropsychological Screening Test (number of colors correctly identified in 30 sec, number of incorrect responses in 30 sec, number of colors answered correctly – number of incorrect responses) Numbers Comparison Test (number of pairs classified correctly in 90 sec – number classified incorrectly) Category Fluency Test (total number of unique examples	No covariates accounted for in correlation analyses	Bivariate correlations revealed LPA to be significantly, positively correlated with interference control[#] and word fluency scores

Table 3 (cont.)

					generated; word fluency score)		
Zhu et al. (2015)	N= 7,098 community dwelling older adults (54.2% F, M_{age}= 70.1)	Cohort study (REasons for Geographic and Racial Differences in Stroke study)	Actical (50-1065 cpm)[†]	ST: 690.5 min/day LPA: 186.9 min/day MVPA: 12.9 min/day	Six-Item Screener (Total score) Word List Learning & Montreal Cognitive Assessment (z-scores from each test combined to produce memory composite measure) Animal Fluency & Letter Fluency (z-scores from each test combined to produce executive function composite measures)	Age, sex, race, region of residence, education, BMI, hypertension, smoking, diabetes. Percent of accelerometer wear time spent in ST and MVPA were included as simultaneous predictors.	Logistic linear regression analyses revealed percent of accelerometer wear time spent in LPA not associated with odds of cognitive impairment. Multiple linear regression models regressing percent LPA time on cognitive assessment outcomes not reported.
Zlatar et al. (2019)	N= 52 cognitively healthy older adults (57.7% F, M_{age}= 72.3)	Cross-sectional	Actigraph GT3X+ and GT3X-BT (100-1951 cpm) [$]	ST: 547.99 min/day LPA: 300.52 min/day MVPA: 23.99 min/day	D-KEFS Color Word Inhibition and Color-Word Inhibition/Switching; TMT- B, Wisconsin Card Sorting Test; Controlled Oral Word Association Letter Fluency Task (z-scores from each task	No covariates accounted for in correlation analyses	Bivariate Pearson correlations revealed no significant correlations between LPA and either cognitive composite score.

Table 3 (cont.)

					used to created composite Executive Function score) WMS-R Logical Memory Immediate and Delayed Recall total scores; California Verbal Learning Test – II Total for trials 1-5; Short and Long Delay Free Recall; Famous Face Naming task (z-scores from each task used to created composite memory score)		

ACC, accuracy; BMI, body mass index; CPM, counts per minute; CVD, cardiovascular disease; D-KEFS, Delis-Kaplan Executive Function System; F, female; LPA, light physical activity; $M_{age,}$ mean age; METs, metabolic task equivalents; MCI, mild cognitive impairment; MPA, moderate-intensity physical activity; MVPA, moderate-vigorous physical activity; PAD, peripheral arterial disease; RT; reaction time; RCT , randomized control trial; ST, sitting time; TMT-A, trail making task part A; TMT-B, trail making task part B; VPA, vigorous physical activity; WMS-R, Wechsler Memory Scale – Revised

*Task outcomes not reported

[#] Study authors did not specify how this outcome was calculated

ǂ Cut-points by Copeland and Eslinger (Copeland & Esliger, 2009)

[$] Cut-points by Freedson et al. (Freedson et al., 1998)

† Cut-points by Hutto et al. (Hutto et al., 2013)

⬧ Cut-points by Miller et al. (Miller et al., 2010)

▲ Cut-points by Studenski et al. (Studenski et al., 2011)

[a] Cut-points by Toriano et al. (Troiano et al., 2008)

APPENDIX E: LONGITUDINAL STUDIES

Table 4: Longitudinal studies included in review

Author (Year)	Participant sample	Study design	LPA measurement and classification	Accelerometer-measured physical activity	Cognitive measure(s) used (outcomes reported)	Covariates used in analysis	Key findings corresponding to LPA engagement
Halloway et al. (2017)	N = 171 (n=59 completed PA and cognitive measures) older, urban Latinos (Females = 71.3%; $M_{age=}$ 67.1)	Assessments administered at baseline and follow-up Average 5-year follow up	Actigraph GT1M (100-1,565 cpm)[♦] CHAMPS Questionnaire[#]	*Baseline* LPA: 272.9 min/day MVPA: 28.6 min/day *Follow-up:* LPA: 258.3 min/day MVPA: 26.2 min/day	East Boston Memory Test (immediate recall score, delayed recall score, average of immediate and delayed score) Modified Stroop Color-Word Task (total correct words; correct minus incorrect words; total correct colors; correct minus incorrect colors) Numbers Comparison Task (number of pairs correctly classified in 90 seconds minus number classified incorrectly) Category Fluency Test (word fluency score)	Baseline age, number of chronic health problems, depressive symptoms, acculturation scores MVPA not adjusted for	Bivariate correlations and linear regression revealed accelerometer-measured LPA was not significantly associated with any cognitive outcomes.
Kojima and Nagano (2019)	N = 15 adults with cerebro-vascular disease (Females = 40%; M_{age}= 78)	4-month testing period. Assessments administered each month	Actigraph GT3X-BT (100-1951 cpm) [$]	*Baseline*[^] ST: 1311.5 min/day LPA: 125.6 min/day MVPA: 2.9 min/day	Raven's Colored Progressive Matrices[±] Symbol Digit Modalities Test (correct number of responses in 90 sec)	Not reported	Spearman's correlations revealed significant, positive correlations between mean LPA measured at each measurement period with Raven's matrices scores

Table 4 (cont.)

		over test period (baseline, 2nd, 3rd, 4th month)		*4-month* ST: 1259.6 min/day LPA: 175.5 min/day MVPA: 4.9 min/day	Symbol Trails[±] Symbol Cancellation (total performance score) Design memory (number of abstract designs correctly identified) Mazes (total performance score)		and Symbol Digit Modalities test. Spearman's correlations revealed significant, positive correlations between mean value of LPA over entire measurement period and 4th month score of Symbol Digit Modality test.
Stubbs et al. (2017)	N = 274 community-dwelling older adults (Females = 54.4%, M_{age}= 74.52)	PA assessments collected at baseline; cognitive function collected at follow-up Average follow-up length: 22.12 months	Actigraph GT3X+ (100-1951 cpm)[$]	Raw data not reported	Ascertain Dementia 8-item Questionnaire (total score)	Age, sex, education, marital status, income source; smoking and alcohol use; BMI; number of chronic diseases MVPA included as simultaneous predictor	Binomial regression analyses revealed baseline LPA was significantly associated with reduced rate of cognitive decline at follow-up (in both crude and adjusted models)
Zhu et al. (2017)	N = 6452 older adults (Females = 55.3%; M_{age} = 69.7)	Participants assessed annually for global cognitive status (for 3 years), every 2 years for memory and executive function Accelerometers	Actical (50-1064 cpm)[†]	*Baseline only:* ST: 688.4 min/day LPA: 190.4 min/day MVPA: 13.5 min/day	Word List Learning and Montreal Cognitive Assessment recall and orientation item (z-scores for each assessment combined to composite memory score) Animal and Letter fluency (z-scores for each assessment combined to composite executive function score)	Age, sex, race, region of residence, education, BMI, hypertension, smoking and diabetes, baseline cognitive scores and follow-up time intervals. Percent accelerometer	Linear regression analyses revealed no significant associations between percent accelerometer wear time spent in LPA and incidence of cognitive impairment, executive function scores or memory scores.

Table 4 (cont.)

		administered at baseline.			Six-Item Screener (total sum score)	wear time spent in MVPA and ST not adjusted for	

BMI, body mass index; PA, Physical Activity; CHAMPS, Community Healthy Activities Model Program for Seniors questionnaire; cpm, counts per minute; LPA, light physical activity; M_{age}, mean age; MVPA, moderate-vigorous physical activity; ST, sitting time

*Study authors did not specify how this outcome was calculated

[#] Questionnaire outcomes not included in scoping review results or discussion

[^] Physical Activity data also collected at months 2 and 3

ǂ Cut-points by Copeland and Eslinger (Copeland & Esliger, 2009)

[$] Cut-points by Freedson et al. (Freedson et al., 1998)

┼Cut-points by Hutto et al. (Hutto et al., 2013)

♦ Cut-points by Miller et al. (Miller et al., 2010)

APPENDIX F: COGNITIVE ASSESSMENTS

Table 5: Cognitive domains assessed and measures used

Memory	Attention and Processing Speed	Executive Function	General Cognitive Function
Semantic Category Fluency test (3) Famous Face Naming task *Episodic* California Verbal Learning Test – II CERAD- Word List Learning test (2) East Boston memory test (2) Montreal Cognitive Assessment - Recall and Orientation (2) Mnemonic discrimination task NeuroTrax- Verbal and Non-Verbal Memory test Rey Auditory Verbal Learning Test (3) Short and Long Delay Free Recall	Eriksen Flanker Task-congruent (5) Feature Match Polygon Number Comparison test (2) Rosvold continuous performance test Stroop test- Neutral (3) Stub & Black mental status test- Attention/Concentration subscale Sustained Attention to Response Task Symbol Digit Modalities test Trail Making Part A (4) Vienna Test System- Cognitrone Test Vienna Test System -Grooved Pegboard Test WAIS-IV Coding task WAIS Digit Symbol WAIS-IV Symbol task	CANTAB Multitasking test CANTAB Inhibitory Control Task Catch Game Cognitive Linguistic Quick Test - Symbol Trails Cognitive Linguistic Quick Test - Symbol Cancellation Cognitive Linguistic Quick Test- Mazes Controlled Oral Word Association Letter Fluency Task D-KEFS- Color Word Inhibition and Inhibition/Switching Eriksen Flanker task- incongruent (5) Go-No-Go Response Inhibition test Grammatical Reasoning Odd One Out Raven's Colored Progressive Matrices Spatial Search	Ascertain Dementia 8-Item Questionnaire Mini-Mental State Examination (2) Montreal Cognitive Assessment Six-Item Screener (2) Telephonic Assessment for Dementia Telephone Interview for Cognitive Status

Table 5 (cont.)

Stub & Black mental status test- Short Term memory subscale WMS-R Logical Memory test (3) WMS-R Visual Reproduction subtest (3) *Working Memory* Brown-Peterson task CANTAB Spatial Working Memory Task Cognitive Linguistic Quick Test- Design memory N-back task Spatial Span Paired Associates (2) Spatial Working Memory Task WAIS-IV Digit Span (2) WMS-R Digit Span subtest		Spatial Slider Stub & Black mental status test- Higher Cognitive Functioning subscale Task-Switching paradigm (3) Trail Making Part B (6) Verbal Fluency (2) Wisconsin Card Sorting Test	

Note: If assessment was used in more than one study, number of studies noted in parentheses.

APPENDIX G: SAMPLE SEARCH STRING

(“light intensity physical activit*” OR “low intensity physical activit*” OR “light intensity walking” OR “light intensity lifestyle” OR “light intensity exercise” OR “low intensity exercise” OR “light intensity activit*” OR “low intensity activit*” OR “light-intensity physical activit*” OR “low-intensity physical activit*” OR “light-intensity walking” OR “light-intensity lifestyle” OR “light-intensity exercise” OR “low-intensity exercise” OR “LPA” OR “LIPA”) AND (“Cognition”[mesh] OR “Cognitive Function” OR “Brain Function” OR “Executive Function”[mesh] OR “Executive Control” OR “Memory”[mesh] OR “mental processes”[mesh] OR “Reaction time” OR “Response latency” OR “Accuracy” OR “Attention”[mesh] OR “Task switching” OR “Problem solving”[mesh] OR “Decision making” OR “Multitasking” OR “Planning” OR “Reasoning” OR “Comprehension” OR “Spatial memory” OR “Episodic memory” OR “Long term memory” OR “Declarative Memory” OR “Intelligence” OR “Neurocognition” OR “Neurocognitive” OR “Neuro-cognition” OR “Neuro-cognitive” OR “Attentiveness” OR “Concentration” OR “Concentrate” OR “Information retrieval” OR “Information processing” OR “Perceptual skills”) AND “adult”