The association between social support and executive function in mid- to late-life within the context of attrition: Results from the Canadian Longitudinal Study on Aging

by
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Author's Declaration

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

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Abstract

Background. As the population over the age of 65 increases, a greater proportion of Canadians will be impacted by the effects of cognitive decline, necessitating research on risk factors that can influence cognitive outcomes. Social support has been identified as a potential area of intervention for the cognitive health of the aging population and may have a particularly strong association with key cognitive domains such as executive function. Executive function is an important cognitive domain in successful aging given its role in the tasks required for daily independent living. While there is largely consistent evidence for a positive cross-sectional association between social support and executive function, longitudinal studies have produced more mixed findings. As both social support and executive function play a role in attrition (i.e., participants dropping out of studies over time), longitudinal studies investigating the association between the two may be at greatest risk of increasingly selective, and possibly biased, samples. Developing a better understanding of how social support impacts executive function within the context of attrition is essential to maximizing public health efforts aimed at supporting the cognitive health of the aging population.

Aim. The overall aim of this thesis was to investigate the association between functional social support and executive function in mid- to late-life and to explore how attrition may be impacting our knowledge of this relationship.

Methods. Modified Poisson and logistic regression analyses utilized baseline (T1; 2012-2015), first (T2; 2015-2018) and second (T3; 2018-2021) follow-up data from the Comprehensive cohort of the Canadian Longitudinal Study on Aging (CLSA). Attrition was assessed based on participation at baseline only (T1), both T1 and T2, and at all timepoints (T1, T2, T3). As data collection for follow-up 2 (T3) occurred both pre- and post-implementation of COVID-19-related restrictions in Canada, this time point was divided into two cohorts (i.e., those who participated pre vs post COVID-19 restrictions). The 19-item Medical Outcomes Study-Social Support Survey was used to assess perceived availability of social support (overall and subtypes: emotional/informational, tangible, affectionate, positive social interactions). Executive function was calculated by averaging standardized scores across multiple cognitive tests. Final models were adjusted for sociodemographic, health, lifestyle, and additional social variables.

Results.

Study 1 (Chapter 4) investigated if baseline social support and executive function were associated with attrition and if the association between social support and executive function varied across those participating at one (T1), two (T1, T2), or three (T1, T2, T3) timepoints. After accounting for covariates, those with low social support, low executive function, or those missing data on any of the tests of executive function were significantly more likely to drop out of the study after baseline (T1) assessment and were significantly less likely to complete all three waves (T1, T2, T3) of the study. The cross-sectional association between low social support and low executive function at baseline was statistically significant for those who participated at baseline-only but not for those who participated at both T1 and T2 or at all three timepoints. This suggests that the association between functional social support and executive function at baseline varies in a meaningful way for those lost to attrition vs those who remained in the study, and that those with the strongest association between social support and executive function may be those most likely to be lost to follow-up. Attrition in longitudinal studies can lead to underestimating or overestimating the impact of risk factors given the cognitively healthier and more socially engaged participants who remain in the study over time.

Study 2 (Chapter 5) investigated the longitudinal role of functional social support (T1) and its subtypes on executive function (T3) while exploring how attrition and individual characteristics may impact the results and conclusions generated from these analyses. The longitudinal association between low social support and low executive function was not statistically significant. Taken at face value, these results would seem to add to the conflicting, non-significant, findings regarding the long-term association between social support and cognitive function. Yet, when those who completed all assessments were compared cross-sectionally (T1) to those who had dropped out of the study, only those lost after baseline had a significant positive association between low social support and low executive function. These findings indicate that attrition may be introducing bias into our longitudinal results and, if we as researchers are not careful in our interpretation, into our conclusions about the value of functional social support for cognitive health.

Study 3 (Chapter 6) investigated how the association between social support and executive function differs pre- vs post-COVID-19 restrictions (T3), with half of the sample completing

their assessments in-person, pre-COVID-19, and the latter half via telephone interviews post-COVID-19 restrictions. While the cross-sectional (T3) association between social support and executive function pre-COVID-19 restrictions was only statistically significant for one subtype of support (i.e., emotional/informational), post-COVID-19 restrictions, overall social support, as well as positive social interactions, emotional/informational and affectionate social support were statistically significantly associated with executive function, such that higher social support was associated with higher executive function. It is unclear whether the significant relationship between social support and executive function post-COVID-19 restrictions reflects the changes in data collection procedures or the greater psychological and cognitive impacts of the COVID-19 pandemic and related changes to daily life. The COVID-19 pandemic will continue to have an undeniable impact on data analyses for the foreseeable future and analyses considering the long-term impact of social exposures on cognitive health should explicitly account for how the COVID-19 pandemic and related restrictions may impact our understanding of this association.

Contributions. Understanding how different aspects of social support impact cognitive function—and, by proxy, independence and adaptability— is essential to public health efforts aimed at improving health outcomes for older adults through evidence-based social programs and policies. The results of this dissertation reveal that the longitudinal relationship between social support and executive function is complex and that conclusions in this research area may be influenced by attrition. This dissertation demonstrated that those with the strongest association between social support and executive function were also those most likely to be lost to follow-up. While the long-term impact of social support on cognitive health is best investigated using longitudinal studies, these samples are vulnerable to biases which can lead to generalizations that do not reflect the greater population. Of greatest concern is that those who are lost to these studies over time may be those who would benefit most greatly from cognitive research, given their poorer health. While what is demonstrated in this dissertation discusses the association between social support and executive function, the limitations of the data represented here have wide-spread implications for longitudinal research on aging. Future research considering the long-term impact of exposures on cognitive health over the lifespan should actively investigate how attrition may impact their samples and findings.

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When I applied for my PhD in the fall of 2019, I had no way of knowing what was on the horizon. I completed my Fall 2020 courses virtually, never actually meeting most of my cohort due to closed borders. I attended virtual funerals (and conferences) squeezed in between regular work meetings, apart from an outdoor memorial for three generations of my family who were all lost to the COVID-19 pandemic. My grandmother died unexpectedly at the start of my comprehensive exam, and before the end of the PhD, I would lose another grandparent, as well as my beloved cat, Moo. I battled many illnesses over the past five and a half years, some requiring months of recovery, and some never fully healing.

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List of Abbreviations

ADL	Activities of Daily Living
AFT	Animal Fluency Test
CI	Confidence Intervals
CIHR	Canadian Institutes of Health Research
CLSA	Canadian Longitudinal Study on Aging
COPD	Chronic Obstructive Pulmonary Disease
COVID-19	Coronavirus Disease 2019
COWAT	Controlled Oral Word Association Test
CVA	Cerebrovascular Accident
IADL	Instrumental Activities of Daily Living
MAT	Mental Alternation Test
MCI	Mild Cognitive Impairment
MMSE	Mini-Mental State Exam
MOS-SSS	Medical Outcomes Survey – Social Support Survey
OR	Odds Ratio
PFC	Prefrontal Cortex
RR	Risk Ratio
SD	Standard Deviation
Stroop	Victoria Stroop Neurological Screening Test
TIA	Transient Ischemic Attack
TMT	Time-based Prospective Memory Test

Chapter 1: Introduction

As the number of births decrease each year (Statistics Canada, 2021) and the proportion of Canadians over the age of 65 increases at four times the rate of the rest of the population (PHAC, 2017), the overall age distribution of the Canadian population will continue to shift further along the lifespan. While an aging population is a good indication of advances being made in health and life expectancy, demographic change presents new challenges that must be addressed. Non-communicable diseases, which often develop over the lifespan, are more common in older adults and are now considered the greatest burden on health worldwide (WHO & NIA, 2011). For example, individuals over the age of 65 account for about 80% of Canadians with heart failure and approximately 65% of those with ischemic heart disease (PHAC, 2018; PHAC, 2019). Chronic conditions are often co-morbid, meaning that an individual with one chronic condition has also been diagnosed with another condition.

Cognitive function

In addition to increasing comorbidity, cognitive function may be altered over the lifespan. Cognitive function can be understood as a collection of mental processes that permit an individual to complete both basic life-sustaining and complex tasks and is therefore an important indicator of healthy aging. Overall cognitive function is the combination of several different overlapping mental processes and can be measured at the global level as well as by domain. While there is not a consensus on the number of domains of cognitive function, commonly listed domains include, but are not limited to, executive function, vocabulary knowledge, language, reasoning, spatial visualization, memory, speed and attention (Salthouse, 2010; Harada et al., 2013; Sachdev et al., 2014; Seraji-Bzorgzad et al., 2019; Salthouse, 2019; Dennis et al., 2020). Of these domains, executive function is particularly important to successful aging, given its role in the tasks required for daily independent living (McAlister & Schmitter-Edgecombe, 2016).

Executive function

Executive function is a domain of cognitive function that has gone through several historical conceptualizations (Suchy, 2009). While the exact definitions are debated, it is generally accepted that overall executive function refers to a collection of separate but overlapping cognitive processes (Burgess & Stuss, 2017; Alvarez & Emory, 2006; Friedman & Miyake, 2017). Whether these high-level processes are ‘supervisory’ of lower functions,

or if these lower functions are part of executive function themselves, executive function depends on these processes (Alvarez & Emory, 2006). Due to its dependence on so many different processes, executive function is sensitive to many physical, emotional and cognitive stressors, including poor health, stress, and loneliness (Diamond, 2013). Executive function is an effortful practice necessary for paying attention, planning for the future, adapting to change, completing goals, and solving problems (Alvarez & Emory, 2006; Diamond, 2013) and is only used when the mind must work in a non-automatic way (Diamond, 2013). Executive function is separate from general intelligence; however, complex tasks of intelligence often require various executive functions (Friedman & Miyake, 2017). Executive function appears to be strongly influenced by genetics, although no specific genes have been identified and it is likely that a variety of genes play a role (Friedman & Miyake, 2017). As is the case with many heritable traits, individuals are born with a window of variance in which environmental factors play a role (Friedman & Miyake, 2017).

Historically, executive function has been associated with the prefrontal cortex (PFC) (Friedman & Miyake, 2017). However, as with many domains of cognitive function, there is not a perfect one-to-one association between any or all of the executive function processes and specific brain anatomy (Burgess & Stuss, 2017). Individuals with dysexecutive syndrome (renamed from frontal lobe syndrome as a reflection of the evolving view of executive function) may have issues in non-PFC areas (Alvarez & Emory, 2006). Lesion studies have demonstrated that while tests of executive function are good at identifying issues in the brain, they are not useful for determining where injuries may be (Burgess & Stuss, 2017). Some have discussed the "unity and diversity" of executive function processes, such that there are specific areas of the brain associated with different abilities; however, there is also great overlap in the different processes (Friedman & Miyake, 2017). For example, the left PFC is associated with working memory, initiation, and details, while the right PFC is associated with inhibition and visual spatial processing (Suchy, 2009; Cristofori et al., 2019). A modern conceptualization of executive function considers specific regions (such as the dorsolateral frontal cortex) as well as networks, including the frontal-subcortical and frontal-limbic circuits (Burgess & Stuss, 2017; Alvarez & Emory, 2006).

Domains of executive function

The core processes making up the executive function domain are not consistently described, but largely fall into six categories: working memory, inhibitory control, cognitive flexibility, planning, reasoning, and problem solving (Cristofori et al., 2019). Additional processes include attention and interference control (Burgess & Stuss, 2017; Diamond, 2013) or switching (Friedman & Miyake, 2017). In a clinical setting, these processes may be redefined more specifically to reflect visible performance on tasks, such as task completion, organization and awareness (Cristofori et al., 2019).

Inhibition (or self-control) involves suppressing temptations and impulses, and controlling behaviour and attention in order to react appropriately in a given situation while organizing and coordinating a response (Diamond, 2013). It further allows an individual to ignore unimportant or background stimuli to concentrate on a chosen idea or task. Declines in the inhibition subdomain would lead to increases in impulsivity and impatience, as well as decreases in attention and discipline. Tests used to assess inhibition include the Stroop Neurological Screening Test (Stroop) and delay-of-gratification tasks (Diamond, 2013).

The second subtype of executive function, working memory, is necessary for following instructions, communicating with others, and connecting and applying ideas to come up with plans or solutions, as well as logical reasoning (Diamond, 2013). Working memory is distinct from the memory domain of cognitive function as it requires an individual to be able to manipulate the information being stored rather than just remembering it, and the processes have been shown to develop separately: short-term memory is present in very young children while working memory develops throughout childhood and adolescence (Diamond, 2013). Popular tests of working memory ask participants to reorder a list of memorized items (e.g., alphabetically) or to repeat a series of actions demonstrated by the administrator.

Finally, cognitive flexibility involves being able to take on different perspectives and to adjust to new and changing situations or demands (Diamond, 2013). An important part of cognitive flexibility is the ability to task-switch, which has been tested using many different measures, including the Dimensional Card Change Sort Test and the Mental Alternation Test (MAT). Assessments of verbal fluency are also often used to assess cognitive flexibility. These include semantic or categorical fluency tests in which participants must list as many

examples as possible of a given category (e.g., animals) within a time period, such as the Animal Fluency Test (AFT). Alternatively, tests may assess letter fluency, such as the Controlled Oral Word Association Test (COWAT), in which participants list words starting with a specific letter (Diamond, 2013; Tuokko, Griffith, Simard, & Taler, 2017).

As executive function is a collection of higher-order processes built on lower processes, no one test assesses all of executive function and any issues with lower processes will inevitably impact performance (Friedman & Miyake, 2017). A non-exhaustive list of lab-based tests of executive function include the Wisconsin Card Sorting Test (WCST), the Stroop Color Word Interference, the Trail Making Test, the Tower of Hanoi, as well as tests of phonemic and semantic verbal fluency (Alvarez & Emory, 2006, Cristofori et al., 2019). The Corsi-block test and tests in which participants manipulate (e.g., reorder) lists of verbal information are used for working memory specifically (Diamond, 2013).

Many factors outside of actual cognitive function can influence an individual's performance on a test of executive function. Individual history with specific aspects of the tests and minute differences in how a test is administered—from specific wording of the script, the type of reward offered, and the emotions elicited during the instruction period—can lead to dramatic differences in performance (Burgess & Stuss, 2017). Other individual confounders may also impact performance. For example, older adults who are bilingual appear to have faster processing speed than non-bilinguals (Diamond, 2013), possibly developed as a response to the greater frequency of task-switching (i.e., switching languages) needed when actively using multiple languages.

Assessments of executive function that work best in a research setting and those that work best for diagnoses and practical assessments in a clinical setting may differ (Cristofori et al., 2019). Suchy (2009) provides the example of an older woman who is able to complete her familiar, seemingly complex daily tasks without problems but, when faced with any new situations, appears to suffer from major issues with executive function. In familiar or structured circumstances, such as receiving prompts and clear instructions in a research-based assessment, a person may appear to have fully intact executive function, but in their daily lives may be incapable of handling unfamiliar situations (Suchy, 2009). Due to these issues with the relevance of lab-based assessments, some have proposed alternative testing

for executive function which is more reflective of everyday life, such as the Multiple Errands Test and the gambling task (Alvarez & Emory, 2006).

Cognitive aging

Cognitive aging considers how cognitive abilities change with age. These age-related cognitive changes may be minor, having little impact on day-to-day life, or may overwhelmingly devastate all areas of a person's life and limit their ability to live independently, as seen in dementia (major neurocognitive disorder), a type of neurodegenerative disorder. There is no cure for the most common forms of dementia, including Alzheimer's disease, the risk for which increases rapidly with age, doubling every five years after age 65 (PHAC, 2020). Given that the population is aging, the number of people living with age-related cognitive impairment, including dementia and mild cognitive impairment, is likely to increase. In Ontario, the mean age of persons with dementia was 81.5 years, and over 40% of those with the diagnosis were over the age of 85 (Ng et al., 2015). It was estimated that 432,000 older adults in Canada were living with dementia in 2016-2017, with this rising to 597,300 by 2020 (PHAC, 2020; Alzheimer's Society, 2022). By 2030, there will be over 185,000 new cases of dementia each year, and over a million cases in Canada (Alzheimer's Society, 2022). Mild cognitive impairment (MCI), or mild neurocognitive disorder, occurs in 12 to 18% of people over the age of 60 (Sachdev et al., 2014; Petersen, 2016) and 10–33% of MCI cases develop into Alzheimer's disease within a year (Ward et al., 2013).

The implications of cognitive decline are not limited to impairment in tests of cognitive function. At the clinical level, dementia refers to severe declines in cognitive function that eventually impact the ability of the individual to complete everyday tasks, such as cooking dinner or getting dressed (Alzheimer's Association, 2016). Over half of those with dementia have mobility limitations (PHAC, 2020) and neurologic disorders (including dementia) were the fourth leading cause of age-standardized years lived with disability and the sixth leading cause of age-standardized disability-adjusted life years in 2016 (Lang et al., 2018). Even on brief measures of cognitive function, individuals with more cognitive errors demonstrate an increased risk of developing limitations in their activities of daily living (Moritz, Kasl, & Berkman, 1995). Cognitive function has further been shown to have a negative relationship with frailty (Kim et al., 2014), with frailty in older adults further

associated with increased risk of functional and cognitive decline as well as mortality (Hoogendijk et al., 2014).

The amount of variability in cognitive function test scores between individuals does not increase with age, indicating that most individuals will experience some level of decline in overall cognitive abilities (Salthouse, 2010). Despite this, there are many benefits to understanding if and how decline occurs across cognitive domains, and for whom. Being able to differentiate decline from normal aging is key in identifying those in need of interventions as early as possible to minimize further decline (Sachdev et al., 2014; Salthouse, 2019; Dennis et al., 2020). While many older adults may be impacted by chronic conditions not everyone will experience them. Some older adults demonstrate generally low levels of physiological and cognitive decline despite advanced age, while others begin to experience increasing fragility in midlife. Understanding what permits some individuals to reach older adulthood—or death—without loss of independence, while others experience devastating declines in cognitive health beginning in middle age or earlier, is key to the development of public health policy and programs that may help prevent or slow the onset of cognitive impairment.

Social support

Given the risk for age-related declines in cognitive function and the devastating impact of severe cognitive decline on daily living, managing and confronting the consequences of the predicted demographic changes (i.e., population aging) that will increase the number of individuals at risk for cognitive decline should be a public health priority (WHO, 2015; PHAC, 2020). Many modifiable risk factors for cognitive decline have been identified (Livingston et al., 2024), including educational attainment (Fratiglioni et al., 2000; Sims et al., 2011; Khondoker et al., 2017; Iraniparast et al., 2022), income (Ramírez et al., 2007; Zhu, Hu & Efird, 2012) and physical health (e.g., Tilvis et al., 2004; Khondoker et al., 2017). Unfortunately, the extent of the risk associated with many of these modifiable factors is established earlier in the lifespan, such that most require interventions long before the early symptoms of cognitive decline develop. In addition, there are likely structural barriers (e.g., economic access to services and supports) involved in the intervention of many of these lifelong factors. While these factors provide important forms of primary prevention, it is also necessary to have potential secondary and tertiary levels of prevention (the latter of which

occur once the condition is already present). These later interventions can be utilized in mid- to late-life with those who are at risk for greater or faster cognitive decline or just starting to experience symptoms of low cognitive function.

Psychosocial factors, such as social support, are a potential area of intervention that could help play a role in delaying onset and slowing the progression of cognitive decline over the lifespan. At the broadest level, social support can be divided into two categories: structural (quantitative/objective) support, and functional (qualitative/subjective) support. Structural social support refers to objective measures of support, such as marital status; living arrangement; number of friends, relatives, and neighbours; and the amount of participation and engagement an individual partakes in, as well as how interconnected these resources are (Sherbourne & Stewart, 1991). While these forms of support are easily measured and thus have been commonly used in epidemiological research, structural support fails to account for how much social support the individual perceives themselves as receiving (Sherbourne & Stewart, 1991). For example, a person may have many friends and neighbours but still feel socially isolated, while a person with a small social network may feel that their social needs are met.

In contrast, functional social support is a subjective rating of the support that individuals perceive as available to themselves when needed and is based on the perceived adequacy of one's social resources to fulfill their specific social needs (Sherbourne & Stewart, 1991). Historically, five distinct areas of functional social support have been identified: emotional support, informational support, affectionate support, tangible or instrumental support, and positive social interactions (Sherbourne & Stewart, 1991), descriptions of which are provided in **Appendix A.1.** Each of these areas of support may not be needed at all times, but different circumstances and life stages may require more or less of each type and so overall assessments of functional support should include measures for all five areas (Pillemer & Holtzer, 2016).

There may be an overlap between structural and functional social support, such that those with larger social networks tend to report higher levels of emotional and tangible social support (Gurung et al., 2003). However, this is not always true, and a discrepancy between the level of social support available and the perceived level of support needed can occur regardless of network size (Yeh & Liu, 2003). Older adults can experience a trimming of

their social networks over time as they focus on their most beneficial relationships; however, this reduction does not necessarily decrease the level of perceived social support they receive (Gurung et al., 2003). Considering only the objective quantity of support through measures of structural social support may not accurately reflect the social support experienced or the potential benefit of social support interventions. Further, it is possible that structural measures of social support are poor proxies for the perceived social support received through these relationships (e.g., not living alone is only useful if the people you live with offer functional support). Functional social support, which considers ratings of an individual's subjective experience of support, may more accurately assess how much support an individual perceives themselves as having access to.

Chapter 2: Background - Literature review

Theoretical frameworks linking social support and cognitive function

While the exact mechanism(s) through which social support may influence cognitive function has not been determined, three main theories—the stress-buffering hypothesis, physical activation theory, and cognitive stimulation theory—have been suggested as potential explanations for this association (Eisele et al., 2012). The *stress-buffering hypothesis* proposes that, by building confidence and self-esteem, emotional social support indirectly improves cognitive function by leading to reduced physiological arousal during periods of stress, thereby producing a sense of calm that inhibits chronic overactive arousal which can damage areas of the brain such as the hippocampus (Sims et al., 2011; Eisele et al., 2012). *Physical activation theory* suggests that maintaining social relationships, especially in large social networks, leads to an increase in one's level of physical activity over the life span (Eisele et al., 2012). Increasing physical activity improves overall health, including lowering the risk of developing vascular diseases, which have been shown to increase the risk of developing various dementias, including Alzheimer's disease (Eisele et al., 2012). Finally, the *cognitive stimulation hypothesis* suggests that social support directly impacts cognitive function through the stimulation of various mental processes required to maintain social relationships (Ellwardt et al., 2013). This theory may help to explain why more negative social interactions (Hughes et al., 2008) and greater social strain in relationships (Ge et al., 2017) are associated with higher global cognitive function, findings that seemingly contradict the other suggested theories.

Public health research interested in the development of interventions aimed at preserving cognitive function have also focused on topics such as *reserve* to identify factors associated with better adaptation to natural age-related cognitive declines and avoidance of cognitive outcomes such as MCI and dementia. Reserve refers to both passive (e.g., brain volume) and active (e.g., plasticity) processes in the brain that allow it to compensate for damage to brain structures as well as other physiological changes (e.g., reductions in neurotransmitter levels) that may occur (Harada et al., 2013; Cabeza et al., 2018). To compensate for atrophy, for example, the aging brain may increase bilaterality (i.e., use of both sides of the brain) and use broader frontal areas when completing complex tasks, compared to younger adults (Dennis et al., 2020). It is likely that each of the above theories

partially explains the association found between social support and cognitive function and that, somewhere in their combination, there is a clearer answer for this relationship.

Social support and cognitive function

The association between social support and cognitive function is complex and appears to vary by assessment of social support, source or provider of support, form of support, and cognitive domain. In addition, this relationship appears to be modified by a variety of sociodemographic and health-related variables. Social variables, such as marital status, also appear to significantly modify this association, although research has been limited.

Overall social support has largely been found to be positively associated with global cognitive function (Zank & Leipold, 2001; Ficker et al., 2002; Yeh & Liu., 2003; Hudetz et al., 2007; Hughes et al. 2008; Krueger et al., 2009; Conroy et al., 2010; Zhu et al., 2012; Eisele et al., 2012; Lee & Waite., 2018; Oremus et al., 2019; Chen & Zhou, 2020; Bourgeois et al., 2020; Saenz et al., 2020; Luo et al., 2021; Mehrabi & Béland., 2021; Pais et al., 2021; Moreno et al., 2021), executive function (Krueger et al., 2009; Hamalainen et al., 2019), and memory (Zahodne et al., 2018; Zuelsdorff et al. 2019, Okely et al., 2021); however, this is not consistent across all studies (e.g., Zuelsdorff et al., 2013; Hudetz et al., 2017; Rutter et al., 2024; Zuelsdorff et al., 2019). It has also been shown to be protective in terms of dementia severity (Yang et al., 2020), Alzheimer's disease (Poey et al., 2017) and cognitive impairment (Rashid et al., 2016; Posis et al., 2023). Andrew and Rockwood (2010), for example, found that the risk of developing cognitive decline increased 3% for every additional one-item increase on a 40-item measure of social vulnerability, with higher scores on the same measure associated with incident dementia.

Perceived *negative social support* or burden from others may increase the risk of dementia (Khondoker et al., 2017). In contrast, some studies have found that greater levels of reported social strain (Ge et al., 2017) and negative social interactions (Hughes et al., 2008) were associated with higher global cognitive function. This finding could be explained by the *cognitive stimulation hypothesis*, as negative relationships still provide opportunities for the use of cognitive processes. It is likely that the severity and duration of negative social experiences matter, with more severe and longer durations likely associated with adverse cognitive outcomes.

Those who report high levels of *satisfaction with social support* have a lower risk of developing dementia (Crooks et al., 2008; Amieva et al., 2010) and feeling satisfied that, across the lifespan, one had received more than they gave in their social relationships reduces the risk of developing dementia and Alzheimer's disease by over half (Amieva et al., 2010). Satisfaction with support is also associated with better global cognitive function (Alpass et al., 2004; Gow et al., 2013) and memory (Hughes, 2008), although this association was not statistically significant in all studies (e.g., Keller-Cohen et al., 2006).

Subtypes of functional social support

Looking more closely at specific domains of functional social support, emotional support and tangible support have been the most commonly investigated. Compared to other subtypes of functional social support, *emotional social support* is most consistently found to be related to cognitive function, while still not reported to be statistically significant in all studies. Higher levels of emotional support are associated with better cognitive function, especially in older adults, and these results are found in both cross-sectional and longitudinal investigations (e.g., Sims et al., 2014). With some exceptions (e.g., Hughes et al., 2008; Heser et al., 2014; Thomas & Umberson, 2018; Noguchi et al., 2019; Liu et al., 2020; Zahodne et al., 2021), emotional support has been most consistently positively associated with global cognitive function (Okabayashi et al., 2004; Holtzman et al., 2004; Ellwardt et al., 2013; Chen & Chang, 2016; Kelly et al., 2017; Kim et al., 2019; Murayama et al., 2019; Nakamura et al., 2019; Harling et al., 2020; Weng et al., 2020; Bedard & Taler, 2021; Deng & Liu., 2021), executive function (Zahodne et al., 2014; Frith & Loprinzi, 2017; La Fleur & Salthouse, 2017; Rutter et al., 2024; Zahodne et al., 2021), memory (Zahodne et al., 2014; Kelly et al., 2017; La Fleur & Salthouse, 2017; Kim et al., 2019; Oremus et al., 2020; Zahodne et al., 2021), language ability (La Fleur and Salthouse, 2017), and processing speed (Hughes et al., 2008), and negatively associated with dementia (Sörman et al., 2015; Salinas et al., 2017; Saito et al., 2018; Murata et al., 2019; Rote et al., 2021; Miyaguni et al., 2021) and Alzheimer's disease (Heser et al., 2014; Sörman et al., 2015).

Research on *tangible social support* offers more inconsistent results: some studies find that reductions in tangible support are associated with worse performance on measures of executive function (Dickinson et al., 2011) and memory (Sims et al., 2014; Zahodne et al., 2021), and that higher tangible support may be positively (Heser et al., 2014), negatively

(Camozzato et al., 2015; Murata et al., 2019; Rote et al., 2021) or not (Riddle et al., 2015) associated with Alzheimer's disease. Longitudinal analyses indicate that high levels of tangible support may actually be associated with the development of cognitive impairment, likely because those experiencing early symptoms of cognitive impairment need more tangible support (Pillemer et al., 2019). However, tangible support has sometimes been found to be positively associated with executive function (Dickinson et al., 2011; Liao & Scholes, 2017), language ability (La Fleur and Salthouse, 2017), and global cognitive function (Hughes et al., 2008; Dickinson et al., 2011; Noguchi et al., 2019; Bedard & Taler, 2020; Harling et al., 2020; Deng & Liu, 2021), particularly in males (Murayama et al., 2019). This relationship was not statistically significant for all studies (Seeman et al., 2001; Ellwardt et al., 2013; Pillemer & Holtzer, 2016; Nakamura et al., 2019; Pillemer et al., 2019).

Combined emotional and tangible social support have also been shown to be positively associated with global cognitive function (Holtzman et al., 2004; Gow et al., 2007; Ge et al., 2017; Noguchi et al., 2019) and executive function (Ge et al., 2017). *Affectionate social support* is often not differentiated from emotional support in the literature; however, recent evidence suggests it is also statistically significantly associated with specific domains of cognitive function, such as memory (Oremus et al., 2020) and executive function (Rutter et al., 2024). Although the research on *positive social interactions* has not been as extensive, results have been largely consistent. Positive social support is statistically, significantly negatively associated with dementia, Alzheimer's disease and cognitive deterioration (Andel et al., 2012; Khondoker et al., 2017; Bedard and Taler, 2021) and positively associated with memory (Liao and Scholes, 2017; Oremus et al., 2020) and executive function (Liao and Scholes, 2017; Rutter et al., 2024).

Modifiers of the association between social support and cognition function

While there appears to be a generally positive association between functional social support and cognitive function, this may not be true for all adults in mid- to late-life. Variation and inconsistencies in the association between social support and cognitive function may be due to many factors, including characteristics of the population (e.g., age, sex/gender, health) and length of follow-up. These findings could be further impacted by the rigor of the methodology employed in the study, such as robust analytical methods and comprehensive adjustment for potential confounders.

Characteristics of the population

Age may modify the relationship between social support and executive function with associations being stronger in younger adults (Seeman et al., 2011). Sex and gender have also been identified as likely effect modifiers, as the type and level of social support available to men and women have been found to differ and change over time (Gurung et al., 2003) and some subtypes of functional social support, such as emotional support, may only be beneficial to cognitive function in women (e.g., Pillemer & Holtzer, 2016; Lee & Waite, 2018). This moderation is likely amplified by sex and gender differences in the measurement and trajectories of cognitive function. Examples include evidence that lower social support in the workplace is statistically significantly associated with higher odds of Alzheimer's disease in females and vascular dementia in males (Andel et al., 2012). Males have been found to receive more tangible support than females (Bourne et al., 2007), but these higher levels may be associated with a greater risk of cognitive decline (Pillemer et al., 2019) and dementia (Murata et al., 2019). Emotional support received from friends and neighbours lowers the risk of dementia for both males and females, but when females receive support from family members within the home, it may be an indication of their increased risk (Murata et al., 2019). It has also been proposed that in persons with chronic illnesses, maintaining relationships and garnering support from others may be perceived as using more energy and resources than they provide (Sims et al., 2014).

Length of follow-up

The strength of the association between social support and cognitive function may further vary depending on the length of time between exposure and outcome. Cross-sectional analyses of the association between social support and executive function have produced relatively consistent findings. A systematic review by Mogic et al. (2023) identified a statistically significant, positive cross-sectional association between social support and overall cognitive function in 10 of 12 studies (83%) on overall social support, 7 of 8 studies (88%) on emotional support, 2 of 6 studies (33%) on tangible support, and 3 of 3 studies (100%) on combined emotional/tangible social support. Looking specifically at executive function, two studies found a positive significant association between overall social support (Hamalainen et al., 2019; Krueger et al., 2009), while one was not statistically significant (Gow et al., 2007). Emotional support and executive function were significantly positively

associated in two of four identified studies (Frith & Loprinzi, 2017; La Fleur & Salthouse, 2017), while one study found no statistically significant effect (Zahodne et al., 2014) and another a significant negative association (Bourne et al., 2007), such that more social support was associated with lower cognitive function. Recently published work by the dissertation author provides further evidence that multiple subtypes of social support (i.e., emotional/informational and affectionate support, positive social interactions) have a statistically significant cross-sectional association with executive function (Rutter et al., 2024).

In contrast, of the studies identified by Mogic et al. (2023) looking at the *longitudinal* relationship between social support and cognitive function, only 4 of 10 studies (40%) of overall support, 1 of 9 studies (11%) of emotional support, and 1 of 8 studies (12.5%) of tangible support showed a statistically significant positive association. Of the five studies identified by Mogic et al. (2023) looking at the longitudinal association between functional social support and executive function, two studies produced statistically significant positive results (Dickinson et al., 2011; Liao & Scholes, 2017). Tangible support showed a statistically significant positive (Dickinson et al., 2011; Liao & Scholes, 2017) and non-statistically significant negative (Zahodne et al., 2021) association with executive function. Positive (vs negative) social support is significantly associated with better executive function (Dickinson et al., 2011; Liao & Scholes, 2017), yet emotional support was not found to be statistically significant with executive function in any studies (Zahodne et al., 2021; Liao et al., 2018).

Attrition and the association between social support and cognitive function

A complicating, or, perhaps, partially explanatory issue affecting our understanding of the longitudinal association between social support and cognitive function is that both of these variables are associated with attrition. Longitudinal data play an essential role in aging research. Large, population-based, prospective cohort studies provide essential evidence on how risk factors impact health outcomes over the life course, allowing for prevention and early intervention targeting these risk factors. Unlike cross-sectional study designs, cohort studies can establish temporality (Kingston & Jagger, 2018), and, due to their large sample sizes, longitudinal observational studies can be uniquely useful for studying the development of rare diseases and outcomes, a weakness of other study designs (Harpe, 2009). Through

analyses of population-based samples and historical trends, these studies can provide valuable information to directly inform public health policy. The increased power in large studies is also able to reveal smaller associations, although this can lead to statistically significant relationships between variables which carry little or no clinical meaning (Harpe, 2009).

Yet, while not exclusive to cohort studies, large samples and long follow-up periods are particularly vulnerable to attrition. This is especially true for research with older adults, where the chance of losing participants between follow-up assessments becomes increasingly likely with each wave. There are many reasons why a participant may not return to a study, including illness, death, loss of contact (e.g., due to relocation) or just electing to withdraw (Katsuno et al., 2023). This process of losing participants usually does not occur at random and has the potential to negatively impact samples that were designed with the best of intentions (e.g., bias the dataset toward healthier samples). While many retention strategies have been identified to assist in maintaining participation (Teague et al., 2018), these protocols are costly and time-consuming to implement and may be cut or limited to save resources. Despite this, the results of these longitudinal studies are often generated from population-based samples and are more likely to be generalizable than those from small clinical studies.

Factors associated with attrition

Cognitive function

Many factors affect whether a participant is retained in a study over time. Cognitive function, for example, has been consistently identified as a significant predictor of attrition. A lower score on the baseline Mini-Mental State Exam (MMSE), a measure of general cognitive health, is associated with an increased risk of attrition (Chatfield et al., 2005; Jacobsen et al., 2020; Van Beijsterveldt et al., 2002; Handels et al., 2020; Matthews et al., 2004; Haberstumpf et al, 2021; Abe et al., 2023), while a higher score is associated with retention (Jacomb et al., 2002). Having a dementia diagnosis (Jacomb et al., 2002) or screening positive for MCI or dementia (Jacobsen et al., 2020; Burke et al., 2019) is significantly associated with attrition. Interestingly, when samples are limited to those with MCI, cognitive scores at baseline did not have as strong an impact on attrition as they did when the samples include those with normal cognition as well (Facal et al., 2016). Regarding

individual domains of cognitive function, baseline scores on reasoning, vocabulary and verbal abilities, attention, spatial visualization and reasoning, episodic and working memory, perceptual and processing speed, and executive function are higher in those who continue to participate in longitudinal studies compared to those who do not (Haberstumpf et al., 2021; Hernandez et al., 2024; Salthouse et al., 2014).

Social support

Looking at social resources, a lack of satisfaction with support received from others is associated with higher attrition (Jacobsen et al., 2020). Being unmarried (Chatfield et al., 2005; Jacobsen et al., 2022; Young et al., 2006), living alone (Chatfield et al., 2005), having fewer than three confidants to confide in (Jacobsen et al., 2022), and an overall lack of social engagement or participation in activities (Jacobsen et al., 2022) are also associated with a higher risk of being lost due to attrition. In contrast, being married (Yue et al., 2023; Radler et al., 2010; Wetterberg et al., 2022), living with others (Jacobsen et al., 2022) and having more living children (Yue et al., 2023) are associated with retention in studies over time, although these associations were not statistically significant in all studies looking at marital status (Van Beijsterveldt et al., 2002) or living arrangements (Knaup et al., 2021). At the level of data collection, being accompanied to the study by a non-spouse co-participant (e.g., care partner) is associated with a greater attrition risk (Burke et al., 2019), while participants who join studies with a friend or relative are more likely to continue to participate (Knaup et al., 2021).

Age, sex & gender

Additional variables associated with social support and cognitive function have also been identified as playing significant roles in attrition, including age, sex and gender. Older age at baseline is associated with an increased risk of attrition (Chatfield et al., 2005; Jacobsen et al., 2022; Handels et al., 2020; Farid et al., 2022; Haberstumpf et al., 2021; Katsuno et al., 2022; Mein et al., 2012; Okpara et al., 2023), with every additional 10 years in age associated with a 25% increase in drop-out (Chatfield et al., 2005). Older age is particularly associated with drop-out due to death (Van Beijsterveldt et al., 2002; Matthew et al., 2004), yet some studies have found older age is associated with being more easily contactable and retained over the course of the study (Knaup et al., 2021; Young et al., 2006; Radler et al., 2010).

In terms of sex and gender, many studies do not clearly distinguish whether they looked at sex or gender, and so the exact effect of biological sex vs gender on attrition is not clear. With that in mind, men generally have higher attrition (Jacobsen et al., 2022; Farid et al., 2022; Haberstumpf et al., 2021; Yue et al., 2023; Mein et al., 2012; Radler et al., 2010); however, some studies have seen the opposite (i.e., women more likely to drop out; Agogo et al., 2018) or found no statistically significant differences (Jacomb et al., 2002). Both Van Beijsterveldt et al. (2002) and Matthew et al. (2004) found that refusal to participate was more common for women, while non-participation due to death was more common for men.

Income and education

Socioeconomic measures such as education and income have an impact on retention in longitudinal data collection but are also associated with cognition. In their review, Chatfield et al. (2005) found that only one of six studies investigating the impact of lower levels of education on drop-out found a significant association, with the US Longitudinal Study of Aging reporting a 6% increase in risk of drop-out per one less year of education. Despite Chatfield et al.'s (2005) findings, many studies have shown that having a lower level of education (i.e., high school or less) is associated with attrition (Jacobsen et al., 2022; Van Beijsterveldt et al., 2002; Brilleman et al., 2010; Katsuno et al., 2022; Young et al., 2006; Mein et al., 2012; Matthew et al., 2004; Powers, Tavener, Graves and Loxton, 2015), while having a higher level of education is associated with retention (Burke et al., 2019; Farid et al., 2022; Okpara et al., 2003; Radler et al., 2010; Salthouse et al., 2019, Wetterberg et al., 2022). Lower levels of education may be specifically associated with refusal (vs inability) to participate in data collection after baseline (Jacomb et al., 2002). Salthouse et al. (2014) identified an age interaction, such that among younger adults, those with lower levels of education were more likely to be retained than those with higher education, but that there was no association for older adults. In terms of financial resources, a higher income and home ownership are associated with retention (Farid et al., 2022; Yue et al., 2023; Radler et al., 2010), while struggling to meet needs with income and not owning one's home are associated with drop-out (Young et al., 2006; Mein et al., 2012).

Physical health

Physical health can have a major impact on ability to participate in research. Poor self-rated health (Jacobsen et al., 2022; Brilleman et al., 2010; Young et al., 2006; Matthew

et al., 2004, Van Beijsterveldt et al., 2002), diabetes (Agogo et al., 2018), and cardiovascular or lung-related issues (e.g., lower lung function, COPD; Katsuno et al., 2022) are associated with non-participation at follow-up. Being underweight (Brilleman et al., 2010) or at high nutritional risk (Farid et al, 2022) is associated with attrition, with this being particularly impactful in underweight men (Radler et al., 2010). In contrast, having a slightly higher BMI is associated with retention (Radler et al., 2010). Physical impairments have a particularly strong impact on attrition in older adults (Radler et al, 2010). Being frail, pre-frail, or being hospitalized in the last year is associated with attrition (Okpara et al., 2023). Further, needing assistance with at least one Instrumental Activities of Daily Living (IADL; Jacobsen et al., 2022), or having impairment with Activities of Daily Living (ADL; Burke et al., 2019; Matthew et al., 2004) is associated with being lost from a study due to attrition, while reporting less impairment is associated with retention (Radler et al, 2010). Reporting no physical activity also increased risk of attrition (Jacobsen et al., 2022; Brilleman et al., 2010). The impact of medication on attrition is complex, with some findings that those who drop out have a lower number of medications (Agogo et al., 2018), while other studies found no difference in prescribed medications for those who refused to return vs those who remained in the study (Van Beijsterveldt et al., 2002). Predictably, participants with better self-rated health and fewer physical limitations had higher rates of retention (Radler et al., 2010). Interestingly, while there may be no gender differences for those in excellent health, men with poor health have higher attrition compared to women with poor health (Radler et al., 2010). Looking at mental health, some studies found that reporting more depressive symptoms is associated with drop-out (Jacobsen et al., 2022; Farid et al., 2022; Katsuno et al., 2022; Burke et al., 2019), yet many others found that there were no significant differences in depression or anxiety for those who were retained vs those lost from studies due to attrition (Jacomb et al., 2002; Salthouse et al., 2014; Matthew et al., 2004).

Lifestyle behaviours

Specific common lifestyle behaviours, such as smoking and alcohol use, are also associated with attrition. Moderate alcohol consumption is associated with retention (Jacobsen et al., 2022; Radler et al., 2010) while the non-use of alcohol is associated with drop-out (Brilleman et al., 2010; Farid et al., 2022). It is worth noting that alcohol use can reflect a myriad of life factors, such as sobriety due to medication interactions, past health

issues or addiction recovery. Being a current smoker is associated with attrition (Katsuno et al., 2022; Young et al., 2006; Okpara et al., 2023), specifically for loss due to death rather than all-cause attrition (Matthew et al., 2004). In contrast, non-smokers are more likely to be retained (Radler et al., 2010). The association between smoking and attrition may depend on income level, with smoking not impacting attrition in those with higher incomes but having a strong influence for those in the lowest income groups (Radler et al., 2010).

Implications of attrition

Generally, those who are lost due to attrition have less support, lower cognitive function, lower educational attainment and income, and poorer overall health. Due to this, it is perhaps not surprising that participants lost from the study have a greater risk of mortality than those who are retained (Akasaski et al., 2020). This is very concerning, as attrition skewed toward the loss of the more physically and socioeconomically vulnerable can lead to estimates that are biased and representative only of those who are more financially and physically well-off (Yue et al., 2023). This is particularly relevant in studies in mid- to late-life, where the *healthy survivor effect* already leads to biased samples (i.e., in order to be included in a study of health outcomes in older adults, one must survive to be an older adult; Young et al., 2006). This can lead to research that neglects those who are most at risk of poor health-related outcomes (e.g., premature death) and public health strategies that do not accurately target those most in need (Kelfve, 2019). In order to accurately support the health of the broader aging population, we need to understand who is missing from our longitudinal study samples and how this might be impacting our understanding of the relationship between risk factors and health outcomes, such as the association between social support and cognitive function.

Given both social support and executive function are associated with attrition, it is unclear how our understanding of the longitudinal relationship between these variables may have been impacted by increasingly selective samples which exclude those with lower support and greater cognitive impairment. The limited research available on how functional support impacts cognitive function over time provides complex and conflicting evidence, and there may be concerns with the representativeness of conclusions drawn from longitudinal analyses on the association between these variables. Further research into how attrition could be clouding the association between social support and cognitive function is essential to

clarifying how and if social support could be used as an area of intervention to support cognitive health in mid- to late-life.

Summary and research aims

Summary

As the population ages, a greater proportion of Canadians will be impacted by the effects of cognitive decline, emphasizing the need for research on risk factors that can influence cognitive outcomes. Social support has been identified as a potential area of intervention for the cognitive health of the aging population and may have a particularly strong association with key cognitive domains such as executive function. Executive function is a particularly important cognitive domain in successful aging given its role in the tasks required for daily independent living. While the evidence for a cross-sectional association between social support and executive function has been fairly consistent, longitudinal studies have produced more mixed findings. As both social support and executive function play a role in attrition, longitudinal studies investigating the association between the two may be particularly at risk of increasingly selective, and possibly biased, samples. Developing a better understanding of how social support impacts executive function within the context of attrition is essential to maximizing public health efforts aimed at supporting the cognitive health of the aging population.

Research aims

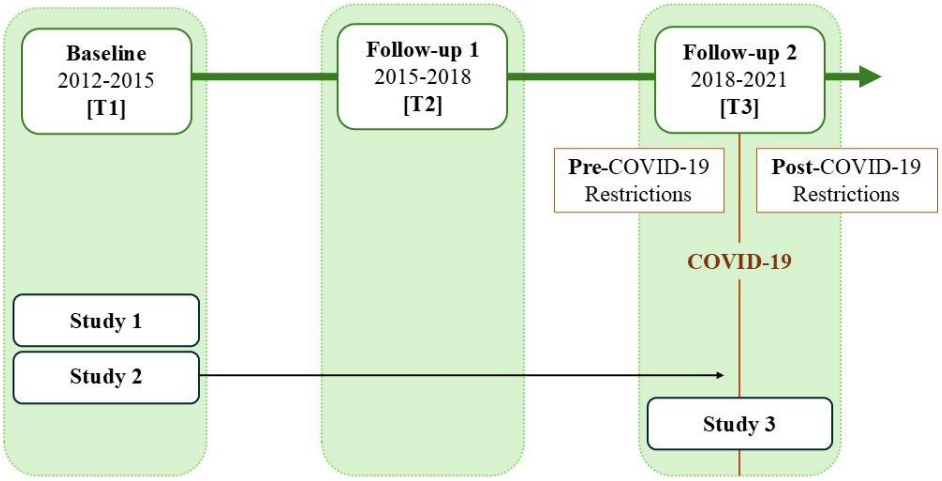
Aims. The overall aims of this dissertation were to investigate the association between functional social support and executive function in mid- to late-life and to explore how attrition and other methodological issues may impact our understanding of this relationship. A visual description of the three studies is provided in **Figure 1.**

Study 1 (Chapter 4) investigated if baseline social support and baseline executive function were associated with attrition after accounting for potential confounders and if the *cross-sectional* association between social support and executive function varied across those participating at one (T1), two (T1, T2), or three (T1, T2, T3) timepoints.

Study 2 (Chapter 5) investigated the *longitudinal* role of functional social support (T1) and its subtypes on executive function (T3) while exploring how attrition and individual characteristics impacted the results and conclusions generated from these analyses.

Study 3 (Chapter 6) investigated how the *cross-sectional* association between social support and executive function differed pre- vs post-COVID-19 restrictions (T3) to assess how the methodological changes may impact this relationship.

Figure 1. A visual description of the three studies, utilizing the first three waves of the Comprehensive cohort of the Canadian Longitudinal Study on Aging



Chapter 3: Background - Methodology

While each of the three studies in this dissertation include details of their specific methodology, much background information was outside of the scope of the individual papers themselves. As such, a brief, overall description of the shared methodological background for all three studies is included here.

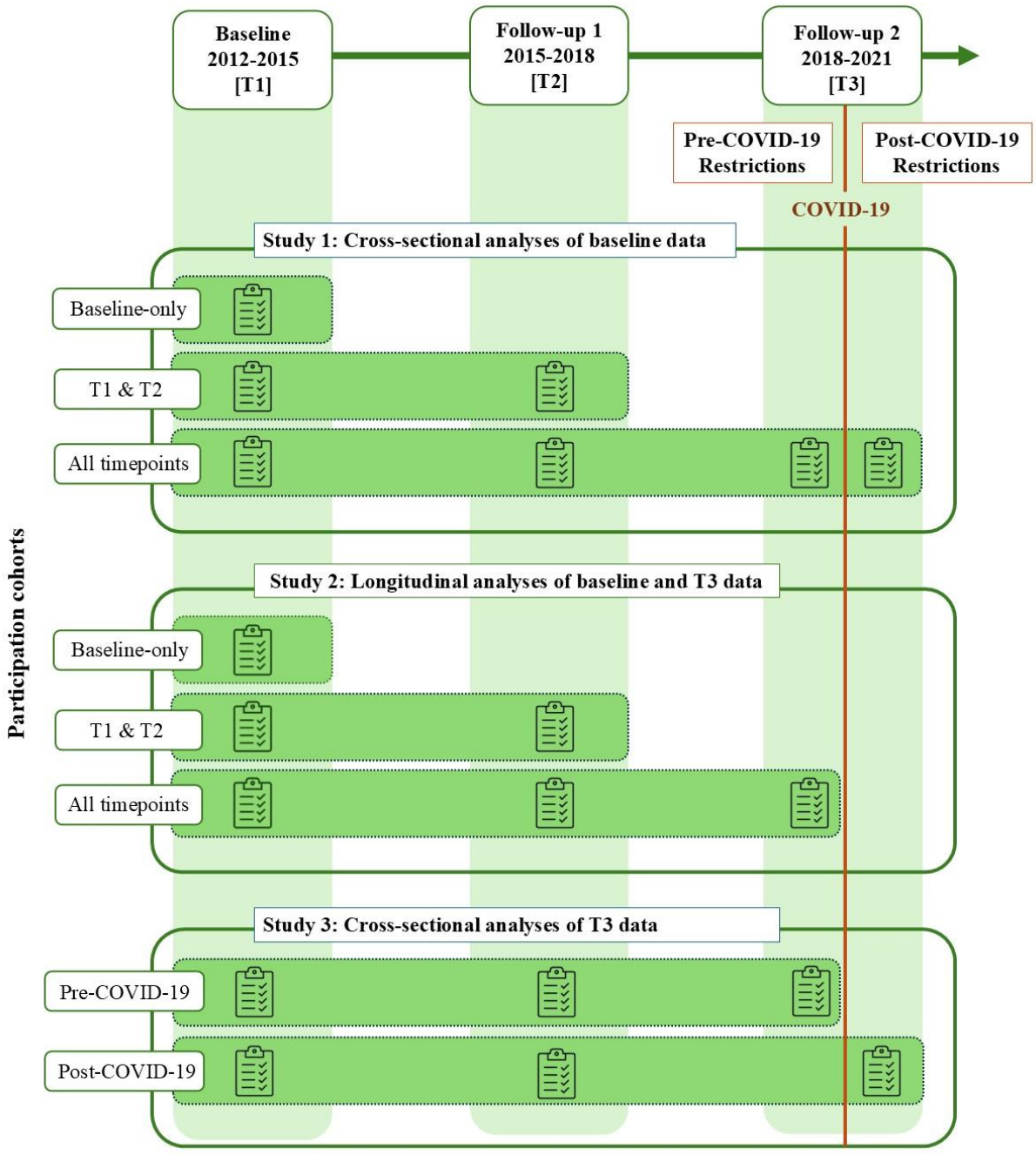
Sample

Analyses utilized baseline (T1; 2012-2015), follow-up 1 (T2; 2015-2018) and follow-up 2 (T3; 2018-2021) data from the Comprehensive cohort of the Canadian Longitudinal Study on Aging (CLSA). The CLSA is an ongoing, prospective cohort study of community-dwelling adults between the ages of 45 and 85 at time of recruitment (Raina et al., 2009). Participants in the CLSA were recruited into the Tracking cohort (n=21,241), where data were collected using phone calls, and the Comprehensive cohort (n=30,097), in which participants living within 25-50 km of 1 of 11 data collection sites across seven provinces were assessed in person, both at home and at data collection sites. Individuals living in the three Canadian territories; on federal First Nations reserves; in institutions; who were full-time members of the Canadian Armed Forces; who did not speak English or French, or who interviewers perceived to have cognitive impairment were excluded by the CLSA at recruitment. Proxy respondents were not utilized for these analyses but will be available in future waves of the CLSA.

Data collection for the third wave (T3) of the CLSA occurred both pre- and post-implementation of COVID-19-related social restrictions in Canada. Prior to March 16, 2020, participants in the Comprehensive cohort of the CLSA completed in-person interviews both at home as well as at their assigned data collection site. After March 16, 2020, the data collection protocol was updated to reflect both the overall increased risk of illness for the aging CLSA participants as well as social restriction measures implemented by federal and provincial governments. This required data collection to move to telephone interviews for the Comprehensive cohort, similar to those conducted in the CLSA's Tracking cohort (CLSA, 2024). To account for these changes in protocol, for the studies in this dissertation which utilized T3 data, participants at T3 were divided into two groups: those who participated pre-COVID-19 vs those who participated post-COVID-19 protocol changes. Additional data on

these samples are included in Study 3. A visual description of how each study accommodated for the COVID-19 protocol changes is included in **Figure 2**.

Figure 2. A visual description of the participation cohorts utilized in each study



Measures

Exposure

Functional social support, also referred to as social support availability, was assessed using the Medical Outcomes Study-Social Support Survey (MOS-SSS) (Sherbourne & Stewart, 1991; RAND, n.d.; **Appendix A.1**). The MOS-SSS assesses the perceived availability of support in various real-life situations. Each of the 19 items on the MOS-SSS is answered based on how often support is available when needed, with responses captured on a 5-point scale from 1 (none of the time) to 5 (all of the time), with a higher score indicating higher levels of social support. The MOS-SSS includes questions assessing four subtypes of support: emotional/informational (e.g., someone you can count on to listen to you when you need to talk), tangible (e.g., someone to take you to the doctor if needed), affectionate (e.g., someone who shows you love and affection), and positive social interactions (e.g., someone to get together with for relaxation). For overall social support and each subtype, scores on each relevant item were combined to produce an average score out of five. Consistent with past work, a dichotomous cut-off of <=3 out of 5 was used for the main analyses to distinguish those with low levels of support for overall support and each subtype. The use of an absolute (versus relative) cut-off score allows for comparison within the study across subtypes of support, as well as for comparison with external studies. In order to maximize the sample size, participants who were missing a single item out of the 19 required for the calculation of overall social support were included in the sample by averaging the scores on the remaining 18 items.

Outcomes

Executive function was assessed using five measures of executive function available in the Comprehensive cohort of the CLSA (Tuokko et al., 2017), which includes measurements of the three most common subtypes of executive function: cognitive flexibility, working memory, and inhibition. Cognitive flexibility is tested using the Animal Fluency Test (AFT; Crossley et al., 1997; Goodglass & Kaplan, 1972), the Mental Alternation Test (MAT; Teng, 1995; Billick et al., 2001), and the Controlled Oral Word Association Test (COWAT; Benton & Hamsher, 1978), while the Time-based Prospective Memory Test (TMT; Loewenstein & Acevedo, 2004) assesses working memory and inhibition, the latter of which is also tested using the Victoria Stroop Neurological Screening

Test (Stroop; Spreen & Strauss, 1998; Strauss et al., 2006; Troyer et al., 2006; Bayard et al., 2009; Moroni & Bayard, 2009; Bayard et al., 2011). Tests were modified for use in the CLSA (Tuokko et al., 2017; CLSA, n.d. [Technical document #1122]). In the Comprehensive cohort of the CLSA, the MAT and AFT were completed during at-home interviews, while the COWAT, Stroop, and TMT were collected during assessments at data collection sites. Further descriptions of each test are provided in **Appendix B.1**.

An overall score of executive function was calculated by averaging the standardized z-scores on the AFT, MAT, COWAT, TMT, and Stroop. Scores were standardized within each test using z-scores and calculated separately for English and French speakers. Bilingual responses were excluded (Tuokko et al., 2017). As the Stroop is calculated based on the time to response, a higher score is an indicator of worse cognitive function and scores are reversed for inclusion in combined calculations of executive function (Demnitz et al., 2018).

Low executive function was defined during analysis based on the distribution of scores after combining z-scores on the described tests. The identification of MCI, more so than dementia, requires the use of cognitive assessments as MCI must be differentiated from both normal cognition as well as major neurocognitive disorders (Sachdev et al., 2014). A cut-off score of 1–2 SD below the average on tests of individual cognitive function domains is generally used as an indicator of MCI (Sachdev et al., 2014). A cut-off of ≥1.5 SD below the mean for low executive function was calculated for all time points (T1, T2, T3; Petersen et al., 1997). The cut-off was calculated on a robustly healthy sample that excluded those who reported being diagnosed with Alzheimer's disease, memory problems, epilepsy, stroke or CVA, multiple sclerosis, Parkinson disease, or ministroke or transient ischemic attack at any time point (O'Connell et al., 2017). Additionally, those who had a positive screen for a traumatic brain injury and reported two or more concussions or any symptoms of a concussion at either baseline or follow-up were removed (O'Connell et al., 2017; Bedard et al., 2018). These groups are not mutually exclusive. This cut-off was then applied to the analytical sample.

Assessments at T3 were interrupted by the COVID-19 pandemic, creating two samples (i.e., pre-COVID-19 vs post-COVID-19 social restrictions). A cut-off date of March 16, 2020 was chosen by the CLSA for protocol changes, yet two date variables were available for identifying when participants completed their assessments at T3:

startdate_COF2 (when participants began their in-home assessments) and ADM_startdate_COF2 (when participants began their assessments at the data collection sites). To accurately capture all participants who completed their data collection sites assessments pre/post COVID-19 protocol changes, the ADM_startdate_COF2 was selected. Those who completed their tests post-COVID-19 restrictions completed only the MAT and AFT. In order to be able to compare those pre- vs post-COVID-19 restrictions, three different executive function outcomes were created: 1) pre-COVID-19 (five tests of executive function: AFT, MAT, COWAT, TMT & Stroop), 2) pre-COVID-19 (two tests: AFT and MAT), and post-COVID-19 restrictions (two tests: AFT and MAT). Cognitive scores at T3 were thus standardized only to those in the same subgroup. Scores for participants who completed their analyses pre-COVID-19 protocol changes were standardized using the scores of other participants who also participated pre-COVID-19 protocol changes, with this repeated for those who completed their assessments post-COVID-19 restrictions (i.e., they were standardized against only those who also did the MAT & AFT via phone interview post-COVID-19 protocol changes). Additional details on samples at T3 are included in Chapter 6 (Study 3).

Reasons for missingness on tests of executive function

A small amount of data was available on reasons for missingness on tests of executive function at baseline in the CLSA (n=219). While detailed discussion of this information extends beyond the scope of this thesis, these data offer useful information as to why many participants may not have completed the cognitive testing and helps to account for sample loss. Factors that were found to have affected completion of cognitive tests include participant-level factors (e.g., had difficulty understanding English/French [n=7], physical impairment such as difficulty hearing [n=120], using an aid [n=2], and impaired concentration/memory problems [n=12]) and study-based factors (e.g., technical difficulties with the laptop [n=28], distraction or noisy environment [n=2]) and other (n=47). Many participants were lost on the Stroop test in particular, due to colour blindness (n=109).

Covariates

Covariates included sociodemographic variables, measures of health, lifestyle, and social factors. Sociodemographic variables were age group (45–54 years, 55–64 years, 65–74 years, 75 years and over), sex (female/male), education (less than high school, high school

graduate, some post-secondary, post-secondary degree/diploma), annual household outcome < $20k, ≥ $20k and < $50k, ≥ $50k and < $100k, ≥ $100k and < $150k, ≥ $150k), and province (Ontario, Alberta, British Columbia, Manitoba, Newfoundland and Labrador, Nova Scotia, Quebec).

Health and lifestyle-related variables included clinical depression (i.e., has a doctor ever told you that you suffer from clinical depression? yes/no), self-rated general health (poor, fair, good, very good, excellent), ever smoked 100 cigarettes (yes/no), and alcohol use (non-user, occasional user, regular user). A combined variable was created for chronic illness using available chronic conditions (i.e., peripheral vascular disease or poor circulation in limbs; heart disease; high blood pressure; back problems excluding fibromyalgia and arthritis; kidney disease or kidney failure, underactive thyroid; COPD; diabetes, borderline diabetes or high blood sugar; angina; heart attack or myocardial infarction; stroke or CVA, Parkinsonism or Parkinson's disease; mini-stroke or TIA (Transient Ischemic Attack); epilepsy; and multiple sclerosis). Items regarding having been diagnosed with Alzheimer's disease or memory problems were not included in this variable as participants who positively identified with these items were excluded from the analytic samples. Additional chronic condition variables were available at follow-up 2 (T3) and were included in the count (i.e., asthma, arthritis, osteoporosis, peripheral arterial disease or poor circulation, migraine headaches, intestinal or stomach ulcers, Crohn's disease, ulcerative colitis, Irritable Bowel Syndrome, cancer, Hepatitis C). The number of chronic conditions were summed and collapsed for inclusion in analyses (0, 1, 2, or 3+ chronic conditions).

Additional measures of social support were also considered in analytic models. Structural measures of social support included marital status (married/living with a partner in a common-law relationship; single, never married or never lived with a partner; widowed; separated/divorced) and living alone (yes/no). Loneliness (i.e., How often did you feel lonely?) was also considered as a measure of emotional social isolation. A dichotomous (yes/no) variable was created with participants who answered that they had experienced loneliness in the last week (i.e., all of the time [5-7 days], occasionally [3-4 days], some of the time [1-2 days]) compared to those who did not (i.e., rarely or never [less than 1 day]).

In order to maximize the number of participants retained in the study, a "missing" category was added to covariates with a large number of missing responses (i.e., greater than

500). These variables (i.e., income [missing n~1800], alcohol use [missing n~1040], number of chronic conditions [missing n~700]) reflect characteristics that individuals may feel self-conscious or uncomfortable answering, perhaps helping to explain the large number of missing responses. If a missing level was not included, large portions of the sample would be lost due to variables which, while providing important data, are not the key exposures or outcomes. The decision to use this method as a way of retaining as many participants as possible reflects the research questions and the goals of these studies. It is acknowledged that this method does not fully adjust for these variables nor does it account for reasons for why these data might be missing and, as such, results for missing levels were not interpreted as equivalent to other levels.

Analyses

Analytic methods

All analyses were conducted using SAS Studio Enterprise Edition 3.6 (SAS Institute Inc., Cary, North Carolina). Bivariate analyses (e.g., Pearson chi-square tests for categorical variables and t-tests for continuous variables, with a two-sided significance level of $p<0.05$) were conducted to provide a description of the exposures, covariates and outcomes in the various analytic samples. Both logistic regression (odds ratios [OR] and 95% confidence intervals [CI]) and modified Poisson regression (risk ratio [RR] and 95% confidence intervals [CI]) were used to assess the strength of the associations.

Modified Poisson models were used for outcomes which were relatively common (i.e., Study 1, Objective 1) and for longitudinal analyses (e.g., Study 2, Objective 1). Modified Poisson models provide relative risk, which is the risk in the exposed group divided by the risk in the unexposed group (Rosella, 2012). The Poisson model can overestimate variance in confidence intervals (leading to very wide CI estimates) and is "modified" to account for robust error variances which lead to more reasonably sized CIs (McNutt et al., 2003; Rosella, 2012). This method may also be referred to as sandwich error estimation (Zou et al., 2004). In SAS coding, this meant including the ID in the class statement, as well as a repeated subject (Lindqvist, n.d.).

In contrast to modified Poisson, logistic regression generates an odds ratio (OR) to estimate the strength of the association. Odds ratios calculate the ratio of the odds of developing an outcome in the exposed group compared to odds in the unexposed group and

is a proxy for estimating relative risk (Rosella, 2012). When an outcome is common (greater than 20%), ORs tend to overestimate the effect and so alternative methods (e.g., modified Poisson) are preferred (Rosella, 2012). Risk ratios are generally preferred over odds ratios (Zou et al., 2004), and logistic regression models require certain assumptions about functional forms within a model which, if violated (e.g., non-linear components, missing interaction terms) can lead to biases that can be better accounted for using modified Poisson analyses (Chen et al., 2018).

These analytic methods varied from those of previous research on the longitudinal association between social support and executive function, which include, but are not limited to bivariate dual change scores (Liao et al., 2018, n= 6,863), linear mixed models (Liao & Scholes, 2017, n= 10,241), and linear regression models (Dickinson et al., 2011, n=212). Several previous studies included multiple measures of social support and cognitive function to account for bidirectionality (Liao et al., 2018; Liao & Scholes, 2017; Dickinson et al., 2011), with this dependent on availability of data (e.g., annual [Dickinson et al., 2011] or bi-annual [Liao & Scholes, 2017] cognitive assessments; number and length of available follow-ups [e.g. 10 years; Liao & Scholes, 2017]). Other studies looking at the association between functional social support (assessed using the MOS-SSS) and cognitive function utilized Cox proportional hazard ratios (Pillemer et al., 2019). As with our longitudinal analyses, Pillemer et al. (2019) excluded those with low cognitive function at baseline and investigated the development of incident cognitive impairment.

Multicollinearity between exposures and covariates (e.g., social support and loneliness, self-rated health and clinical depression) was assessed using a variance inflation factor (VIF), where a score greater than 10 is an indicator that two or more predictor variables are too highly correlated with each other to see individual effects (Kleinbaum, Kupper, Nizam, & Rosenberg, 2013). Model fit for logistic regression models were assessed using the Mann-Whitney U statistic for the area under the receiver operating characteristic curve. For models using modified Poisson, there are several potential ways to assess model fit, including looking at residuals and ensuring plotted values fall within two standard deviations; looking at overdispersion in variation in the data set (i.e., data do not follow a Poisson distribution); and confirming there are no zero cells (i.e., no cross-points of variables that do not include any participants; Statistical Consulting and Survey Research Unit; 2025).

Methods for addressing generalizability

Despite efforts by the CLSA to recruit a diverse sample from within limited geographic areas (i.e., within 25 to 50 km of 11 data collection sites across seven provinces) and to oversample those with low education (CLSA, 2017), volunteers for the CLSA were biased toward those who were white, highly educated (e.g., over 77% of those in the baseline Comprehensive cohort had a bachelor's degree), and wealthy (e.g., approximately 35% of the baseline Comprehensive cohort had a household income of over $100,000). This likely reflects a *healthy volunteer bias*, which is often seen in large population-based studies (e.g., Fry et al., 2017). Given this information and knowing that the response rate in the Comprehensive cohort across the country was approximately 10% across Canada (with some provincial variation: Alberta [11%], British Columbia [9%], Manitoba [10%], Newfoundland and Labrador [12%], Nova Scotia [13%], Ontario [9%], Quebec[10%]), it can be predicted that there were some self-selection biases (Thompson et al., 2025). One piece of evidence for this is that while the CLSA participants are >95% white, only 78% of Canadians identified as 'not a visual minority' in 2016 (Statistics Canada, 2017).

While previous studies utilized the weights provided by the CLSA in an attempt to make it simpler to extend results to the greater Canadian population (Rutter, 2019; CLSA, 2017), many analyses do not allow for the incorporation of weights (e.g., modified Poisson) and work is still ongoing on how and if weights can be included at all time points to account for missingness. Additionally, the value in terms of generalizability of baseline weights when using increasingly select waves of follow-up data may not be worth the limitations of weighted analyses if participants of underrepresented groups continue to be lost from the study due to attrition. While follow-up weights are available, they were not useable with the analyses described.

Attempts were made in these analyses to address this limitation by controlling for related variables during multivariable modelling (Cole & Trinh, 2017). This, with support from the literature review indicating the importance of many variables to the association between social support and cognitive function, led to final models with a large number of variables included as potential confounders. Additional supplementary models which included themed chunks of exposure variables (i.e., sociodemographic, health and lifestyle, social resources) entered in sequence were run to provide further evidence of the association

between social support and executive function within more streamlined models and to explore how the inclusion of different variables may have altered the associations.

Missing data were of particular concern for the analyses of this study given the focus on identifying variables associated with attrition and how they may impact the relationship between social support and executive function. As discussed above (See: Covariates), this was addressed, in part, by adding a "missing" category when large percentages of data were unavailable on particular variables. While this method does not replace the missing data nor does it fully adjust for these variables in the analytic models, this approach was selected to retain as many participants as possible due to our investigations into attrition. Popular methods for managing missing data vary from using complete case analyses, in which only those with values for all variables of interest are included, to complex statistical analyses such as multiple imputation, which are designed to fill in the gaps on missing variables using values of other variables (Walani & Cleland, 2015; Little et al, 2014; Twisk & de Vente, 2002; Jelicić et al., 2009). Multiple imputation is not without limitations and may not produce accurate results when data are not missing at random (Twisk et al., 2013). Additional complex statistical methodologies to investigate the longitudinal associations are being identified (e.g., Rouanet et al., 2022), which could be beneficial to explore in future analyses but were not within the scope of this dissertation.

Chapter 4: Attrition over time suppresses the association between functional social support and executive function in the Canadian Longitudinal Study of Aging

Introduction

Psychosocial factors, such as social support, are a potential area for interventions to optimize the cognitive health of the increasing number of individuals at risk for age-related cognitive decline as a result of population aging (WHO, 2015; PHAC, 2020). Social support can be assessed as either an objective measure of structural support (e.g., marital status, living alone vs with others) or as a subjective measure of the functional quality of social resources (e.g., how much support individuals perceive as available when needed) (Sherbourne & Stewart, 1991). While both forms of support likely play an important role in the overall composition of one's social resources, greater attention in research has been given to structural measures of support and how they may impact the health of older adults, while less research has been conducted on functional social support.

Previous *cross-sectional* findings demonstrate a positive association between functional social support and cognitive function, such that higher levels of support are associated with higher levels of global cognition, memory, and executive function (Mogic et al., 2023). *Longitudinal studies*, in contrast, have produced less consistent findings. Of nine such studies identified by Mogic et al., (2023) assessing the longitudinal impact of higher overall functional social support on global cognitive function, only four produced statistically significant results showing that higher social support is associated with higher cognitive function (Mogic et al., 2023). This association was less consistent for specific domains of cognitive function, with both negative and positive associations being observed with social support and memory and executive function (Mogic et al., 2023).

While these findings may be an indication of a weakening longitudinal association between social support and measures of cognitive function over time, another explanation for these mixed results originates in the design of longitudinal data itself. Longitudinal studies play an important role in research on healthy aging by providing information on the role of risk factors over the lifespan. However, due to their use of repeated assessments, these studies are vulnerable to attrition (i.e., participants dropping out or otherwise being lost to the study) which can lead to increasingly selective samples that are biased from their original population of interest (Yue et al., 2023).

Many sociodemographic, health, lifestyle, and social factors impact attrition. Individual factors including older age, lower educational attainment, depression (Chatfield et al., 2005; Jacobsen et al, 2020) and being a current smoker (Young et al., 2006) are associated with an increased risk of attrition in longitudinal studies. In contrast, participants with higher incomes and higher educational attainment are more likely to remain in studies over time (Farid et al. 2022). For indicators of social support, those who are unmarried (Chatfield et al., 2005; Jacobsen et al, 2020; Young et al., 2006), who have fewer than three people they feel close to, who are not living with another participant, or who report no social activities or no social engagement (Jacobsen et al., 2020) are more likely to be lost to follow-up. While not the only potential cause, loss to follow-up of these select groups could result in underestimates of any association with social support.

Cognitive function has also been consistently identified as a significant predictor of attrition. A lower score on the baseline Mini-Mental State Exam (MMSE), a measure of general cognitive health, is associated with an increased risk of attrition (Chatfield et al., 2005; Jacobsen et al., 2020; Van Beijsterveldt et al., 2002; Handels et al., 2020; Matthews et al., 2004; Haberstumpf et al, 2021), while a higher score is associated with retention (Jacomb et al., 2002). Having a dementia diagnosis (Jacomb et al., 2002) or screening positive for mild cognitive impairment or dementia (Jacobsen et al., 2020; Burke et al., 2019) is significantly associated with attrition. Regarding individual domains of cognitive function, baseline scores on executive function, reasoning, vocabulary and verbal abilities, attention, spatial visualization and reasoning, episodic and working memory, perceptual and processing speed are higher in those who continue to participate in longitudinal studies compared to those who do not (Haberstumpf et al., 2021; Hernandez et al., 2024; Salthouse et al., 2014).

What can result from this pattern of attrition is a leaning in longitudinal research samples toward a much cognitively healthier, wealthier, and socially engaged subset of the population. Unchecked attrition in longitudinal studies can therefore lead to biased conclusions on the association between individual health and social factors, underestimating or overestimating the roles of different characteristics based on who has remained in the study over time. Considering the individual factors that have been demonstrated to significantly impact whether an individual continues to participate over multiple assessments (e.g., education, income, chronic health conditions), it is likely that by losing more

vulnerable participants over time, this attrition bias will lead to neglecting those of lower socioeconomic status and poorer health who may be in a position to most benefit from health research.

To accurately assess the longitudinal association between variables, researchers must understand how the data being used may be vulnerable to factors such as attrition and how potential biases may be impacting analyses. The association between social support and cognitive function provides an opportunity to explore this concept. Both social support and cognitive function impact, and are impacted by, attrition, potentially leading to bias in longitudinal studies looking at the association between the two.

Since we expect that attrition bias may be impacting our current knowledge on the association between social support and cognitive function, we investigated how social support and a key domain of cognitive function (i.e., executive function) impact attrition in a large, community-based, longitudinal study of adults in mid- to late-life. The objectives of this study were twofold. For objective one, we identified whether social support and executive function may be associated with attrition versus retention after accounting for other sociodemographic and health factors. To explore how attrition may impact our knowledge of the long-term impact of social factors on health outcomes such as cognitive function, our second objective was to investigate whether there were differences in the cross-sectional association between social support and executive function in those who were lost to the study after baseline assessment compared to those who participated in further waves of data collection.

Methods

Sample

Analyses utilized baseline (T1; 2012-2015), first (T2; 2015-2018) and second follow-up (T3; 2018-2021) data from the Comprehensive cohort of the Canadian Longitudinal Study on Aging (CLSA). The CLSA is an ongoing, prospective cohort study of community-dwelling adults between the ages of 45 and 85 at time of recruitment (Raina et al., 2009). Participants in the Comprehensive cohort (n=30,097) were recruited from within 25-50 km of 1 of 11 data collection sites across seven provinces. Individuals living in the three Canadian territories, on federal First Nations reserves, or in institutions; who were full-time members

of the Canadian Armed Forces; or who interviewers subjectively determined to have cognitive impairment at time of interview were excluded by the CLSA.

To retain the greatest sample, a "missing" level was included for some categorical variables which were missing a large number of responses, possibly due to social desirability bias (i.e., annual household income, alcohol use, number of chronic conditions). After removing those who did not complete their assessments at data collection sites to account for environmental testing differences (n=225) or who were missing data on any of the remaining exposure or outcome variables at baseline (n=804), the analytic sample for objective one consisted of 28,970 participants (96.3% of the overall baseline Comprehensive cohort sample). An additional sample was created for objective two which investigated the cross-sectional association between social support and executive function. This sample required participants to have data available on tests of executive function, leading to a loss of 4422 participants and a final sample of 24,548. A visual description of the creation of the analytic sample is included in Appendix **Figure C.1**.

Measures

Exposures

Social variables. Functional social support (T1) was assessed using the Medical Outcomes Study-Social Support Survey (MOS-SSS; Sherbourne & Stewart, 1991; RAND, n.d.). Each of the 19 items on the MOS-SSS are answered based on how often support is available when needed on a 5-point scale from 1 (none of the time) to 5 (all of the time), with higher scores indicating higher levels of social support. To calculate overall social support, scores on each item were combined to produce an average score out of five. To maximize the sample for investigation into attrition, individuals were allowed to miss one of the 19 items, with the remaining 18 items used to calculate the average score. A dichotomous cut-off of <=3 out of 5 (i.e., support was available some/a little/none of the time), was applied to distinguish those with low levels of support, with the use of an absolute (versus relative) cut-off score allowing for comparison with current and future studies utilizing the MOS-SSS. Structural social variables included marital status (married/common-law, single/never married, separated/divorced, and widowed) and whether a participant lived alone (yes/no), while loneliness (lonely; yes/no) was included as a measure of emotional social isolation.

Executive function. Five measures of executive function are available in the Comprehensive cohort of the CLSA (Tuokko et al., 2017): the Animal Fluency Test (AFT [version 2]; Goodglass & Kaplan, 1972), the Mental Alternation Test (MAT; Teng, 1995; Billick et al., 2001), the Controlled Oral Word Association Test (COWAT; Benton & Hamsher, 1978), the Time-based Prospective Memory Test (TMT; Loewenstein & Acevedo, 2004) and the Victoria Stroop Neurological Screening Test (Stroop; Spreen & Strauss, 1998; Strauss et al., 2006; Troyer et al., 2006; Bayard et al., 2009; Moroni & Bayard, 2009; Bayard et al., 2011). Tests were modified for use in the CLSA (e.g., Stroop errors were not corrected during administration but were recorded, with many participants having 0 errors; O'Connell et al., 2023; Tuokko et al., 2017; CLSA, n.d. [Technical document #1122]). Scores were standardized within each test using z-scores and calculated separately for English and French speakers. Bilingual responses were excluded (Tuokko et al., 2017). An overall score of executive function was calculated by averaging the standardized z-scores on the AFT, MAT, COWAT, TMT, and Stroop.

Low executive function (T1) was defined using a cut-off of ≥1.5 SD below the mean of a neurologically healthy sample that excluded those who reported being diagnosed with Alzheimer's disease, memory problems, epilepsy, stroke or cerebrovascular accident, multiple sclerosis, Parkinson disease, or ministroke or transient ischemic attack at any time point (Petersen et al., 1997; O'Connell et al., 2023). Additionally, those who had a positive screen for a traumatic brain injury and reported two or more concussions or any symptoms of a concussion at any time point were removed (O'Connell et al., 2017; Bedard et al., 2018). The generated cut-off was then applied to the analytical sample to create a two-level variable: low versus normal executive function. An additional level was added to account for participants missing scores on one or more of the cognitive tests, creating a three-level variable: 1) low executive function, 2) normal executive function, and 3) missing executive function score.

Potential confounders (T1) for both objective one (looking at the association between social support and executive function and attrition) and objective two (looking at the cross-sectional association between social support and executive function) including sociodemographic variables (i.e., age, sex, education, total household income, province of residence) and measures of health and lifestyle (i.e., chronic conditions, depressive

symptoms, self-rated health, smoking and alcohol use) were also accounted for in multivariable models.

Outcome

Participants in the first three waves of the CLSA had four potential participation patterns: 1) participation at baseline (T1) only; 2) participation at T1 and T2 only; 3) participation at all time points (T1, T2, & T3); or 4) participation at T1 and T3 (missing T2). For objective one, participants were categorized into two cohorts based on participation status at their last assessment: participation at baseline only and participation at all timepoints (T1, T2, & T3). Two attrition-based outcomes were created depending on the number of assessments that were completed. The *baseline-only cohort* (those who completed only the first assessment vs. those who completed at least two assessments (T1 plus T2 and/or T3) was defined to identify variables associated with dropping out of the study after baseline. In contrast, the *all-timepoints cohort* (those who participated in all three waves of data collection [T1,T2,T3] vs. those who did not participate in all three waves of data collection [only T1 or T1 and T2]) identified variables associated with study retention. The third cohort including those who participated at baseline and follow-up 1 (T1, T2 only) were included separately in descriptive analyses for clarity and to fully describe the sample.

Analyses

All analyses were conducted using SAS Studio Enterprise Edition 3.6 (SAS Institute Inc., Cary, North Carolina). Univariate and bivariate analyses (Pearson chi-square tests with a significance level of $p<0.05$) were conducted to describe the overall analytic sample and the two cohorts (i.e., baseline only, all timepoints). Two forms of regression models were used for the longitudinal and cross-sectional analyses. Modified Poisson regression models were used to estimate relative risk (RR; 95% confidence intervals [CI]) in assessing the longitudinal association between baseline characteristics and participation at *baseline-only* and at *all-timepoints*. For the second objective, which looked at the cross-sectional (T1) association between social support and executive function, logistic regression was utilized to estimate the odds ratio (OR; 95% CI). After running the crude models (i.e., social support as exposure and executive function as outcome), covariates were added to regression models in sequential themed chunks (i.e., sociodemographic, health and lifestyle, social) until a final fully adjusted model which accounted for all covariates was generated.

Results

Descriptive results

A description of the participation cohorts and overall sample is included in **Table 1.** These include the baseline-only cohort (participation at T1 only; n=2031) as well as the all-timepoints cohort (participation at T1, T2, & T3; n=24,607). For descriptive purposes, an additional column was included to describe those who participated at only T1 & T2 (n=2224). A final cohort of those who participated at baseline (T1) and second follow-up (T3), missing the first follow-up (T2), were not included in the descriptive table due to size (n=108).

Statistically significant differences between the participation cohorts were found for all variables at baseline. Nearly 12% of those who participated only at baseline had low social support, compared to 5.9% of those who participated at all time points. Low executive function was present in 15.8% of those who participated at baseline only, compared to 4.8% of those who participated at all time points. Significant differences existed between the cohorts on sociodemographic and health variables, with those who participated at all timepoints being younger, more highly educated, having a higher income, having fewer chronic illnesses, and higher self-rated health than those who participated only at baseline. In terms of additional social variables, those who participated at all time points also had lower rates of loneliness (24.6% compared to 33.9% of those who participated at baseline only), and were more commonly married and not living alone.

Table 1. The distribution of sociodemographic, health, lifestyle, and social characteristics at baseline (T1) stratified by participation cohort in the Canadian Longitudinal Study on Aging (n=28,970)

	Participation cohort			
	Baseline-only		All time points	
	Participation at T1 only (n=2031)	Participation at T1 & T2 (n=2224)	Participation at T1, T2, & T3 (n=24,607)	All participants (n=28,970)
Key exposures (%)				
Functional social support				
Low	11.82	9.98	5.86***	6.59
High	88.18	90.02	94.14	93.41
Executive function				
Normal	66.32	68.53	80.18***	78.29
Low	15.81	14.61	4.78	6.33
Missing	17.87	16.86	15.04	15.38
Sociodemographic characteristics (%)				
Age group				
45–54 years	19.55	16.95	27.06***	25.78
55–64 years	24.86	20.23	34.95	33.12
65–74 years	25.50	26.03	24.18	24.38
75 years and over	30.08	36.78	13.81	16.71
Sex				
Female	50.81	48.02	51.20*	50.95
Male	49.19	51.98	48.80	49.05
Education				
Less than high school	11.28	9.98	4.43***	5.35
High school graduate	13.05	12.01	8.92	9.44
Some post-secondary	9.31	8.63	7.11	7.39
Post-secondary degree/diploma	66.37	69.38	79.54	77.82
Annual household income				
< $20k	10.88	8.72	4.10***	4.95
≥ $20k and < $50k	31.51	28.55	19.04	20.67
≥ $50k and < $100k	27.33	31.70	33.77	33.14
≥ $100k and < $150k	13.39	12.86	19.59	18.63
≥ $150k	8.17	8.86	17.69	16.32
Missing	8.71	9.31	5.81	6.29
Province				
Ontario	18.91	22.84	21.65***	21.51
Alberta	8.12	9.26	9.84	9.65
British Columbia	19.84	19.78	21.12	20.97
Manitoba	11.23	12.01	10.36	10.52

Newfoundland and Labrador	9.55	9.58	7.05	7.45
Nova Scotia	12.51	9.08	10.00	10.14
Quebec	19.84	17.45	19.97	19.76
Health characteristics (%)				
Clinical depression				
Yes	18.51	16.64	16.15*	16.38
No	81.49	83.36	83.85	83.62
Number of chronic conditions				
0	23.78	21.99	32.58***	31.13
1	27.87	27.61	33.51	32.67
2	20.97	22.89	18.71	19.19
3+	22.01	21.90	11.94	13.41
Missing	5.37	5.62	3.26	3.60
Self-rated health				
Poor	4.23	2.29	1.20***	1.51
Fair	14.62	12.54	6.47	7.53
Good	35.55	35.03	28.35	29.39
Very good	33.14	35.16	42.79	41.48
Excellent	12.46	14.97	21.20	20.09
Ever smoked				
Yes	59.72	59.35	51.21***	52.45
No	40.28	40.65	48.79	47.55
Alcohol use				
Non-user	17.28	14.25	10.32***	11.15
Occasional user	16.49	15.02	11.50	12.13
Regular user	62.68	67.72	75.95	74.33
Missing	3.55	3.01	2.23	2.39
Social characteristics (%)				
Marital Status				
Married/living with a partner in a common-law relationship	58.44	61.06	71.17***	69.49
Single, never married or never lived with a partner	10.78	9.62	8.38	8.65
Widowed	14.67	14.75	7.82	8.84
Separated/divorced	16.10	14.57	12.62	13.02
Live alone				
Yes	31.27	28.96	20.55***	21.93
No	68.73	71.04	79.45	78.07
Lonely				
Yes	33.87	31.92	24.57***	25.82
No	66.13	68.08	75.43	74.18

*p < .05; **p < .01; ***p < .001

Participation at baseline assessment (T1) only

Before investigating the association between social support and executive function, we explored whether these variables may be associated with attrition versus retention after accounting for other sociodemographic and health factors. Results identifying those social, sociodemographic and health factors associated with participation at baseline-only (T1) are presented in **Table 2**. After accounting for all sociodemographic, health, lifestyle, and social variables, both low social support (RR = 1.02, 95% CI = 1.00-1.04) and loneliness (RR =1.01, 95% CI = 1.00-1.02) were significantly, albeit moderately, associated with completing only the baseline assessment of the CLSA. In terms of cognitive health, low executive function (RR = 1.07, 95% CI = 1.05-1.09) or missing data on any of the tests of executive function (RR = 1.01, 95% CI = 1.01-1.02) was associated with attrition after baseline (T1). Older age, province of residence and ever being a smoker were associated with a greater risk of attrition after baseline, while higher income, higher education, better self-rated health, and younger age lowered the risk. Being a regular drinker compared to a non-drinker was also associated with attrition after baseline (RR = 0.98, 95% CI = 0.97-0.99).

Table 2. The association between sociodemographic, health, lifestyle, and social characteristics (T1) with participation at baseline assessment only in the Canadian Longitudinal Study on Aging (n=28,970)

	Participation at baseline-only Yes (n=2031) vs no (n=26,939)			
	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)
	Model A	**Model B**	**Model C**	**Final model**
Functional social support				
Low vs high	**1.06 (1.04-1.08)**	**1.04 (1.02-1.05)**	**1.02 (1.01-1.04)**	**1.02 (1.00-1.04)**
Age group (vs 45–54 years)				
55–64 years		**0.99 (0.99-0.999)**	**0.99 (0.99-0.999)**	**0.99 (0.99-0.9995)**
65–74 years		1.00 (0.996-1.01)	1.00 (0.995-1.01)	1.00 (0.995-1.01)
75 years and over		**1.05 (1.04-1.06)**	**1.04 (1.03-1.05)**	**1.04 (1.03-1.05)**
Female (vs male)		0.99 (0.99-0.998)	0.99 (0.99-1.00)	0.99 (0.99-1.00)
Education (vs post-secondary degree)				
Some post-secondary		**1.02 (1.01-1.03)**	**1.01 (1.00-1.03)**	**1.01 (1.00-1.03)**
High school graduate		**1.02 (1.01-1.04)**	**1.01 (1.01-1.03)**	**1.02 (1.01-1.03)**
Less than high school		**1.05 (1.03-1.07)**	**1.03 (1.01-1.05)**	**1.03 (1.01-1.05)**
Annual household income (vs < $20,000)				
≥ $20,000 and < $50,000		**0.96 (0.94-0.98)**	**0.97 (0.96-0.99)**	**0.97 (0.95-0.994)**
≥ $50,000 and < $100,000		**0.92 (0.91-0.94)**	**0.95 (0.93-0.97)**	**0.95 (0.93-0.97)**
≥ $100,000		**0.91 (0.91-0.94)**	**0.95 (0.93-0.97)**	**0.95 (0.93-0.97)**
Missing		**0.95 (0.93-0.98)**	**0.97 (0.95-0.995)**	**0.97 (0.95-0.99)**
Province (vs Ontario)				
Alberta		0.999 (0.99-1.01)	0.997 (0.99-1.01)	1.00 (0.99-1.01)
British Columbia		1.00 (0.99-1.01)	1.00 (0.99-1.01)	1.00 (0.99-1.01)
Manitoba		1.01 (0.998-1.02)	1.01 (0.996-1.02)	1.01 (0.996-1.02)

Newfoundland and Labrador	**1.03 (1.02-1.04)**	**1.02 (1.01-1.04)**	**1.03 (1.01-1.04)**
Nova Scotia	**1.02 (1.01-1.03)**	**1.02 (1.01-1.03)**	**1.02 (1.01-1.03)**
Quebec	0.997 (0.988-1.01)	0.998 (0.99-1.01)	0.997 (0.99-1.01)
Low executive function (vs normal)			
Low		**1.07 (1.05-1.09)**	**1.07 (1.05-1.09)**
Missing		**1.01 (1.01-1.02)**	**1.01 (1.01-1.02)**
Chronic condition (vs no conditions)			
1 condition		0.99 (0.99-1.00)	0.99 (0.99-1.00)
2 conditions		0.996 (0.99-1.00)	0.996 (0.99-1.00)
3+ conditions		1.01 (0.997-1.02)	1.01 (0.997-1.02)
Missing		1.01 (0.99-1.03)	1.00 (0.99-1.02)
Clinical depression (vs no)		1.00 (0.99-1.01)	1.00 (0.99-1.01)
Self-rated health (vs poor/fair)			
Good		**0.96 (0.95-0.97)**	**0.96 (0.95-0.97)**
Very good		**0.94 (0.93-0.96)**	**0.94 (0.93-0.96)**
Excellent		**0.93 (0.92-0.95)**	**0.93 (0.92-0.95)**
Ever smoked (vs no)		**1.01 (1.01-1.02)**	**1.01 (1.01-1.02)**
Alcohol consumption (vs non-user)			
Occasional drinker		0.99 (0.98-1.00)	0.99 (0.98-1.00)
Regular drinker		**0.98 (0.97-0.99)**	**0.98 (0.97-0.99)**
Missing		1.00 (0.98-1.03)	1.00 (0.98-1.03)
Marital status (vs married/common-law)			
Single/never married			1.01 (0.99-1.02)

Widowed	1.01 (0.99-1.03)
Divorced/separated	1.00 (0.99-1.02)
Loneliness (vs not lonely)	**1.01 (1.00-1.02)**
Living alone (vs not living alone)	1.00 (0.99-1.01)

Significant results are **bolded**.
Model A: social support; Model B: adds sociodemographic variables (age, sex, education, annual household income, province); Model C: adds health variables (chronic conditions, clinical depression, self-rated health, ever smoked, alcohol consumption); Final model: adds social variables (marital status, loneliness, living alone)

Participation at all-timepoints (T1, T2 & T3)

Results for factors associated with retention at all available time points are presented in **Table 3**. Having low social support (RR=0.97, 95% CI = 0.95-0.99), being single (vs married; RR = 0.97, 95% CI = 0.96-0.99), and being lonely (RR = 0.98, 95% CI = 0.97-0.99) at baseline were moderately significantly associated with not participating at all three timepoints in the CLSA. Those with low executive function (RR = 0.88, 95% CI = 0.86-0.90) or who were missing tests of executive function (RR = 0.98, 95% CI = 0.97-0.99) at baseline were also significantly less likely to complete all three waves of the CLSA. Further, those who were older, had three or more chronic conditions, had ever smoked cigarettes, or were single/never married at baseline were less likely to remain in the study. In contrast, identifying as female, having a higher education or annual income, and reporting higher self-rated health increased the likelihood of being retained in the study for all time points.

Table 3. The association between sociodemographic, health, lifestyle, and social characteristics (T1) and participation in the first three waves of the Canadian Longitudinal Study on Aging (n=28,970)

	Participation at all time points (T1, T2, T3) Yes (n=24,607) vs no (n=4,363)			
	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)
	Model A	**Model B**	**Model C**	**Final model**
Functional social support				
Low vs high	**0.90 (0.89-0.92)**	**0.95 (0.93-0.97)**	**0.97 (0.95-0.98)**	**0.97 (0.95-0.99)**
Age group (vs 45–54 years)				
55–64 years		**1.02 (1.01-1.03)**	**1.02 (1.01-1.03)**	**1.02 (1.01-1.03)**
65–74 years		**0.98 (0.97-0.99)**	**0.99 (0.97-0.997)**	**0.98 (0.97-0.99)**
75 years and over		**0.86 (0.85-0.88)**	**0.88 (0.87-0.90)**	**0.88 (0.87-0.89)**
Female (vs male)		**1.02 (1.01-1.03)**	**1.02 (1.01-1.02)**	**1.02 (1.01-1.03)**
Education (vs Post-secondary)				
Some post-secondary		**0.97 (0.96-0.99)**	**0.98 (0.96-0.998)**	**0.98 (0.97-0.997)**
High school graduate		**0.96 (0.95-0.98)**	**0.97 (0.96-0.99)**	**0.97 (0.96-0.99)**
Less than high school		**0.92 (0.90-0.94)**	**0.95 (0.93-0.97)**	**0.95 (0.93-0.97)**
Annual household income (vs < $20,000)				
≥ $20,000 and < $50,000		**1.07 (1.05-1.10)**	**1.05 (1.02-1.07)**	**1.05 (1.02-1.08)**
≥ $50,000 and < $100,000		**1.14 (1.11-1.17)**	**1.09 (1.06-1.12)**	**1.09 (1.06-1.12)**
≥ $100,000		**1.16 (1.13-1.19)**	**1.10 (1.07-1.13)**	**1.10 (1.07-1.13)**
Missing		**1.07 (1.04-1.10)**	**1.04 (1.01-1.07)**	**1.04 (1.01-1.07)**
Province (vs Ontario)				
Alberta		1.01 (0.99-1.02)	1.01 (0.997-1.03)	1.01 (0.998-1.03)
British Columbia		1.00 (0.99-1.02)	1.00 (0.99-1.02)	1.00 (0.99-1.02)
Manitoba		0.99 (0.97-1.00)	0.99 (0.98-1.01)	0.99 (0.98-1.01)

Newfoundland and Labrador	**0.95 (0.93-0.97)**	**0.95 (0.94-0.98)**	**0.96 (0.94-0.97)**
Nova Scotia	0.99 (0.97-1.00)	0.99 (0.98-1.01)	0.99 (0.98-1.01)
Quebec	**1.02 (1.01-1.04)**	**1.02 (1.01-1.04)**	**1.02 (1.01-1.04)**
Low executive function (vs normal)			
Low		**0.88 (0.86-0.90)**	**0.88 (0.86-0.90)**
Missing		**0.98 (0.97-0.99)**	**0.98 (0.97-0.99)**
Chronic condition (vs no conditions)			
1 condition		1.01 (0.997-1.02)	1.01 (0.997-1.02)
2 conditions		1.00 (0.98-1.01)	0.996 (0.98-1.01)
3+ conditions		**0.97 (0.96-0.99)**	**0.97 (0.96-0.99)**
Missing		**0.97 (0.94-0.99)**	**0.97 (0.95-0.99)**
Clinical depression (vs no)		1.00 (0.99-1.01)	1.00 (0.99-1.01)
Self-rated health (vs poor/fair)			
Good		**1.06 (1.05-1.08)**	**1.06 (1.04-1.08)**
Very good		**1.10 (1.08-1.12)**	**1.10 (1.08-1.12)**
Excellent		**1.11 (1.09-1.13)**	**1.11 (1.09-1.13)**
Ever smoked (vs no)		**0.97 (0.97-0.98)**	**0.98 (0.97-0.98)**
Alcohol consumption (vs non-user)			
Occasional drinker		1.01 (0.99-1.03)	1.01 (0.99-1.03)
Regular drinker		**1.03 (1.02-1.05)**	**1.03 (1.02-1.05)**
Missing		1.00 (0.97-1.03)	1.00 (0.97-1.03)
Marital status (vs married/common-law)			
Single/never married			**0.97 (0.96-0.99)**

Widowed	0.98 (0.96-1.00)
Divorced/separated	0.99 (0.97-1.005)
Loneliness (vs not lonely)	**0.98 (0.97-0.99)**
Living alone (vs not living alone)	1.02 (1.00-1.03)

Significant results are **bolded.**
Model A: social support; Model B: adds sociodemographic variables (age, sex, education, annual household income, province); Model C: adds health variables (chronic conditions, clinical depression, self-rated health, ever smoked, alcohol consumption); Final model: adds social variables (marital status, loneliness, living alone)

Baseline association between social support (T1) and executive function (T1) by cohort

To compare the association between social support and executive function by participation cohort (i.e., baseline-only vs all time points), it was necessary to conduct cross-sectional analyses using baseline data, as this was the only data available for those lost to attrition after baseline assessment. After accounting for all covariates, the association was statistically significant for those who participated at baseline only (OR=1.60, 95% CI= 1.04-2.46) and not for those who participated at all time points (OR = 1.01, 0.81-1.27).

Table 4. The cross-sectional, baseline association between low functional social support and low executive function, stratified by participation cohort, in the Canadian Longitudinal Study on Aging (n=24,548)

	Executive function (Low vs normal)			
	Model A OR (95% CI)	Model B OR (95% CI)	Model C OR (95% CI)	Final model OR (95% CI)
Participation at baseline only (T1)				
Functional social support				
Low vs high	**1.74 (1.23-2.45)**	**1.87 (1.26-2.79)**	**1.66 (1.11-2.50)**	**1.60 (1.04-2.46)**
Participation at all time points (T1, T2 & T3)				
Functional social support				
Low vs high	**1.96 (1.60-2.39)**	1.22 (0.98-1.52)	1.07 (0.86-1.34)	1.01 (0.81-1.27)

Significant results are **bolded.**
Model A: social support; Model B: adds sociodemographic variables (age, sex, education, annual household income, province); Model C: adds health variables (chronic conditions,

clinical depression, self-rated health, ever smoked, alcohol consumption); Final model: adds social variables (marital status, loneliness, living alone)

Discussion

This study investigated the association between social support, executive function and participation in a large, ongoing study of Canadian adults in mid- to late-life. After accounting for all covariates, those with low social support, low executive function or who were missing data on any of the tests of executive function were more likely to participate only in the baseline data collection and were significantly less likely to complete all three waves of the CLSA. Looking then at the baseline cross-sectional association between functional social support and executive function, social support was only significantly associated with executive function for those who participated only at baseline and not for those who participated at all timepoints, after adjusting for all potential confounding variables.

The results of objective one, which identified characteristics associated with attrition, were largely consistent with available literature. The finding that those with low executive function were more likely to be lost over the course of the longitudinal study is supported by evidence that cognitive function appears to strongly impact attrition (Chatfield et al., 2005; Jacobsen et al., 2020; Van Beijsterveldt et al., 2002; Handels et al., 2020; Matthews et al., 2004; Haberstumpf et al, 2021; Burke et al., 2019; Liao et al. 2016). Less attention has been given to the relationship between social support and attrition, particularly functional measures of social support. In general, having less structural support (e.g., being unmarried, living alone, having less than three close relationships) is associated with greater odds of being lost over the course of longitudinal data collection (Chatfield et al., 2005; Jacobsen et al, 2020; Young et al., 2006). While a significant difference in social support by participation status may not have been found in all studies (e.g., Liao et al., 2016), the results of the current study indicate that the functional quality of social resources may play an important role in whether participants are willing or able to continue their participation after the initial baseline assessment.

The second objective of this study was to explore whether there were differences in the association between social support and executive function in those who were lost to the study after baseline assessment compared to those who participated in further waves of data

collection. The results of these analyses provide some evidence for why the significant association between social support, executive function and attrition should raise concern. Specifically, the cross-sectional association between social support and executive function was only statistically significant for those who were lost from the dataset after baseline and was not significant for those who remained within the study over time after adjusting for potential confounders. This indicates that those who were lost to attrition may be more sensitive to the effects of social support on executive function than those who remained in the study. While there are many refined analytical methods for dealing with attrition, longitudinal analyses using highly skewed data, such as is seen with social support, can only utilize data on participants who remain in the study over time. As such, the study results reveal a potential limitation in the current literature: that those who drop out may have a different association between social support and cognitive health than those who remain in studies over time. As such, research on the long-term impact of social support on executive function in samples with attrition may produce findings that underestimate the effect of social support over time for the broader population. These findings contribute to our knowledge of the cross-sectional and longitudinal association between social support and executive function and how sample attrition may impact how this association has been interpreted in past literature.

This study is not without its own limitations. The first, introduced above, is that the original sample selection process may have introduced bias. Despite efforts by the CLSA to recruit a diverse sample from within limited geographic areas and to oversample those with low education (CLSA, 2017), volunteers for the CLSA were biased toward those who are white, highly educated, and wealthy. Given that approximately 10% of Canadians who were contacted to participate in the CLSA agreed to participate, it can be predicted that there were some self-selection biases (CLSA, n.d.). This self-selection bias is likely reflected in the very high average scores on the MOS-SSS and the overall cognitive health of the sample, the latter of which was exacerbated as the CLSA excluded those who had obvious cognitive impairment at baseline. This raises concerns that, even at baseline, our analyses start with a selective sample that may not reflect the average experience of middle-aged and older adults living in the community. Interestingly, our findings would indicate that, even among this

healthy base sample, there are still variations in how social support and executive function impact further participation.

Conclusion

As the population ages, having a better understanding of how social support impacts cognitive function over time is essential for guiding public health policies and future research directed at helping adults maintain their independence and adapt to changes. Unfortunately, despite best efforts by investigators to create more diverse baseline samples that better reflect the population of interest, the study findings demonstrate that there may still be sociodemographic, health, lifestyle and social differences between participants who agree to participate as well as remain in longitudinal studies and those who are lost to attrition after the initial baseline assessment. Those with the strongest association between social support and executive function are also those most likely to be lost to follow-up. Attrition in longitudinal studies can lead to underestimating the impact of social support given the cognitively healthier and more socially engaged participants who remain in the study. Of greatest concern is that those who are lost to these studies over time may be those who would benefit most greatly from results generated from research, given they may have worse cognitive health than those who remain. Researchers and policy makers must base their decisions on the available data, which, for longitudinal analyses, may not be providing accurate and generalizable information. While what is demonstrated in this paper discusses the association between social support and executive function, the limitations of the data represented here have wide-spread implications for longitudinal research on aging.

Chapter 5: Investigating the impact of attrition on the long-term association between functional social support and executive function in the Canadian Longitudinal Study on Aging

Introduction

As the population over the age of 65 increases (Statistics Canada, 2022), a greater proportion of Canadians will become vulnerable to cognitive decline, leading to greater risks of frailty (Kim et al., 2014) and subsequent physical declines and mortality (Hoogendijk et al., 2014). Executive function is a particularly important cognitive domain for successful aging given its role in the tasks required for daily independent living (McAlister & Schmitter-Edgecombe, 2016). Executive function is an effortful cognitive process necessary for paying attention, planning for the future, adapting to change, completing goals, and solving problems (Alvarez & Emory, 2006; Diamond, 2013) and is engaged when the mind must work in a non-automatic way (Diamond, 2013). While the exact definitions are debated, it is generally accepted that overall executive function refers to a collection of separate but overlapping cognitive processes (Burgess & Stuss, 2017; Alvarez & Emory, 2006; Friedman & Miyake, 2017). Whether these high-level processes are 'supervisory' of lower functions, or if these lower functions are part of executive function themselves, the interconnections are likely complex (Alvarez & Emory, 2006). Due to its dependence on so many different processes, executive function is sensitive to many physical, emotional and cognitive stressors, including poor health, stress, and loneliness (Diamond, 2013).

Of the many factors identified as playing a significant role in late-life executive function, social support is a potentially modifiable and accessible area of intervention that could be targeted to help protect against cognitive decline (Livingston et al., 2024). Social support is measured in two ways: structurally and functionally. Structural or objective measures of social support include marital status; living arrangement; and number of friends, relatives and neighbours as well as the frequency of social participation one partakes in with this social network (Sherbourne & Stewart, 1991). In contrast, functional social support is based on the perceived adequacy of one's social resources to fulfill specific social needs and can provide important information on how much support an individual believes they truly have access to when they need it (Sherbourne & Stewart, 1991). Functional social support can be further divided into subtypes including emotional/informational support (e.g., having

someone you can turn to in a crisis), tangible support (e.g., having someone who can help you get groceries), affectionate support (e.g., having someone who provides love and attention), and positive social interactions (e.g., having someone to relax or have fun with). Structural measures have historically received more attention than functional or subjective measures (Sherbourne & Stewart, 1991), likely, at least in part, due to the lack of availability of functional measures of social support in large datasets.

While limited, there is growing literature on functional social support and cognitive function, with cross-sectional analyses providing much of the statistically significant evidence for the association between these characteristics. In their systematic review on functional social support and cognitive function, Mogic et al. (2023) identified a statistically significant, positive *cross-sectional* association between social support and overall cognitive function in 10 of 12 studies on overall social support, 7 of 8 on emotional social support, 2 of 6 on tangible social support, and 3 of 3 on combined emotional/tangible social support. Looking specifically at executive function, two studies found a positive significant association between overall social support (Hamalainen et al., 2019; Krueger et al., 2009), while one was not statistically significant (Gow et al., 2007). Emotional social support and executive function were significantly positively associated in 2 of 4 identified studies (Frith & Loprinzi, 2017; La Fleur & Salthouse, 2017), one study found no significant effect (Zahodne et al., 2014) while one study had a significant negative association (Bourne et al., 2007), such that more support indicated lower cognitive function. Recent evidence for this cross-sectional relationship also comes from Rutter et al. (2024), who demonstrated that low positive social interactions, emotional/informational support and affectionate support were significantly associated with low executive function in a large, community-based cohort of adults in mid- to late-life.

In contrast to the cross-sectional findings, of the studies identified by Mogic et al. (2023) looking at the positive *longitudinal* relationship between social support and cognitive function, only 4 of 10 studies (40%) of overall support, 1 of 9 studies (11%) of emotional support, and 1 of 8 studies (12.5%) of tangible support were statistically significant. Of the five studies identified by Mogic et al., (2023) looking at the longitudinal association between functional social support and executive function, two studies produced significant results (Dickinson et al., 2011; Liao & Scholes, 2017). Tangible support was significantly positively

(Dickinson et al., 2011; Liao & Scholes, 2017) and non-significantly negatively (Zahodne et al., 2021) associated with executive function. Positive social support was positively significantly associated with executive function (Dickinson et al., 2011; Liao & Scholes, 2017), yet emotional support was not found to statistically significantly support executive function in any studies (Zahodne et al., 2021; Liao et al., 2018).

While the nonsignificant longitudinal findings may be an indication that the relationship between social support and executive function is cross-sectional and transient, this association is understudied, and inconsistent conclusions about the long-term relationship may arise due to the limited available research and differences in populations and/or in methodological rigor across studies. A lack of significant findings from longitudinal study designs could, for example, reflect the biases in the samples on which longitudinal analyses have been conducted. Attrition (i.e., loss of participants over the course of a study) may be one factor leading to weaker evidence of a long-term association between social support and executive function in longitudinal research, if loss is biased based on health and social factors. Functional and structural social support (Jacobsen et al, 2020, Young et al., 2006; Yue et al., 2023; Chatfield et al., 2005) and cognitive function (Chatfield et al., 2005; Jacobsen et al., 2020; Jacomb et al., 2002; Burke et al., 2019; Van Beijsterveldt et al., 2002) are both associated with attrition, with those reporting lower social support and/or lower cognitive function at baseline assessment more likely to be lost to follow-up over time. These attrition patterns can lead to longitudinal data that are increasingly biased toward more socially supported and cognitively healthy samples. As such, rather than providing evidence for a weakening association between social support and executive function over time, a lack of positive and significant longitudinal findings may reflect changes in samples over the course of cohort studies caused by attrition. This, unfortunately, can lead to results and conclusions that not only do not reflect the greater population but also specifically exclude those with lower cognitive function and lower social support who may be in greater need of intervention.

As a greater proportion of individuals become vulnerable to age-related declines in cognitive health, determining how potential areas of intervention impact key domains of cognitive function, such as executive function, is essential for informing public health initiatives aimed at helping adults in mid- to late-life maintain their cognitive and physical

functioning. Social support may provide an accessible and modifiable area of intervention to support cognitive health, but longitudinal results on this association are inconsistent and may reflect biases in samples given both social support and cognitive function are associated with attrition. This inconsistency may lead to incorrect assumptions about the relationship between social support and executive function, such that mixed results are interpreted as evidence of a lack of association between these variables. Further complicating this relationship is the role that individual factors, such as age and sex, may have on the impact of social support to cognitive function.

This study contributes to this area of research by: 1) investigating the longitudinal association between functional social support and incident executive function in a large, community-based study of adults in mid- to late-life while, 2) exploring how attrition may impact the results and conclusions generated from these analyses. Additional supplementary analyses were conducted, including: 1) stratified analyses for sex and age, 2) exploration of different analytic approaches (i.e., modified Poisson vs logistic regression), and 3) investigation into how the effect of length of follow-up between social support and executive function may impact the association.

Methods

Sample

This longitudinal study utilized existing data from the first (baseline, T1; 2012-2015), second (follow-up 1, T2; 2015-2018) and third (follow-up 2, T3; 2018-2021) waves of the Comprehensive cohort (n=30,097) of the Canadian Longitudinal Study on Aging (CLSA), a prospective, ongoing cohort study of community-dwelling adults between the ages of 45 and 85 at time of recruitment (Raina et al., 2019). Participants in the CLSA were recruited into the Tracking cohort (n=21,241), where data were collected using phone calls, and the Comprehensive cohort, in which participants living within 25-50 km of one of 11 data collection sites across seven provinces were assessed in person. The Comprehensive cohort was selected for analysis due to the greater number of cognitive tests available. Individuals living in the three Canadian territories, on federal First Nations reserves, or in institutions; who were full-time members of the Canadian Armed Forces; or who interviewers perceived to have cognitive impairment were excluded by the CLSA at recruitment.

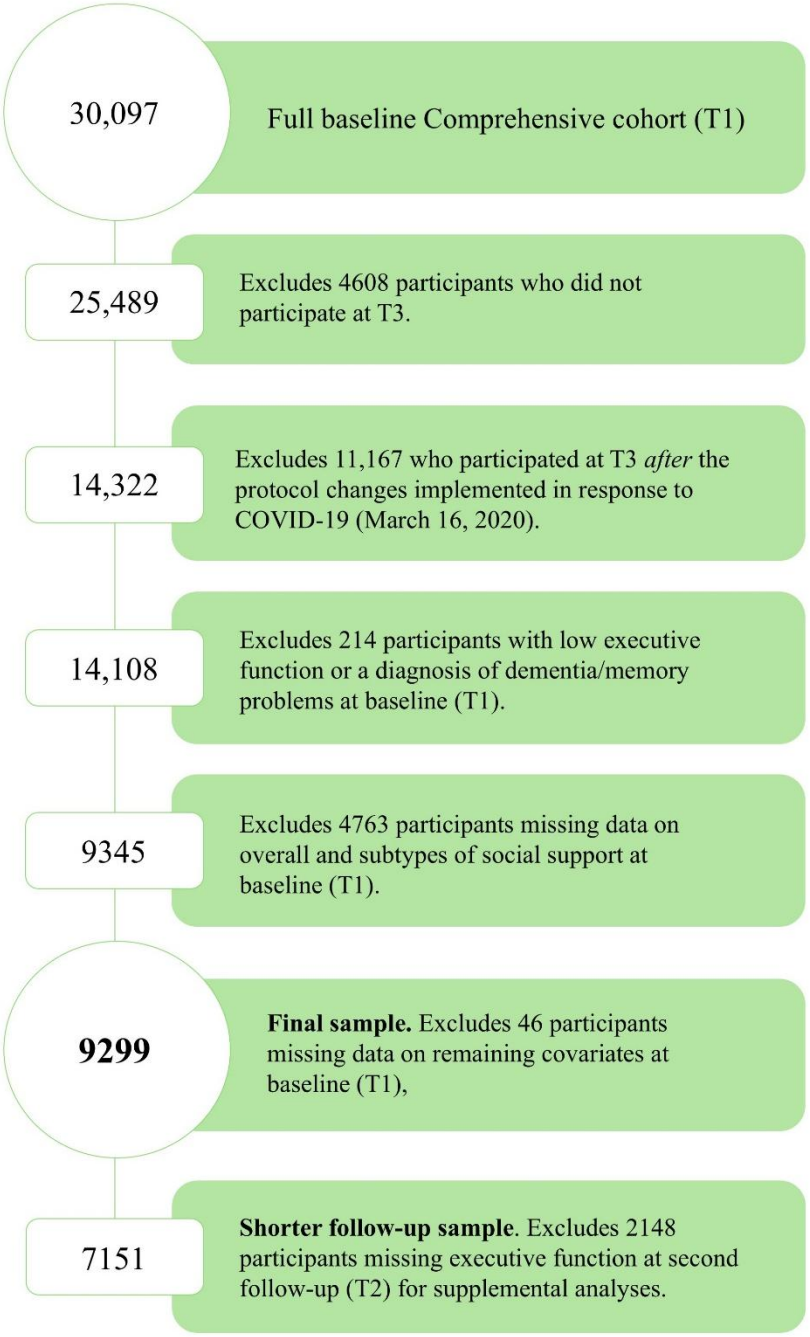
Data collection for follow-up 2 (T3) occurred both pre- and post-implementation of COVID-19-related restrictions in Canada. Prior to March 16, 2020, participants in the Comprehensive cohort completed in-person interviews both at home as well as at their assigned data collection site. After March 16, 2020, the data collection protocol was updated to reflect both the overall increased risk of illness for the aging CLSA participants as well as COVID-19 restriction measures implemented by federal and provincial governments. This required data collection to move to telephone interviews, similar to those conducted in the CLSA's Tracking cohort (CLSA, 2024).

This change in data collection method had a profound impact on the testing of executive function in particular, with only two tests of executive function in the CLSA being measurable using phone interviews (i.e., Animal Fluency Test [AFT; Crossley et al., 1997; Goodglass & Kaplan, 1972] and the Mental Alternation Test [MAT; Teng, 1995; Billick et al., 2001]), compared to the five tests which were previously conducted in person (i.e., AFT; MAT; the Controlled Oral Word Association Test [COWAT; Benton & Hamsher, 1978]; Time-based Prospective Memory Test [TMT; Loewenstein & Acevedo, 2004] and Victoria Stroop Neurological Screening Test [Stroop; Spreen & Strauss, 1998; Strauss et al., 2006; Troyer et al., 2006; Bayard et al., 2009; Moroni & Bayard, 2009; Bayard et al., 2011]). O'Connell et al. (in preparation) found that the covariances between the tests measuring executive function were different for the in-person and telephone administered tests even after equating them using appropriately normed scores (i.e., telephone tests used telephone normative comparison standards). Given the alteration of both the number of tests and the environmental conditions in which these assessments were conducted, it was deemed inappropriate to combine those who completed their assessments pre- and post-implementation of the COVID-19 protocol (Falck et al., 2025). Consequentially, the analytic sample was restricted to those who completed their interviews and cognitive assessments prior to March 16, 2020 (n=14,322), excluding those who completed their assessments after that date.

To accurately assess incident cases of low executive function at follow-up 2 (T3), it was necessary to also exclude those with a previous diagnosis of dementia or memory problems or who had low executive function at baseline. A final analytic sample of 9,299

remained after exclusion of participants missing data on remaining variables. A flowchart of the analytic sample creation is included in **Figure 3.**

Figure 3. The creation of the analytic samples for the Chapter 5 cross-sectional and longitudinal samples analyses, with T3 analyses split by pre- and post-COVID-19 restrictions in the Canadian Longitudinal Study on Aging



Measures

Exposures

Functional social support (T1) was assessed using the 19-item Medical Outcomes Study-Social Support Survey (MOS-SSS) (Sherbourne & Stewart, 1991; RAND, n.d.). Items on the MOS-SSS are rated on a 5-point scale from 1 (none of the time) to 5 (all of the time), with a higher score indicating higher levels of social support. The MOS-SSS includes questions assessing four subtypes of support: emotional/informational support, tangible support, affectionate support, and positive social interactions. For overall social support and each subtype, scores on each relevant item were combined to produce an average score out of five. In order to maximize the sample for investigation into attrition, individuals were allowed to miss one of the 19 items, with the remaining 18 items used to calculate the average overall social support score. Given the limited number of items used to calculate each subtype (i.e., 3 to 8), the calculation of subtypes of support required participants to have all items of that subtype. As data was skewed toward the high end of the MOS-SSS scale, a dichotomous cut-off of ≤ 3 out of 5 was used to distinguish those with relatively low levels of support for overall SSA and each subtype. The use of an absolute (versus relative) cut-off score allows for comparison within the study across subtypes of support, as well as for comparison with external studies.

Outcome

An overall score of low executive function was calculated by averaging the standardized z-scores on the Animal Fluency Test (AFT [version 2]), the Mental Alternation Test (MAT), Controlled Oral Word Association Test (COWAT), Time-based Prospective Memory Test (TMT), and the Victoria Stroop Neurological Screening Test (Stroop). Scores were standardized within each test using z-scores and calculated separately for English and French speakers, with bilingual responses excluded (Tuokko et al., 2017). Tests were modified for use in the CLSA (Tuokko et al., 2017; CLSA, n.d. [Technical document #1122]). Low executive function (T3) was defined using a cut-off of ≥1.5 SD below the mean of a neurologically healthy sample that excluded those who reported being diagnosed with Alzheimer's disease, memory problems, epilepsy, stroke or cerebrovascular accident, multiple sclerosis, Parkinson disease, or ministroke or transient ischemic attack at any time point (Petersen et al., 1997; O'Connell et al., 2017). Additionally, those who had a positive

screen for a traumatic brain injury and reported two or more concussions or any symptoms of a concussion at any time point were removed (O'Connell et al., 2017; Bedard et al., 2018). The generated cut-off was then applied to the analytical sample to create a two-level variable: low versus normal executive function.

Covariates

Potential confounders (T1) included sociodemographic variables (i.e., age, sex, education, annual household income, province of residence), measures of health and lifestyle (i.e., self-reported clinical depression, number of chronic conditions, self-rated health, smoking and alcohol use) and other measures of social support (i.e., marital status, living alone and loneliness).

Analyses

All analyses were conducted using SAS Studio Enterprise Edition 3.6 (SAS Institute Inc., Cary, North Carolina). Univariate and bivariate analyses (Pearson chi-square tests with a significance level of $p<0.05$) were conducted to describe the samples. For objective one, modified Poisson regression models were used to estimate the relative risk (RR, 95% confidence intervals [CI]) for the association between low social support (T1) and incident low executive function (T3), after accounting for covariates (T1). Modified Poisson models provide relative risk, which is the risk in the exposed group divided by the risk in the unexposed group (Rosella, 2012). Models excluded those with low executive function at baseline in order to assess incident cases of low executive function (i.e., cases which develop during the course of the study) to assist in establishing temporality.

For objective two, participation cohort groups were created to examine whether the baseline association between social support and executive function varied across those who remained in the study over time compared to those who were lost to attrition. Participants were categorized into one of three cohorts based on participation status at their last assessment: baseline only (T1); baseline and follow-up 1 only (T1 & T2); and all timepoints (T1, T2, T3). Logistic regression models were used to estimate the odds ratio (OR, 95% confidence intervals [CI]) in cross-sectional analyses.

Supplementary analyses

To provide a more in-depth investigation of this area of interest, several subgroup analyses were completed for objective one, which looked at the longitudinal association

between social support and incident low executive function. First, analyses were rerun with each of the subtypes of functional social support (i.e., tangible, affectionate and emotional/informational support; positive social interactions) as the exposure. Further analyses were run stratified by key sociodemographic variables (i.e., age and sex). To investigate the impact of length of follow-up (three years vs six years), additional longitudinal analyses were run for objective one, using executive function at follow-up 1 (T2) compared to original analyses utilizing executive function at follow-up 2 (T3). Logistic regression models were used in supplementary analyses to accommodate smaller sample sizes in stratified models, which modified Poisson models were unable to run. Finally, to account for how this different type of regression modelling (e.g., logistic regression vs modified Poisson) may impact result estimates and conclusions (e.g., significance of the association), objective one was repeated using logistic regression.

Results

Descriptive results

A description of the sample stratified by baseline executive function is included in **Table 5**. Levels of low social support at T1 did not differ significantly between those with low and normal executive function at T3. Participants with low executive function were significantly more likely than those with normal executive function to be older, have lower educational attainment, lower income, to have a greater number of chronic conditions, lower self-rated health, have smoked, and to be a non- or occasional user of alcohol. Two measures of structural social support (i.e., marital status and living alone) varied with executive function, such that those with normal executive function were more likely to be married (75% vs 68%) and not living alone (82.1% vs 73.8%), while those with low executive function were more likely to be widowed (17% vs 7%).

Table 5. The distribution of sociodemographic, health, lifestyle, and social characteristics at baseline (T1) stratified by low executive function (T3) in the Canadian Longitudinal Study on Aging (n=9,299)

		Executive function (T3)	
	Total sample n=9,299	**Low n=553**	**Normal n=8,746**
	n (%)	n (%)	n (%)
Sociodemographic characteristics			
Age group			
45–54 years	2663 (28.64)	33 (5.97)	2630 (30.07)***
55–64 years	3468 (37.29)	110 (19.89)	3358 (38.39)
65–74 years	2199 (23.65)	210 (37.97)	1989 (22.74)
75 years and over	969 (10.42)	200 (36.17)	769 (8.79)
Sex			
Female	4955 (53.29)	293 (52.98)	4662 (53.30)
Male	4344 (46.71)	260 (47.02)	4048 (46.70)
Education			
Less than high school	314 (3.38)	73 (13.20)	241 (2.76)***
High school graduate	827 (8.89)	71 (12.84)	756 (8.64)
Some post-secondary	594 (6.39)	41 (7.41)	553 (6.32)
Post-secondary degree/diploma	7564 (81.34)	368 (66.55)	7196 (82.28)
Annual household income			
< $20k	282 (3.03)	41 (7.41)	241 (2.76)***
≥ $20k and < $50k	1633 (17.56)	177 (32.01)	1456 (16.65)
≥ $50k and < $100k	3312 (35.62)	218 (39.42)	3094 (35.38)
≥ $100k and < $150k	1963 (21.11)	50 (9.04)	1913 (21.87)
≥ $150k	1643 (17.67)	34 (6.15)	1609 (18.40)
Missing	466 (5.01)	33 (5.97)	433 (4.95)
Province			
Ontario	1925 (20.74)	111 (20.07)	1814 (20.74)
Alberta	876 (9.42)	48 (8.68)	828 (9.47)
British Columbia	2049 (22.03)	112 (20.25)	1937 (22.15)
Manitoba	1099 (11.82)	61 (11.03)	1038 (11.87)
Newfoundland and Labrador	751 (8.08)	42 (7.59)	709 (8.11)
Nova Scotia	988 (10.62)	76 (13.74)	912 (10.43)
Quebec	1611 (17.32)	103 (18.63)	1508 (17.24)
Health & lifestyle characteristics			
Clinical depression			
Yes	1470 (15.81)	77 (13.92)	1393 (15.93)
No	7829 (84.19)	476 (86.08)	7353 (84.07)
Number of chronic conditions			
0	3135 (33.71)	104 (18.21)	3031 (34.66)***
1	3210 (34.52)	158 (28.57)	3052 (34.90)
2	1713 (18.42)	133 (24.05)	1580 (18.07)
3+	1008 (10.84)	128 (23.15)	880 (10.06)

		Executive function (T3)	
	Total sample n=9,299	**Low n=553**	**Normal n=8,746**
	n (%)	n (%)	n (%)
Missing	233 (2.51)	30 (5.42)	203 (2.32)
Self-rated health			
Poor	92 (0.99)	10 (1.81)	82 (0.94)***
Fair	490 (5.27)	45 (8.14)	445 (5.09)
Good	2476 (26.63)	187 (33.82)	2289 (26.17)
Very good	4089 (43.97)	212 (38.34)	3877 (44.33)
Excellent	2152 (23.14)	99 (17.90)	2053 (23.47)
Ever smoked			
Yes	4718 (50.74)	315 (56.96)	4403 (50.34)**
No	4581 (49.26)	238 (43.04)	4343 (49.66)
Alcohol use			
Non-user	898 (9.66)	74 (13.38)	824 (9.42)***
Occasional user	986 (10.60)	106 (19.17)	880 (10.06)
Regular user	7227 (77.72)	358 (64.74)	6869 (78.54)
Missing	188 (2.02)	15 (2.71)	173 (1.98)
Social characteristics			
Overall functional social support			
Low	444 (4.77)	36 (6.51)	408 (4.66)
High	8855 (95.23)	517 (93.49)	8338 (95.34)
Marital status			
Married/living with a partner in a common-law relationship	6932 (74.55)	375 (67.81)	6557 (74.97)***
Single, never married or lived with a partner	657 (7.07)	33 (5.97)	624 (7.13)
Widowed	614 (6.60)	96 (17.36)	518 (5.92)
Divorced	884 (9.51)	41 (7.41)	843 (9.64)
Separated	212 (2.28)	8 (1.45)	204 (2.33)
Living alone			
Yes	1701 (18.29)	145 (26.22)	1556 (17.79)***
No	7598 (81.71)	408 (73.78)	7190 (82.21)
Lonely			
Yes	2048 (22.02)	133 (24.05)	1915 (21.90)
No	7251 (77.98)	420 (75.95)	6831 (78.10)

*p < .05; **p < .01; ***p < .001

Longitudinal association between low social support (T1) and executive function (T3)

Low overall functional social support at baseline (T1) was not significantly associated with low executive function (T3) in the crude model (Model A; RR = 1.02, 95% CI = 0.997-1.05) or the fully adjusted model (RR = 1.00, 95% CI = 0.98-1.03; **Table 6)**. In the final model adjusted for all sociodemographic, health, lifestyle and social variables, older age,

lower education, and a greater number of chronic conditions or missing chronic condition data at baseline were all significantly associated with a higher risk of low executive function at T3. In contrast, higher (or missing) income at baseline was associated with a lower risk of low executive function (T3) in the fully adjusted model.

Table 6. The longitudinal association between low social support (T1) and low executive function (T3) in the Canadian Longitudinal Study on Aging (n=9,299)

	Executive function (Low vs normal)			
	Model A (Crude) RR (95% CI)	**Model B RR (95% CI)**	**Model C RR (95% CI)**	**Final model RR (95% CI)**
Overall social support				
Low vs high	1.02 (0.997-1.05)	1.00 (0.98-1.03)	1.00 (0.97-1.02)	1.00 (0.98-1.03)
Age group (vs 45–54 years)				
55–64 years		**1.01 (1.01-1.02)**	**1.01 (1.05-1.02)**	**1.01 (1.00-1.02)**
65–74 years		**1.07 (1.06-1.08)**	**1.07 (1.05-1.08)**	**1.07 (1.05-1.08)**
75 years and over		**1.19 (1.16-1.22)**	**1.18 (1.15-1.21)**	**1.17 (1.14-1.21)**
Female (vs male)		1.00 (0.99-1.01)	1.00 (0.99-1.01)	1.00 (0.988-1.01)
Education (vs post-secondary degree/diploma)				
Some post-secondary		1.01 (0.99-1.03)	1.00 (0.98-1.03)	1.00 (0.98-1.02)
High school graduate		**1.02 (1.00-1.04)**	**1.02 (1.00-1.04)**	**1.02 (1.00-1.04)**
Less than high school		**1.14 (1.09-1.20)**	**1.13 (1.08-1.19)**	**1.13 (1.07-1.18)**
Annual household income (vs < $20,000)				
≥ $20,000 and < $50,000		0.96 (0.92-1.01)	0.97 (0.93-1.01)	0.97 (0.93-1.01)
≥ $50,000 and < $100,000		**0.95 (0.91-0.99)**	**0.96 (0.92-0.997)**	**0.95 (0.91-0.99)**
≥ $100,000		**0.93 (0.90-0.97)**	**0.95 (0.91-0.99)**	**0.93 (0.90-0.97)**
Missing		**0.94**	**0.95**	**0.94**

	(0.90-0.98)	**(0.91-0.99)**	**(0.90-0.98)**
Province (vs Ontario)			
Alberta	1.00 (0.99-1.02)	1.00 (0.98-1.02)	1.00 (0.98-1.02)
British Columbia	1.00 (0.98-1.01)	1.00 (0.98-1.01)	1.00 (0.98-1.01)
Manitoba	1.00 (0.98-1.01)	1.00 (0.98-1.01)	1.00 (0.98-1.01)
Newfoundland and Labrador	1.01 (0.99-1.03)	1.01 (0.99-1.03)	1.01 (0.988-1.03)
Nova Scotia	1.02 (0.998-1.04)	1.01 (0.99-1.03)	1.01 (0.99-1.03)
Quebec	1.00 (0.98-1.02)	1.00 (0.99-1.02)	1.00 (0.98-1.02)
Chronic condition (vs no conditions)			
1 condition		1.00 (0.99-1.01)	1.00 (0.99-1.01)
2 conditions		1.01 (0.995-1.02)	1.00 (0.995-1.02)
3+ conditions		**1.04 (1.01-1.06)**	**1.04 (1.01-1.06)**
Missing		**1.06 (1.02-1.10)**	**1.06 (1.02-1.10)**
Clinical depression (vs absence)		0.99 (0.98-1.01)	0.99 (0.98-1.01)
Self-rated health (vs poor/fair)			
Good		0.99 (0.97-1.02)	0.99 (0.97-1.02)
Very good		0.98 (0.95-1.00)	0.98 (0.95-1.00)
Excellent		0.98 (0.95-1.00)	0.98 (0.95-1.00)
Ever smoked (vs no)		1.00 (0.99-1.01)	1.00 (0.99-1.01)
Alcohol consumption (vs non-user)			
Occasional drinker		1.02 (0.997-1.05)	1.02 (0.997-1.05)
Regular drinker		**0.98 (0.96-0.999)**	0.98 (0.97-1.00)
Missing		1.00 (0.96-1.04)	1.00 (0.96-1.04)
Marital status (vs married/common-law)			

Single/never married	0.99 (0.97-1.01)
Widowed	1.02 (0.99-1.05)
Divorced/separated	**0.97 (0.95-0.99)**
Loneliness (vs not lonely)	1.00 (0.99-1.01)
Living alone (vs not living alone)	0.99 (0.97-1.01)

Significant results are **bolded**.
Model A: Social support; Model B: Model A plus sociodemographic variables (age, sex, education, annual household income, province); Model C: Model B plus health and lifestyle variables (chronic conditions, clinical depression, self-rated health, ever smoker, alcohol consumption); Final Model: Model C plus social variables (marital status, loneliness, living alone)

Supplemental analyses

Additional supplemental analyses were run to explore how the association between social support and executive function varied across subtypes of support and between subgroups of participants. First, analyses were rerun with each of the subtypes of functional social support (i.e., tangible, affectionate and emotional/informational support; positive social interactions) as the exposure (**Appendix D.1**). Analyses were then stratified by key sociodemographic variables: sex (**Appendix D.2**) and age (**Appendix D.3**). These models stratified by subtypes of functional support (**Appendix D.1**), sex (**Tables D1 & D2**) or age (**Table D3**) did not demonstrate statistically significant differences in the association between functional social support and executive function across subtypes of functional social support, sex or age.

To investigate the impact of length of follow-up (three years vs six years), additional longitudinal analyses were run for objective one, using executive function at follow-up 1 (T2) to compare to original analyses utilizing executive function at follow-up 2 (T3). Results of these analyses are included in **Appendix D.4.** Results for the association between baseline (T1) social support and follow-up 1 (T2) social support are included in **Table D4.** The association between baseline social support and executive function at first follow-up (T2) was not statistically significant (RR = 1.00, 95% CI = 0.98-1.02).

It was necessary to utilize logistic regression modelling in many of the supplementary analyses in order to accommodate the smaller cell sizes caused by stratification which could not be processed by the modified Poisson procedure. As such, analyses addressing objective one (**Table 2**) were repeated using logistic regression to account for how this different regression modelling may have impacted results and conclusions (e.g., significance of the association between social support [T1] and executive function [T3]). When models were run using logistic regression (**Appendix D.5**) social support was not significantly associated with later low executive function (n=9299; OR = 1.13, 95% CI = 0.76-1.68; **Table D5**).

Baseline association between low social support (T1) and executive function (T1) by participation cohort

In objective 2, we investigated whether the association between social support and executive function differed between those who remained in the study for all three assessments and those who were lost from the study over time. Baseline (T1) cross-sectional analyses were run using logistic regression models stratified by participation cohort (**Table 7**). After accounting for all sociodemographic, health, lifestyle, and social covariates (T1), the cross-sectional association between low (vs high) social support and low (vs normal) executive function was statistically significant for those who participated at baseline only (T1; OR = 1.60, 95% CI = 1.04-2.46) but not for those who participated at two time points (T1 & T2; OR = 1.15, 95% CI = 0.74-1.80) or those who participated at all time points (T1, T2 & T3; OR = 1.16, 95% CI = 0.84-1.59).

Table 7. The cross-sectional, baseline association between low functional social support and low executive function, stratified by participation cohort (T3 pre-COVID-19 restrictions) in the Canadian Longitudinal Study on Aging (n=28,970)

	Executive function (Low vs normal)
Participation cohort	OR (95% CI)
Baseline only (T1; n=2031)	
Social support (low vs high)	**1.60 (1.04-2.46)**
Baseline and follow-up 1 (T1 & T2; n=2224)	
Social support (low vs high)	1.15 (0.74-1.80)
All time points (T1, T2 & T3; n=24,607)	
Social support (low vs high)	1.16 (0.84-1.59)

Significant results are **bolded**.
Final model includes social support, sociodemographic variables (age, sex, education, annual household income, province); health variables (chronic conditions, clinical depression, self-rated health, ever smoker, alcohol consumption); and additional social variables (marital status, loneliness, living alone)

Discussion

The aims of this paper were to: 1) investigate the longitudinal association between functional social support and incident executive function in a large, community-based study of adults in mid- to late-life, and 2) explore how attrition may impact the results and conclusions generated from these analyses. We found no statistically significant longitudinal association between low functional social support (T1) and low executive function (T3). Despite this, there is a significant, baseline cross-sectional association between low social support and low executive function for some participants who were not retained for longitudinal analyses. Taken at face value, the null longitudinal results would seem to add to the nonsignificant findings regarding the long-term association between social support and cognitive function. Yet, in objective 2, when those who completed all assessments were compared cross-sectionally to those who had dropped out of the study after baseline assessment, only those lost after baseline had a significant positive cross-sectional association between low social support and low executive function. These findings indicate that attrition may be introducing bias into our longitudinal results and, if we are not careful in our interpretation, into our conclusions about the value of functional social support for longer-term cognitive health.

The lack of significant longitudinal findings for the association between low functional social support and low executive function is generally consistent with much of the past research looking into the relationship between functional social support and cognitive function (Mogic et al., 2023). Yet, it is unclear as to why the available literature seems to indicate a significant positive cross-sectional association, but not a longitudinal one. While there are many potential explanations (e.g., changes in social support over time and its relative importance to cognition, impact of confounders), it is possible that the lack of significant longitudinal results for the association between social support and executive function may reflect a weakening or non-existent relationship between social support and executive function over time. This finding may or may not be a product of attrition in the sample, with this appearing to hold truth for some cohorts, including the cognitively healthy sample who have continued to participate in the CLSA. That this sample had no significant longitudinal association between low social support and low executive function is predictable, given that they also did not have a significant association in cross-sectional analyses. In contrast, those who did show a significant cross-sectional association between social support and executive function did not remain in the study after baseline and thus could not be included in longitudinal analyses.

Given this pattern, it is possible that attrition may be biasing our understanding of the longitudinal effect of social support on cognitive function. Lower levels of both our exposure (functional social support) and outcome (executive function) are associated with higher attrition. Structural and functional social support (Jacobsen et al, 2020, Young et al., 2006; Yue et al., 2023; Chatfield et al., 2005) as well as cognitive function (Chatfield et al., 2005; Jacobsen et al., 2020; Jacomb et al., 2002; Burke et al., 2019; Van Beijsterveldt et al., 2002) are associated with study participation, with those with lower social support and/or lower cognitive function more likely to be lost to follow-up over time. Many of the characteristics found to have a statistically significant association with low executive function in this study are also further associated with attrition. These characteristics include older age (Chatfield et al., 2005; Jacobsen et al., 2020; Agogo et al., 2018; Van Beijsterveldt et al., 2002; Farid et al., 2022; Handels et al., 2020; Haberstumpf et al., 2021; Okpara et al., 2023), lower education (Jacobsen et al., 2020; Jacomb et al., 2002; Van Beijsterveldt et al., 2002; Brilleman et al., 2010; Katsuno et al., 2022; Young et al., 2006; Salthouse et al., 2019), lower

income (Young et al., 2006; Radler et al., 2010), the presence of chronic conditions (e.g., Agogo et al., 2018; Katsuno et al., 2022) and being unmarried (Chatfield et al., 2005; Jacobsen et al., 2022; Young et al., 2006). This trend can lead to longitudinal samples which are more cognitively healthy and socially connected subsamples of the population, and, while valid and representative of some members of society, do not necessarily reflect the greater population, some of whom have gaps in their social and cognitive resources.

Objective two considered the baseline association between social support and executive function across participation cohorts. Even though those participants who remained in the study over time did not have a significant relationship between social support and executive function, those who were lost to attrition did. The null longitudinal findings may reflect that those who would have benefited from social support were not included in the longitudinal sample and therefore were not studied.

This study has several limitations. One is the high overall cognitive health of our baseline sample, who were screened at recruitment in order to exclude those who had obvious cognitive impairment. This created an initial sample of adults who had reached middle- and late- adulthood with no cognitive impairment and may not reflect the greater population. From there, the included sample may have also benefited from a *learning effect* over time. A learning effect occurs when participants become familiar with the tests when they are repeated across multiple follow-ups, allowing them to maintain higher scores despite increasing cognitive decline (Twisk, 2013). In addition, approximately half of the follow-up 2 sample had to be excluded due to the testing protocol changes which occurred during the COVID-19 pandemic, leading to a smaller sample and limiting the extent to which additional stratified analyses could be completed.

Despite these limitations, this paper provides important evidence to support cautious interpretation of longitudinal analyses looking at the association between functional social support and executive function. Rather than interpreting our results as proof of a null longitudinal relationship, it is important to consider that the statistically non-significant findings reported in this thesis may only be representative of those who remained in the study over time. As demonstrated by the findings in objective two (i.e., variation in the association between social support and executive function by participation cohort), if the full baseline sample had been retained for all assessments, there may have been very different results (e.g.,

a significant longitudinal association between social support and executive function). Those who remained in the study for all time points may represent a uniquely cognitively healthy group who have not yet started to experience meaningful cognitive changes and may require a longer follow-up period to see significant results. Alternatively, those who dropped out after baseline who appear to have poorer overall social and physical health may have a more tightly connected relationship between social support and cognitive health due to increased needs. Both social support and cognitive function are associated with attrition, as are many factors identified as statistically significantly associated with executive function. Any investigation of this relationship must consider how attrition, particularly attrition biased on the exposure and outcome of interest, may impact results. While the long-term impact of social support on cognitive health must be investigated using longitudinal samples, these samples are vulnerable to biases which can lead to generalizations that do not reflect the greater population. Future research considering the long-term impact of exposures on cognitive health over the lifespan should actively investigate and consider how attrition may impact their samples and findings.

Chapter 6: The association between functional social support and executive function pre- and post-COVID-19 restrictions in the Canadian Longitudinal Study on Aging

Introduction

During the initial waves of the COVID-19 pandemic, many research projects were forced to make major protocol changes to accommodate regional emergency response legislation and the increased risk to the health of the study population. In the Comprehensive cohort of the Canadian Longitudinal Study on Aging (CLSA), a study of adults in mid- to late-life, data collection during second follow-up (2018-2021) pivoted from in-person data collection to assessments being completed over the phone for those who interviewed after March 16th, 2020 until the end of follow-up 2 data collection (CLSA, 2024). These protocol updates led to substantial changes in the way that cognitive testing for domains such as executive function was assessed. These changes, while necessary, have implications for how these data should be analyzed and interpreted in future longitudinal analyses. Further, how these testing changes and the greater overall COVID-19 experience may have altered the association between executive function and potential risk factors such as social support is unclear.

Many factors outside of actual cognitive abilities can influence an individual's performance on tests of cognitive function, with study design, testing environments, and participants' past exposures all impacting how cognitive data are interpreted. Cross-sectional studies are impacted by cohort effects and longitudinal studies by learning effects (Salthouse, 2010; Salthouse, 2019). Cohort effects refer to unique historical, sociocultural experiences and exposures of a particular cohort as they move across time (e.g., birth cohort), which may lead to variations in associations across generations, with this being a consistent problem in studies of cognitive trajectories (Dodge et al., 2014). Executive function appears to be particularly vulnerable to cohort effects, with age-group differences holding strong even after accounting for generational changes in educational attainment (Dodge et al., 2014). Longitudinal studies of memory and reasoning demonstrate an increase in scores over time until the age of 65, likely due to the impact of learning effects (Salthouse, 2019). The learning effect occurs when participants become familiar with tests repeated across multiple follow-ups (Twisk, 2013) and can complicate conclusions about cognitive change over time as participants get better at those specific tests. Individual history with specific aspects of the

tests and minute differences in how a test is administered, from specific wording of the script, the type of reward offered, and the emotions elicited during the instruction period, can lead to dramatic differences in performance (Burgess & Stuss, 2017) and subsequent conclusions about cognitive health. In contrast, cross-sectional and longitudinal studies with new participants added at each wave to account for practice effects reveal declines in cognitive performance with each wave, followed by a dramatic decrease after 65 (Salthouse, 2019).

Recent evidence suggests that the COVID-19 pandemic has had a negative impact on cognitive performance. A systematic review of the impact of COVID-19 infection and COVID-19 restriction measures on cognitive health (Manfredini et al., 2023) identified that not only did 85% of available studies on cognitive performance of individuals with COVID-19 report a worsening of cognitive function, but that the COVID-19 restriction experience itself was associated with declines across many domains of cognitive function regardless of infection, with 12 out of 16 studies of the cognitive effects of COVID-19 restrictions showing declines in cognitive function. These negative effects were seen both in those with and without neurological conditions and across many domains of cognitive function, including key domains such as executive function (Manfredini et al., 2023).

Executive function refers to a collection of separate but overlapping cognitive processes that play an essential role in functional independence with age (Burgess & Stuss, 2017; Alvarez & Emory, 2006; Friedman & Miyake, 2017). Whether these high-level processes are 'supervisory' of lower cognitive processes, or if these lower processes are part of executive function themselves, executive function depends on the collaboration of numerous cognitive processes (Alvarez & Emory, 2006). Due to its dependence on so many different processes, executive function is sensitive to many physical, emotional and cognitive stressors, including poor health, stress, and loneliness (Diamond, 2013).

Recent findings from the CLSA investigating the effect of the COVID-19 pandemic on executive function reveal significant changes in testing scores pre- and post-COVID-19 restrictions. Participants in the CLSA's Tracking cohort did not experience a change in the data collection protocol, as they were always tested using phone-based cognitive assessments. Despite this, older adults participating at the second follow-up (2018-2021) of the CLSA who completed their cognitive tests during the COVID-19 pandemic (i.e., post-

March 16, 2020 to 2021) had lower scores on tests of executive function compared to those who completed their assessments pre-COVID-19 (2018 to pre-March 16, 2020; Falck et al, 2025). Older women who were tested during COVID-19 restrictions (i.e., post-March 16, 2020 to 2021) also saw greater declines (since their last previous assessment three years prior) in some tests of their executive function than women in the same cohort who were tested pre-COVID-19 (Falck et al, 2025). These findings have concerning implications for the long-term impact of COVID-19 on the cognitive health of the aging population.

Finding potential interventions for supporting executive function across the lifespan is essential for protecting the overall cognitive health of the aging population. Social support has been identified as a potential accessible intervention for cognitive health. Social support is measured in two overlapping ways: structurally and functionally. Structural or objective measures of social support include marital status; living arrangement; and number of friends, relatives and neighbours as well as the frequency of social participation in the community (Sherbourne & Stewart, 1991). In contrast, functional social support is based on the perceived adequacy of one's social resources to fulfill specific social needs and can provide important information on how much support an individual believes they truly have access to when they need it (Sherbourne & Stewart, 1991). Many subtypes of functional social support appear to have a positive association with cognitive function. Emotional/informational social support (e.g., having someone you can turn to for advice; Zahodne et al., 2014; Frith & Loprinzi, 2017; La Fleur & Salthouse, 2017; Rutter et al., 2024; Zahodne et al., 2021), affectionate social support (e.g., having someone who provides love and attention; Rutter et al., 2024), positive social interactions (e.g., having someone to relax or have fun with; Liao and Scholes, 2017; Rutter et al., 2024) and tangible social support (e.g., having someone to prepare meals if one was sick in bed; Dickinson et al., 2011; Liao & Scholes, 2017) are positively associated with executive function. Tangible social support, though, has also been associated with worse performance on measures of executive function (Dickinson et al., 2011, Liao & Scholes, 2017) and longitudinal analyses indicate that high levels of tangible support may be indicative of extra needs resulting from present cognitive impairment (Pillemer et al., 2019). While social support may provide a useful area of intervention for executive function, how this relationship may change in the face of major societal shifts such as COVID-19 is unclear.

Access to and perception of social resources also has likely changed as a result of the COVID-19 pandemic and related restrictions. Adults with lower levels of perceived social support (measured using the 10-item Social Provisions Scale [SPS-10]; Caron, 2013) had lower levels of self-reported perceived resilience (e.g., "I tend to bounce back after illness, injury, or other hardships."; Liu et al., 2025) as well as greater scores on measures of depressive symptoms during the pandemic (Ju, Kim & Lee, 2023). Recent findings from the CLSA indicate there was an increase in reported loneliness during the COVID-19 pandemic, with those with higher social support pre-COVID-19 experiencing lower levels of loneliness during the pandemic (Oremus et al., 2025). Concerningly, these wide-spread variations in social support appear to have had an impact on the cognitive health of older adults. In their systematic review, Prommas et al. (2023) identified that over half of older adults living with dementia and about a quarter of cognitively healthy older adults experienced worsened cognitive impairment associated with social isolation due to the COVID-19 pandemic.

While *Study 2* (Chapter 5) of this dissertation did not find a statistically significant relationship between social support and executive function for the current longitudinal CLSA sample, the testing changes (e.g., moving from in-person testing to telephone assessments) and major societal upheaval resulting from COVID-19 and the related restrictions that impacted both cognitive function and perceptions of social support may have altered the association between these variables as well. The CLSA provides a unique opportunity to explore how a change in testing protocol and conditions may impact both performance on tests of executive function as well as the relationship between potential risk factors and executive function. In order to explore how the COVID-19 pandemic may have altered our current understanding of this relationship, this study investigated how the association between: 1) low overall functional social support and 2) low functional social support subtypes and low executive function differed for participants who completed their assessments pre- vs post-COVID-19 restrictions.

Methods

Sample

Analyses utilized the first (T1; 2012-2015) and third wave (T3; 2018-2021) of the Comprehensive cohort (n=30,097 at baseline) of the CLSA, a prospective, ongoing cohort study of community-dwelling adults between the ages of 45 and 85 at time of recruitment

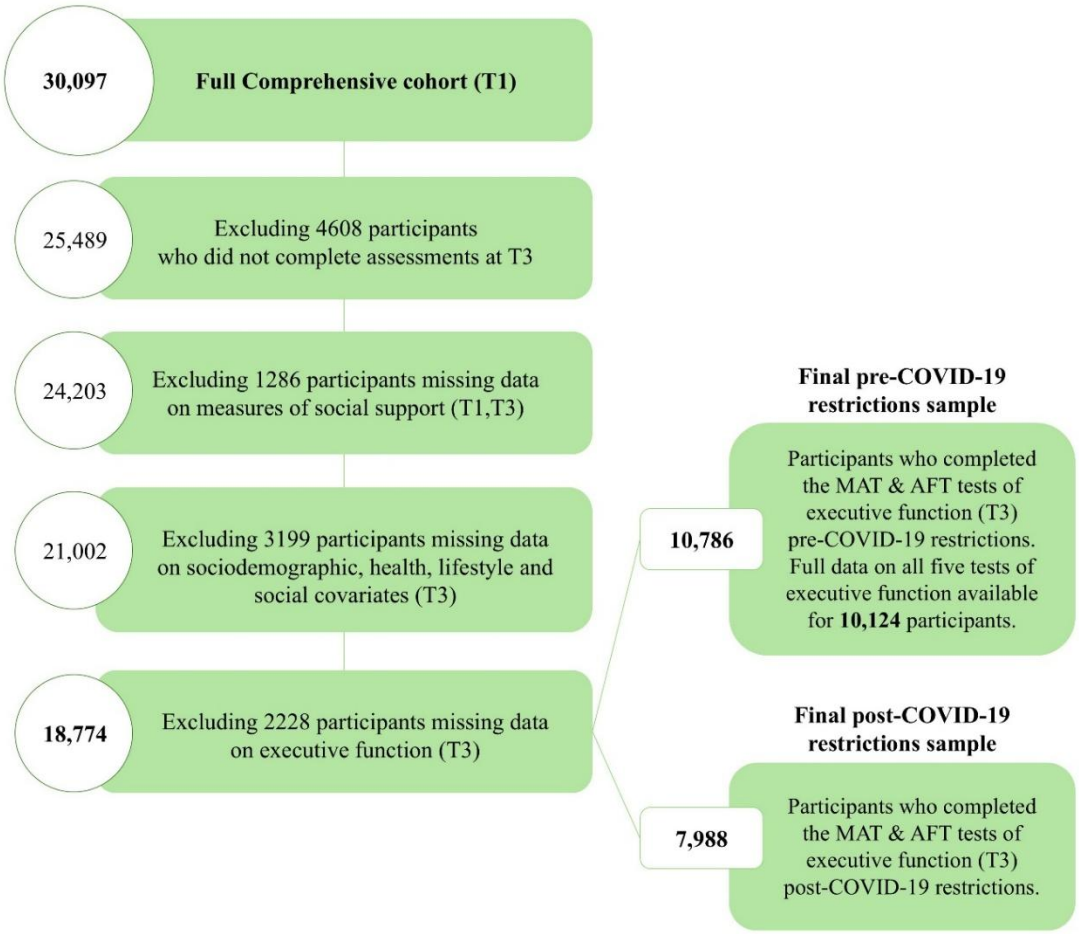
(Raina et al., 2019). Participants in the CLSA were recruited into the Tracking cohort (n=21,241), where data were collected using phone calls, and the Comprehensive cohort (n=30,097), in which participants living within 25-50 km of 1 of 11 data collection sites across seven provinces were assessed in person. Individuals living in the three Canadian territories, on federal First Nations reserves, or in institutions; who were full-time members of the Canadian Armed Forces; or who interviewers perceived to have overt cognitive impairment were excluded by the CLSA at recruitment.

Data collection for the third wave (T3) of the CLSA occurred both pre- and post-implementation of COVID-19-related restrictions in Canada. Prior to March 16, 2020, participants in the Comprehensive cohort of the CLSA completed in-person interviews both at home as well as at their assigned data collection site. After March 16, 2020, the data collection protocols were updated to reflect both the overall increased risk of illness for the aging CLSA participants as well as public health restriction measures implemented by federal and provincial governments. This required data collection to move to telephone interviews, similar to those conducted in the CLSA's Tracking cohort (CLSA, 2024).

This change in data collection method had a profound impact on the testing of executive function in particular, with only two tests of executive function in the CLSA being measurable using phone interviews (i.e., the Animal Fluency Test [AFT; Crossley et al., 1997] and the Mental Alternation Test [MAT; Teng, 1995; Billick et al., 2001]), compared to the five executive function tests that were previously conducted in person (i.e., AFT; MAT; the Controlled Oral Word Association Test [COWAT; Benton & Hamsher, 1978]; Time-based Prospective Memory Test [TMT; Loewenstein & Acevedo, 2004] and Victoria Stroop Neurological Screening Test [Stroop; Spreen & Strauss, 1998; Strauss et al., 2006; Troyer et al., 2006; Bayard et al., 2009; Moroni & Bayard, 2009; Bayard et al., 2011]). O'Connell et al. (in preparation) found that the covariances between the tests measuring memory and executive function were different for the in-person and telephone-administered tests even after equating them using appropriately normed scores (i.e., telephone tests used telephone normative comparison standards). Given the alteration in both the number of tests and the environmental conditions in which these assessments were conducted, it was deemed inappropriate to combine those who completed their assessments pre- and post-implementation of the COVID-19 protocol (Falck et al., 2025).

As such, three main samples were created, with a visual description provided in **Figure 4**. Nearly 25,500 participants from the Comprehensive cohort were included at follow-up 2 (T3). To exclude those missing data on tests of executive function, the sample was divided into those who completed their interviews and cognitive assessments at data collection sites pre-COVID-19 restrictions (n=10,786), and post-COVID-19 restrictions (n=7,988). Participants who were missing data on their tests of executive function were excluded (n= 2,228). Of the pre-COVID-19 group, 10,124 participants (94%) had data available for all five tests of executive function assessed in person, which formed a comparison group used in the supplemental analyses to look at differences in the association between low functional social support and low executive function when executive function was assessed using two vs five tests. Longitudinal samples were created for both those who participated pre-COVID-19 and post-COVID-19. These samples excluded those with low executive function at baseline (T1), leaving 8714 participants in the pre-COVID-19 restrictions sample, and 6564 participants in the post-COVID-19 restrictions sample.

Figure 4. The creation of the analytic samples for the Chapter 6 cross-sectional and longitudinal samples analyses, with T3 analyses split by pre- and post-COVID-19 restrictions in the Canadian Longitudinal Study on Aging



Measures

Exposure of interest

Functional social support (T1, T3) was assessed using the 19-item Medical Outcomes Study-Social Support Survey (MOS-SSS) (Sherbourne & Stewart, 1991; RAND, n.d.). Items on the MOS-SSS are rated on a 5-point scale from 1 (none of the time) to 5 (all of the time), with a higher score indicating higher levels of social support. The MOS-SSS includes questions assessing four subtypes of support: emotional/informational support, tangible support, affectionate support, and positive social interactions. For overall social support and each subtype, scores on each relevant item were combined to produce an average score out of five. In order to maximize the sample for investigation into attrition, individuals were allowed to miss one of the 19 items, with the remaining 18 items used to calculate the

average overall social support score. This was not completed for the subtypes of social support given the limited number of variables available to calculate each subtype. A dichotomous cut-off of ≤ 3 out of 5 was used to distinguish those with low levels of support for overall SSA and each subtype.

Outcome: Executive function

An overall score of five tests of executive function was calculated by averaging the standardized z-scores on the Animal Fluency Test (AFT [version 2]), the Mental Alternation Test (MAT), Controlled Oral Word Association Test (COWAT), Time-based Prospective Memory Test (TMT), and the Victoria Stroop Neurological Screening Test (Stroop) completed at T3. To accommodate changes post-COVID-19 restrictions, an additional measure of executive function was calculated averaging the standardized scores on only the AFT and the MAT for both those who completed their tests pre- and post-COVID-19 restrictions. Pre-COVID-19, the AFT and the MAT were assessed in person, while post-COVID-19 restrictions, these tests were collected over the phone. Scores were standardized within each test using z-scores and calculated separately for English and French speakers, with bilingual responses excluded (Tuokko et al., 2017). Some tests were modified for use in the CLSA (e.g., the Stroop test was streamlined to exclude errors in interference scores due to skew in the data resulting from many participants having no errors; O'Connell et al., 2023; Tuokko et al., 2017; CLSA, n.d. [Technical document #1122]). Low executive function (T3) was defined using a cut-off of ≥1.5 SD below the mean of a neurologically healthy sample that excluded those who reported being diagnosed with Alzheimer's disease, memory problems, epilepsy, stroke or cerebrovascular accident, multiple sclerosis, Parkinson disease, or ministroke or transient ischemic attack at any time point (Petersen et al., 1997; O'Connell et al., 2017). Additionally, those who had a positive screen for a traumatic brain injury and reported two or more concussions or any symptoms of a concussion at any time point were removed (O'Connell et al., 2017; Bedard et al., 2018). The generated cut-off was then applied to the analytical sample to create a two-level variable: low versus normal executive function. Tests of executive function were standardized to participants within their same sample (i.e., pre-COVID-19 restrictions and post-COVID-19 restrictions) before being averaged for the overall executive function score to account for testing differences (i.e., pre-

COVID-19 tests were completed in person, post-COVID-19 tests were completed via telephone interview).

Covariates

Potential *confounders* (T3) included sociodemographic variables (i.e., age group, sex, education, annual household income, province of residence), measures of health and lifestyle (i.e., self-reported clinical depression, number of chronic conditions, self-rated health, alcohol use) and additional social measures (i.e., marital status, living alone and loneliness). Follow-up 2 (T3) confounders were utilized in cross-sectional and longitudinal analyses to reflect potential changes in relevant characteristics which may have been impacted by the COVID-19 restrictions.

Analyses

All analyses were conducted using SAS Studio Enterprise Edition 3.6 (SAS Institute Inc., Cary, North Carolina). Univariate and bivariate analyses (Pearson chi-square tests with a significance level of $p<0.05$) were conducted to describe the samples. Multiple logistic regression models were used to estimate the odds ratio (OR, 95% confidence intervals [CI]) of the association between: 1) overall functional social support (T3) and low executive function (T3) and 2) the subtypes of social support (T3) and executive function (T3), pre- and post-COVID-19 restrictions. Crude models (i.e., including only social support and low executive function) were run first, with covariates being entered in themed chunks (i.e., sociodemographic, health and lifestyle, and remaining social variables) for further models. Final models included social support, age group, sex, educational attainment, annual household income, province of residence, clinical depression, number of chronic conditions, self-rated health, alcohol use, marital status, whether participants lived alone, and loneliness.

Further supplemental analyses assessed the longitudinal association between baseline social support (T1) and executive function (T3), both pre- and post-COVID-19 restrictions to explore if COVID-19 restrictions and the related protocol changes (i.e., moving from in-person to telephone-based assessments) impacted the relationship between earlier social support on executive function. To capture incident cases of low executive function, these samples further excluded those who had low executive function at baseline, resulting in 8,714 participants pre-COVID-19 and 6,564 post-COVID-19 restrictions.

Additional supplemental analyses were conducted to examine whether the number of tests (two vs five) used to calculate low executive function in the pre-COVID-19 (in-person) sample impacted the association between low social support and low executive function. Of the 10,786 participants with scores on the MAT and AFT tests of executive function pre-COVID-19, 10,124 (94%) also had data available on the remaining three tests of executive function (i.e., Stroop, COWAT, TMT).

Results

Descriptive results

A description of the pre- and post-COVID-19 restriction cohorts stratified by the presence of low executive function (limited to participants who completed the AFT and MAT) are included in **Table 8** and **Table 9**. Looking at those who completed their assessment in person pre-COVID-19 restrictions, 92% (n=9897) had normal executive function while 8.2% (n=889) had low executive function. This ratio was similar for the sample of those who were assessed via telephone interviews post-COVID-19 restrictions, with 93% of the sample having normal executive function (n=7373) and 7% (n=615) having low executive function. There were statistically significant differences in the frequency of low social support by low executive function for both the pre-COVID-19 and post-COVID-19 restriction samples for overall social support and all subtypes, with those with lower social support being more likely to have low executive function (**Table 8**).

Table 8. The association between overall and subtypes of functional social support in the pre- and post-COVID-19 restriction samples, stratified by low executive function, in the Canadian Longitudinal Study on Aging

	Pre-COVID-19[a] restrictions sample (n=10,786)		Post-COVID-19[a] restrictions sample (n=7988)	
	Executive function		**Executive function**	
	Low n=889 n (%)	Normal n=9897 n (%)	Low n=615 n (%)	Normal n=7373 n (%)
Functional social support				
Overall social support				
Low	13.93	86.07***	17.25	82.75***
High	7.96	92.04	7.20	92.80
Positive social interactions				
Low	13.41	86.59***	14.18	85.82***
High	7.81	92.19	7.09	92.91
Emotional/informational support				
Low	14.98	85.02***	14.94	85.06***
High	7.70	92.30	7.21	92.79
Tangible support				
Low	11.58	88.42***	11.91	88.09***
High	7.93	92.07	7.31	92.69
Affectionate support				
Low	12.95	87.05***	13.43	86.57***
High	7.89	92.11	7.21	92.79

*p < .05; **p < .01; ***p < .001

[a] Executive function was assessed using the AFT and MAT for both the pre- and post-COVID-19 restriction samples. Assessments were completed in person pre-COVID-19 and via telephone interviews post-COVID-19 restrictions.

For both the pre- and post-COVID-19 restriction samples, there were consistent findings regarding statistically significant associations between various participant characteristics and low executive function (**Table 9**). Low executive function was more prevalent among older age groups and those with lower educational attainment, the lowest or highest incomes, more chronic conditions (and those with missing data for this item), poorer self-rated health and non-users of alcohol. In terms of additional social variables, low executive function was more common in those who lived alone or reported experiencing loneliness. Finally, those who were widowed had the highest frequencies of low executive function across marital status groups.

Table 9. The distribution of baseline (T1) sociodemographic, health, lifestyle, and social characteristics stratified by low executive function (T1) for those who participated pre- and post-COVID-19 restrictions in the Canadian Longitudinal Study on Aging

	Pre-COVID-19 restrictions			Post-COVID-19 restrictions		
	Executive function [a]			Executive function [a]		
	Low n=889 (%)	Normal n=9897 (%)	% of sample (n=10,786)	Low n=615 (%)	Normal n=7373 (%)	% of sample (n=7988)
Sociodemographic characteristics (%)						
Age group						
45–54 years	1.68	98.32***	7.17	3.04	96.96***	7.00
55–64 years	2.73	97.27	32.94	2.33	97.67	34.43
65–74 years	6.16	93.84	34.74	5.89	94.11	33.59
75 years and over	20.20	79.80	25.15	18.84	81.16	24.99
Sex						
Female	8.78	91.22*	51.44	8.36	91.64*	47.77
Male	7.67	92.33	48.56	7.09	92.91	52.23
Education						
Less than high school	30.09	69.91***	4.01	27.95	72.05***	3.72
High school graduate	12.00	88.00	9.27	13.41	86.59	8.40
Some post-secondary	9.74	90.26	6.38	9.03	90.97	7.49
Post-secondary degree/diploma	6.60	93.49	80.34	6.04	93.96	80.40
Annual household income						
< $20k	19.48	80.52***	3.57	17.67	82.33***	3.12
≥ $20k and < $50k	14.03	85.97	18.31	13.71	86.29	17.35
≥ $50k and < $100k	7.59	92.41	35.66	6.89	93.11	33.44
≥ $100k and < $150k	3.56	96.44	36.21	3.19	96.81	39.60
≥ $150k	15.73	84.27	6.25	18.50	81.50	6.50
Province						
Ontario	8.80	91.20	20.24	7.23	92.77	23.37
Alberta	8.53	91.47	10.22	7.45	92.55	9.58
British Columbia	6.65	93.35	20.76	6.81	93.19	23.34
Manitoba	8.03	91.97	10.97	8.46	91.54	6.36
Newfoundland and Labrador	7.74	92.26	7.79	10.37	89.63	6.40
Nova Scotia	9.53	90.47	10.61	7.54	92.46	10.47
Quebec	8.83	91.17	19.42	8.37	91.63	20.49
Health and lifestyle characteristics (%)						
Clinical depression						

	Pre-COVID-19 restrictions			Post-COVID-19 restrictions		
	Executive function [a]			Executive function [a]		
	Low n=889 (%)	Normal n=9897 (%)	% of sample (n=10,786)	Low n=615 (%)	Normal n=7373 (%)	% of sample (n=7988)
Yes	9.58	90.42	8.33	8.84	91.16	9.49
No	8.12	91.88	91.67	7.58	92.42	90.51
Number of chronic conditions						
0	4.74	95.26***	18.38	4.29	95.71***	19.25
1	5.93	94.07	23.29	5.92	94.08	21.80
2	8.47	91.53	14.78	5.83	94.17	14.61
3+	11.00	89.00	12.65	11.88	88.12	14.33
Missing	10.83	89.17	30.90	10.10	89.90	30.01
Self-rated health						
Poor	17.42	82.58***	1.22	20.14	79.86***	1.80
Fair	15.84	84.16	7.84	12.93	87.07	8.81
Good	10.10	89.90	29.28	9.36	90.64	30.22
Very good	6.77	93.23	42.32	5.97	94.03	40.91
Excellent	4.99	95.01	19.33	5.08	94.92	18.25
Alcohol use						
Non-user	14.20	85.80***	13.05	13.06	86.94***	14.86
Occasional user (<1/month)	11.96	88.04	10.77	10.89	89.11	10.80
Regular user (≥1/month)	6.69	93.31	76.17	6.16	93.84	74.34
Social characteristics (%)						
Marital status						
Married/common-law	6.78	93.22***	71.19	6.45	93.55***	69.33
Single	6.25	93.75	7.27	7.76	92.24	8.39
Widowed	19.89	80.11	10.16	16.50	83.50	10.09
Divorced	9.06	90.94	8.90	8.83	91.17	9.21
Separated	5.24	94.76	2.48	3.36	96.64	2.98
Living alone						
Yes	12.61	87.39***	22.57	11.31	88.69***	23.02
No	6.97	93.03	77.43	6.62	93.38	76.98
Lonely						
Yes	12.31	87.69***	20.49	10.13	89.87***	23.22
No	7.19	92.81	79.51	6.96	93.04	76.78

*p < .05; **p < .01; ***p < .001

[a] Executive function was assessed using the AFT and MAT for both the pre- and post-COVID-19 restriction samples. Assessments were completed in person pre-COVID-19 and via telephone interviews post-COVID-19 restrictions

Multivariable association between functional social support and executive function

Objective 1: Overall functional social support and executive function, pre- vs post-COVID-19 restrictions

Results for whether the cross-sectional association between functional social support and executive function varied in those who were assessed pre- vs post-COVID-19 restrictions are included in **Table 10** (Objective 1: overall social support) and **Table 11** (Objective 2: subtypes of social support). Stepwise models for overall social support are available in **Appendix E: Table E1** and **Table E2** (pre- and post-COVID restrictions, respectively). The crude association between low social support and low executive function was significant for those who completed their tests in person pre-COVID-19 restrictions (OR = 1.87, 95% CI = 1.45-2.43) and for those who were assessed over telephone post-COVID-19 restrictions (OR = 2.69, 95% CI = 2.05-3.54). After accounting for sociodemographic, health, lifestyle, and social variables, social support did not have a statistically significant association with executive function pre-COVID-19 restrictions (OR = 1.18, 95% CI = 0.89-1.57); however, this association was statistically significant among the post-COVID-19 restrictions sample (OR = 1.61, 95% CI = 1.17-2.20; **Table 10**). An opposite effect was seen for loneliness, which was significantly associated with low executive function pre-COVID-19 (OR = 1.37, 95% CI = 1.16-1.62), but not post-COVID-19 restrictions (OR = 1.07, 95% CI = 0.87-1.31). Other characteristics significantly associated with low executive function included being over the age of 65 and having lower educational attainment. In the sample of participants who were assessed post-COVID-19 restrictions, a greater number of, or missing values for, chronic conditions was also significantly associated with low executive function.

Table 10. The cross-sectional (T3) association between low functional social support and low executive function in those tested pre- vs post-COVID-19 restrictions in the Canadian Longitudinal Study on Aging

	Pre-COVID-19 restrictions (n=10,786)	Post-COVID-19 restrictions (n=7988)
	Executive function (T3) [a] (Low vs normal)	**Executive function (T3) [a] (Low vs normal)**
Exposures (T3)	OR (95% CI)	OR (95% CI)
Social support (low vs high)	1.18 (0.89-1.57)	**1.61 (1.17-2.20)**
Over 65 (vs 45–64 years)	**3.84 (3.10-4.77)**	**3.51 (2.73-4.51)**
Female (vs male)	0.94 (0.81-1.10)	0.91 (0.76-1.10)
Education (vs post-secondary degree/diploma)		
Some post-secondary	1.21 (0.92-1.60)	1.25 (0.92-1.71)
High school graduate	**1.55 (1.24-1.93)**	**1.72 (1.33-2.23)**
Less than high school	**3.30 (2.58-4.21)**	**3.36 (2.49-4.54)**
Annual household income (vs < $20,000)		
≥ $20,000 and < $50,000	0.76 (0.56-1.04)	0.89 (0.60-1.32)
≥ $50,000 and < $100,000	**0.54 (0.39-0.75)**	**0.56 (0.37-0.85)**
≥ $100,000	**0.38 (0.27-0.55)**	**0.38 (0.24-0.61)**
Missing	1.06 (0.73-1.53)	1.47 (0.94-2.30)
Province (vs Ontario)		
Alberta	0.99 (0.75-1.29)	1.04 (0.74-1.46)
British Columbia	0.74 (0.58-0.93)	1.04 (0.80-1.36)
Manitoba	0.80 (0.61-1.06)	0.98 (0.67-1.44)
Newfoundland and Labrador	0.94 (0.69-1.27)	**1.55 (1.09-2.21)**
Nova Scotia	0.99 (0.77-1.29)	1.10 (0.79-1.53)
Quebec	0.84 (0.67-1.06)	0.91 (0.69-1.19)
Chronic condition (vs no conditions)		
1 condition	0.93 (0.71-1.23)	1.05 (0.75-1.45)
2 conditions	1.14 (0.86-1.51)	0.86 (0.60-1.24)
3+ conditions	1.15 (0.87-1.53)	**1.51 (1.09-2.10)**
Missing	1.25 (0.97-1.61)	**1.37 (1.01-1.86)**
Clinical depression (vs no)	0.93 (0.72-1.21)	0.90 (0.67-1.21)
Good or greater self-rated health (vs poor/fair)	**0.66 (0.53-0.81)**	**0.75 (0.59-0.95)**
Alcohol consumption in last year (vs non-user)		
Occasional user (<once per month)	0.83 (0.65-1.06)	0.85 (0.64-1.13)
Regular user (≥once per month)	**0.63 (0.52-0.76)**	**0.65 (0.52-0.80)**
*Marital status (*married/common-law vs not*)*	1.02 (0.77-1.33)	1.08 (0.80-1.47)
Lonely (vs not lonely)	**1.37 (1.16-1.62)**	1.07 (0.87-1.31)
Living alone (vs not living alone)	1.03 (0.78-1.35)	0.99 (0.73-1.34)

Significant results are **bolded**.

[a] Executive function was assessed using the AFT & MAT for both pre- (in person) and post-COVID-19 restriction (via telephone) samples.

Objective 2: Functional social support subtypes and executive function, pre- vs post-COVID-19 restrictions

Looking at subtypes of functional social support, low scores on all subtypes were significantly associated with low executive function in crude models pre-COVID-19: emotional/informational support (OR = 2.11, 95% CI = 1.72-2.60), positive social interactions (OR = 1.83, 95% CI = 1.48-2.26), affectionate support (OR = 1.84, 95% CI = 1.46-2.32) and tangible support (OR = 1.52, 95% CI = 1.23-1.88). The crude association between low social support and low executive function was also significant for all subtypes of social support for those assessed post-COVID-19 restrictions: emotional/informational support (OR = 2.26, 95% CI = 1.74-2.93), positive social interactions (OR = 2.17, 95% CI = 1.72-2.73), affectionate support (OR = 2.00, 95% CI = 1.56-2.55) and tangible support (OR = 1.72, 95% CI = 1.34-2.20).

After adjusting for sociodemographic, health, lifestyle and additional social variables only emotional/informational social support was significantly associated with executive function pre-COVID-19 (OR = 1.38, 95% CI = 1.10-1.73; **Table 11**). Full final models (which include output for all covariates) for the subtypes of social support are included in **Appendix E.2**, **Table E3** (pre-COVID-19 restrictions) and **Table E4** (post-COVID-19 restrictions). In contrast, post-COVID-19 restrictions, low positive social interactions (OR = 1.43, 95% CI = 1.09-1.87) and affectionate social support (OR = 1.38, 95% CI = 1.04-1.83) were significantly associated with low executive function. Post-COVID restrictions, the association between low emotional/informational and low executive function also remained statistically significant (OR = 1.41, 95% CI = 1.05-1.89).

Table 11. The cross-sectional (T3) association between low functional social support subtypes and low executive function in those tested pre- vs post-COVID-19 restrictions in the Canadian Longitudinal Study on Aging

	Executive function (T3) [a] (Low vs normal)			
	Positive social interactions OR (95% CI)	Emotional/ informational OR (95% CI)	Tangible OR (95% CI)	Affectionate OR (95% CI)
Pre-COVID-19 restrictions				
Two tests of executive function (MAT & AFT)				
Social support (Low vs high)	1.16 (0.91-1.47)	**1.38 (1.10-1.73)**	0.98 (0.77-1.24)	1.09 (0.85-1.41)
Post-COVID-19 Restrictions				
Two tests of executive function (MAT & AFT)				
Social support (Low vs high)	**1.43 (1.09-1.87)**	**1.41 (1.05-1.89)**	1.14 (0.86-1.51)	**1.38 (1.04-1.83)**

Significant results are **bolded**.
Final models include social support, age, sex, education, annual household income, province, chronic conditions, clinical depression, self-rated health, alcohol consumption, marital status, loneliness, living alone.
[a] Executive function was assessed using the AFT and MAT for both the pre- and post-COVID-19 restriction samples. Assessments were completed in person pre-COVID-19 and via telephone interviews post-COVID-19 restrictions

Supplementary analyses

Several supplementary analyses were conducted. First, additional analyses were conducted to compare the association between social support and executive function pre-COVID-19 (i.e., all tests administered in person) when overall combined executive function was calculated using two tests (i.e., MAT and AFT; n=10,786) vs when this sample was restricted to those who had all five available tests of executive function (i.e., MAT, AFT, STROOP, COWAT, and TMT; n=10,124). No statistically significant differences were found in the pre-COVID-19 cross-sectional association between functional social support and executive function, regardless of the number of tests used to calculate executive function (**Appendix E.3; Table E5 and Table E6**), indicating that the number of tests used to calculate executive function did not impact the association in this context.

The results of *Study 2* indicated that there is not a longitudinal association between overall functional social support and executive function in the pre-COVID-19 sample. An

exploration of whether the longitudinal relationship between social support and executive function may differ for those who completed their tests of executive function pre- vs post-COVID-19 restrictions is included in **Appendix E.4**. Results for the longitudinal association between functional social support at baseline (T1) and executive function, pre- and post-COVID-19 restrictions (T3) are included in **Table E7**. The longitudinal association between social support (overall and subtypes) and executive function was not statistically significant for those who participated pre- or post-COVID-19 restrictions after adjusting for all sociodemographic, health, lifestyle and additional social variables.

Discussion

The second follow-up (T3; 2018-2021) of the CLSA was disrupted by the COVID-19 pandemic. While participants prior to March 16, 2020 were tested in person, those who participated in the second follow-up after this date completed their assessments via telephone interviews. In addition to any changes in social resources and cognitive health resulting from the societal disruptions of the COVID-19 pandemic, the CLSA's necessary protocol changes led to major differences in testing conditions which may have impacted the measurement of cognitive domains, such as executive function. To investigate whether the association between functional social support and executive function may differ for those tested prior to vs after the COVID-19 restrictions, this study explored: 1) the cross-sectional (T3) association between low social support and low executive function, both in those who were tested pre-COVID-19 vs post-COVID-19 restrictions, and 2) whether this association varied across subtypes of functional social support (i.e., emotional/informational support, affectionate support, positive social interactions, and tangible support) and executive function.

The cross-sectional association between functional social support and executive function varied between those who completed their assessments pre-COVID-19 in person and those who participated during post-COVID-19 protocol changes and completed a reduced number of cognitive assessments by phone. Objective 1 analyses demonstrated that there was no statistically significant association between social support and executive function pre-COVID-19. Yet, this association was statistically significant for those tested during the COVID-19 pandemic, with those with low social support having greater odds of low executive function. When further divided into subtypes of functional social support for

objective 2, only emotional/informational support was statistically significantly associated with executive function pre-COVID-19. In contrast, for those assessed after the COVID-19 restrictions, low emotional/informational support, affectionate support, and positive social interactions were all significantly associated with low executive function. While the exact explanation for this discrepancy pre- and post-COVID-19 restrictions is not clear (e.g., differences testing in person vs by phone, cognitive and social changes in response to the COVID-19 pandemic), these results indicate that the relationship between social support and executive function appears to have varied pre- and post-COVID-19 restrictions.

That the relationship between social support and executive function appears to be stronger following the start of the COVID-19 pandemic is not unexpected. Despite the overall robust health of the retained CLSA sample, executive function scores were lower for those tested post-COVID-19 restrictions compared to those tested pre-COVID-19 (Falck et al, 2025). This suggests that the greater pandemic experience may have had an impact on the cognitive health of the Canadian population in mid- to late-life, leaving space for social support as an area of intervention. Changes in the environment and routines resulting from COVID-19 and related restrictions may have put pressure on normal social resources, leading to an increase in overall loneliness in this population (Oremus et al., 2025). While higher levels of functional social support may have offered some protection (Oremus et al., 2025), participants in the CLSA may have required more support than during normal circumstances. Given the literature suggests that both social support and cognitive function appear to have been impacted by the pandemic, it makes sense that the relationship between these variables would also change.

The association between social support and executive function pre- and post-COVID-19 restrictions further varied across functional social support subtypes. Only the emotional/informational subtype of support was significantly associated with low executive function pre-COVID-19 restrictions. Emotional/informational social support (e.g., having someone you can turn to for advice when needed) is one of the most commonly researched subtypes and the subtype most consistently associated with cognitive function (e.g., Zahodne et al., 2014; Frith & Loprinzi, 2017; La Fleur & Salthouse, 2017; Rutter et al., 2024; Zahodne et al., 2021). Post-COVID-19 restrictions, emotional/informational support, positive social interactions, and affectionate support were significantly associated with executive function.

As such, emotional/informational and tangible support were the only subtypes that did not differ pre- vs post-COVID-19 restrictions. The association between tangible support and cognitive function appears to be more complicated than the other subtypes, with longitudinal analyses indicating that high levels of tangible support may actually be associated with the development of cognitive impairment and that reporting high tangible support may indicate that one is already in need of those resources (Pillemer et al., 2019). The relationship between social support and executive function is likely bidirectional, with higher tangible support over time being a marker of greater need and possibly poorer functional and cognitive health.

A major limitation of this study is that it cannot confirm whether the variation in the association between social support and executive function is a result of testing differences pre- vs post-COVID-19 restrictions or if they represent consequential changes in the association caused by living through the initial waves of the COVID-19 pandemic. It is unclear from this sample whether the decline in overall executive function (e.g., Falck et al, 2025) represents clinically meaningful changes in cognitive function during the COVID-19 pandemic, or whether the altered testing conditions resulting from COVID-19 restrictions (i.e., assessments collected over the phone vs in person) explain the discrepancy. Up until the COVID-19-related protocol alterations, participants in the Comprehensive cohort of the CLSA had completed all testing in person and may have not had the same benefits of the lab environment when the protocol changed and they completed their testing over the phone. Some evidence that testing conditions do not fully explain the change in cognitive performance comes from Falck et al. (2025) who utilized the CLSA's Tracking cohort (in which participants completed their assessments over the phone both pre- and post-COVID-19 restrictions) and found that executive function scores were lower after the start of the COVID-19 pandemic.

The COVID-19 pandemic will have an impact on longitudinal data for the foreseeable future. While essential, the protocol changes resulting from the COVID-19 pandemic altered testing conditions and how participants in the Comprehensive cohort of the CLSA experienced their assessments, moving from a lab environment to the home. Beyond the effects of the pandemic itself, this raises concerns about how these data should be considered as part of overall longitudinal analyses completed using future waves of data. If COVID-19-

era data are used in analyses of cognitive trajectories, for example, it could cloud interpretations of findings (e.g., dramatic drops in cognitive function) that resulted from testing changes as well as cognitive changes in this population. However, if the post-COVID-19 restriction data are excluded from future longitudinal analyses, a large part of the sample will be lost, as will meaningful information on how cognitive function is impacted at a population level during times of societal upheaval. The long-term effects of the pandemic may also lead to changes in cognitive function in future waves of assessment, the analyses of which would benefit from including follow-up 2 (T3) data. The decision on how to include data collected during the COVID-19 pandemic is not limited to this area of research and will have to be carefully considered for all future longitudinal studies.

Future analyses can build on the limitations of this study in several ways. First, participants in the CLSA's Comprehensive cohort were recruited from within limited geographic areas (i.e., within 25 to 50 km of 11 data collection sites across seven provinces), with approximately 10% of Canadians who were contacted to participate in the CLSA agreeing to participate (CLSA, n.d.). This self-selection bias likely led to a healthier than average sample which may not reflect the greater Canadian population of community-dwelling adults in mid- to late-life. Given their initially high levels of cognitive function and that those with overt cognitive impairment were excluded at baseline, it may be that those who remained in the study over time had other resources to support their cognitive health and social support was not needed until the COVID-19 pandemic. Research with a more representative (e.g., lower average education and income) sample may produce a more robust relationship between social support and executive function pre- and post-COVID-19 restrictions. While this study's outcome was limited to a single domain of cognitive function, analyses into additional domains (e.g., memory) or clinical outcomes (e.g., dementia) would provide evidence for how functional social support impacts cognitive health over time. Finally, those who participated in follow-up 2 (T3) did not show a significant association between social support and executive function at baseline (T1; see *Study 2*), yet this cross-sectional association became significant by follow-up 2 (T3), including for those tested prior to the COVID-19 pandemic restrictions for emotional/informational support. What caused this shift in the relationship between social support and cognitive function over time is unclear and could result from a variety of factors such as increased age or changes in health.

Future longitudinal analyses with further follow-up waves could determine if this relationship continues to evolve and what factors may be influencing that change.

Conclusion

Functional social support was not significantly associated with executive function for participants who completed their assessments in person pre-COVID-19, but was significant for those who were assessed by phone after the implementation of COVID-19 restrictions. This relationship further differed across subtypes of support. Whether this variation pre/post COVID-19 restrictions was a result of environmental testing changes (i.e., in-person assessment in the lab conditions vs telephone) or if the pandemic experience altered the relationship between social support and this key cognitive domain is unclear. The COVID-19 pandemic will continue to have an undeniable impact on data analyses for the foreseeable future. Data collected during the pandemic hold invaluable information on how our health may have altered during major societal upheaval, yet the necessary resulting protocol changes complicates the use of these data in future longitudinal analyses and studies of cognitive trajectories. Future analyses considering the long-term impact of health exposures such as functional social support on cognitive health should explicitly account for how the COVID-19 pandemic and related restrictions may impact our understanding of this association.

Chapter 7: Discussion

The overall purpose of this dissertation was to investigate the association between social support and executive function in community-dwelling adults in mid- to late-life, and to explore how our understanding of this relationship may be impacted by attrition and other methodological changes. This question was explored through three connected studies. The first study (Chapter 4) investigated: a) whether baseline (T1) social support and executive function were associated with attrition after accounting for potential confounders and b) if the cross-sectional association between social support and executive function varied across those participating at one (T1), two (T1, T2) or three (T1, T2, T3) timepoints. The second study (Chapter 5) built upon these findings by: a) investigating the longitudinal relationship between functional social support (T1) and executive function (T3) while, b) exploring how the role of attrition in the CLSA may impact the results and conclusions. These analyses demonstrated that the longitudinal association between overall social support and executive function was not statistically significant for those participants who had remained in the CLSA for all three timepoints (prior to COVID-19 restrictions). Finally, the third study (Chapter 6) looked deeper at those participants who were retained in the CLSA and how the relationship between social support and executive function might have altered in the face of the major societal upheaval and methodological protocol changes resulting from the COVID-19 pandemic. Specifically, the third study considered how the association between social support and executive function differed pre- vs post-COVID-19 social restrictions and resulting protocol changes (T3).

In *Study 1* (Chapter 4), after accounting for relevant covariates, those with low social support, low executive function, or those missing data on any of the tests of executive function at baseline (T1) were significantly more likely to drop out of the study after baseline (T1) assessment and were significantly less likely to complete all three waves (T1, T2, T3) of the CLSA. When those who were lost to attrition were compared to those who were retained in the study, the cross-sectional association between low social support and low executive function at baseline was statistically significant only for those who were lost to attrition after the baseline assessment, but not for those who were retained. These findings were consistent with literature demonstrating that many health and social variables are associated with attrition in longitudinal studies, and that those who are vulnerable to attrition may have a

stronger relationship between social support and executive function than those who are retained in studies.

In *Study 2* (Chapter 5), no significant longitudinal association was found between social support and executive function in those who were retained for at least three assessments in the CLSA. These findings build on those from Study 1 showing that, in contrast to those lost to attrition, participants who remained in the study did not have a statistically significant association between social support and executive function. This conclusion is in line with the literature which shows a complex and inconsistent longitudinal relationship between social support and executive function. While not the only possible explanation (e.g., there could be variations in social support over time between assessments which are not accounted for), the lack of a statistically significant longitudinal association may reflect a weakening or non-existent relationship between social support and executive function over time, possibly resulting from attrition and the factors associated with attrition in the sample. This appears to be true for some cohorts, including the cognitively healthy sample who have continued to participate in the CLSA.

This work naturally lent itself to the questions addressed in *Study 3* (Chapter 6). Study 1 provided evidence that both low functional social support and low executive function were associated with attrition, potentially leading to a retained sample that was too healthy for social support to have an impact on their cognitive health. Study 2 supported this theory, showing that those who were retained did not have a significant longitudinal association between baseline social support and later executive function. Study 3 provided a unique opportunity to investigate how those who were retained in the study (and who did not have a significant relationship between social support and executive function prior to COVID-19) may see changes in the association between social support and executive function as a result of the pandemic and/or the resulting protocol changes. While social support was not significantly cross-sectionally associated with executive function prior to COVID-19, those tested after the introduction of protocol changes in March 2020 (i.e., those who completed their cognitive assessments over the phone vs in-person) had a significant association. This association varied across subtypes of support.

The results of these studies paint a complicated picture of the association between social support and executive function. The answer to whether there is an association between

these two variables may be: it depends. The results of Study 1 demonstrate that there is a cross-sectional relationship between social support and executive function for some participants (although these analyses cannot account for directionality of the relationship). This is consistent with the bounty of supportive literature showing a strong positive cross-sectional association for both overall social support and subtypes (see: *Social support and cognitive function*). The work completed in Study 2 did not demonstrate a statistically significant longitudinal association between baseline social support and later executive function, which was not surprising given that this particular sample did not have a statistically significant cross-sectional association between these two measures at baseline. These results combined suggest that there may be some selection biases, such that those who may benefit the most from social support are being lost after baseline assessment. This is also supported by the analyses of Study 1 which found that both low social support and low executive function were associated with attrition. One could suggest that this leaves us with a retained sample that is too healthy (at least at T3) to need social support to support their cognitive health, compared to those who have dropped out of the study. Yet, when those healthy retained participants faced a major societal change (and subsequent testing and protocol changes) relating to COVID-19, suddenly the cross-sectional association between social support and executive function became statistically significant (Study 3). Thus, though one might be tempted to claim that social support isn't a significant factor in cognitive health for all persons, given the right circumstances and upheaval of normal resources, social support may be an essential resource to help buffer the effects of stress on the brain (as supported by the stress-buffering hypothesis; see: *Theoretical frameworks*).

Strengths

Strengths to this dissertation included the value of the CLSA to research on aging in Canada. The CLSA provided a unique opportunity to explore a large, community-based, Canadian sample of adults in mid- to late-life, with the second follow-up (T3) being almost perfectly split in half by the start of the COVID-19 pandemic. The CLSA's Comprehensive cohort recruited participants from across Canada and included an additional follow-up sampling of areas with lower levels of educational attainment to capture a more diverse sample (CLSA, 2017). In addition to the generous overall sample size, the CLSA includes a wide variety of variables, and while as secondary users of data, researchers do not have

control over the variables collected, there was enough diversity (and power) available in the CLSA to include many relevant characteristics that have not been investigated within a single study before. Many of these variables were collected at each time point, allowing for comparisons over time. The number of follow-up waves available at analyses (i.e., baseline and two follow-ups) was another strength, as it allowed for a longer follow-up and exploration of attrition across time.

Additionally, the questions addressed in this dissertation naturally connected and built upon each other. This allowed for the exploration of the association between social support and executive function from multiple perspectives (e.g., cross-sectionally, longitudinally, pre- and post-COVID-19 restrictions) while also thoughtfully considering how attrition and sample limitations may influence the results and interpretations. This created a cohesive story which came together clearly for the overall dissertation project.

Limitations and future directions

This study had several limitations, some of which can be addressed in future analyses. These include overall limitations to the sample and analyses, such as the problem of missing data and the availability of alternative methodologies to investigate the longitudinal association between exposures and executive function. In addition, there are study-specific limitations which could be addressed in future work to further this area of research.

Limitations: Analytic methods

The analyses selected for this dissertation were conventional methods utilized in epidemiological research (i.e., logistic regression and modified Poisson regression). This reflects both the theoretical complexity of the questions explored in Studies 1 to 3, as well as the scope of the dissertation. Novel alternative statistical methods for addressing questions about attrition and the impact of longitudinal data are available and may be useful for future analyses. In their paper on how attrition clouds our understanding of the association between sex/gender and cognitive decline, Rouanet et al. (2022) used eight longitudinal studies to explore two different statistical approaches: 1) population models (weighted and unweighted generalized estimating equations [GEE]) and 2) subject-specific models (joint or linear mixed models fitted by likelihood maximization), which they also refer to as population estimands vs subject-specific estimands. Weighted GEE models appear to model steeper declines in cognitive function than unweighted models as they were overweighted to account

for those lost to attrition and those who were more likely to be lost due to lower cognitive function. The conclusions made by the reviewed studies varied depending on the rates of attrition in each specific study (Rouanet et al., 2022). The paper suggests that subject-specific models are better for longitudinal analyses of differences in sex/gender and when attrition is not random, as the weighted and unweighted GEE models may become biased by attrition over time (Rouanet et al., 2022). Future work looking at the association between social support and executive function, particularly when stratified by sex/gender, would likely benefit from this approach.

Additional statistical methods also exist for accounting for survival bias, which can reasonably be expected to have impacted the longitudinal analyses described in Study 2, despite the overall good health of the participants in the CLSA. Joint models can be used to explore attrition in studies of cognitive function (Stuckwisch et al., 2025). For exposures which may be associated with non-random attrition (e.g., smoking status), there can be biases in the longitudinal sample which violate the assumptions of some analyses (e.g., maximum likelihood) and other methods may be a better fit (e.g., joint longitudinal-survival, inverse probability weights; Stuckwisch et al., 2025). Again, Stuckwisch et al.'s preferred and recommended model (joint longitudinal-survival model) generated a steeper decline than the linear mixed model given its ability to account for attrition biases in the sample over time (Stuckwisch et al., 2025). Whether these conclusions would extend to social support as an exposure is unknown, but consideration should be given to identifying the best models for exploring differing aspects of the association between social support and executive function.

Reverse causality is a concern in studies of cognitive function, and it is likely that there is a reciprocal relationship between social support and executive function. Longitudinal analyses in this dissertation accounted for this in part by excluding anyone with low executive function at baseline, which can cause sample bias (Study 2; Banack et al., 2019). Banack et al. (2019) utilized an alternative method, starting with generalized linear models with a log link to get adjusted rate ratios and comparing them to marginal structural models (which account for time-varying confounding that accommodates previous exposures) that accounted for attrition using inverse probability of censoring weights. These models do not require the exclusion of those with the exposure at baseline or the removal of early deaths in the sample (Banack et al., 2019), which could help to increase sample size in longitudinal

analyses incorporating later waves of the CLSA. This method may be useful in future analyses as a way to examine the association between social support and executive function, as well as other health exposures which have a bidirectional relationship with cognitive health (e.g., depression).

Finally, some of the included variables identified as confounders may in fact be better characterized as mediators. Based on the literature review, these may include the role of marital status and depression, but could also include less explored variables, such as the presence of chronic conditions. Future research would benefit from investigating the specific roles of these variables (e.g., depression) in the association between social support and executive function.

Limitations: Study 1

Each study included in this dissertation provided additional guidance for future analyses. In Study 1 (determining if baseline social support and executive function were associated with attrition after accounting for potential confounders), information was not available on what reason participants had for no longer participating in the study. It is likely that those data would have helped to reveal patterns of attrition and would have allowed for an exploration of whether social support and executive function were associated with specific attrition outcomes (e.g., refusal vs loss due to declining health or death). It's possible, for example, that the loss of participants who were not included in the study due to a lack of contact may not bias estimates as greatly as those lost to causes such as mortality (e.g., Powers et al., 2015). If the CLSA has access to these data, future analyses can explore in more depth the relationship between social support, executive function, and different causes of attrition, which would help to identify whether the association between these variables varies depending on cause of attrition.

The second objective of Study 1 explored whether there were differences in the association between social support and executive function for those who were lost to attrition after baseline assessment compared to those who participated in further waves of data collection. Results indicated that the association was only statistically significant for those who were lost from the study after baseline assessment. The baseline-only sample was older, had poorer health and had greater odds of both low social support and low executive function. If these participants had been retained long-term, the longitudinal association

between social support and executive function would have likely looked different in Study 2. While the CLSA sample is limited (at baseline) to only those living in the community, future work in clinical or long-term care settings would perhaps be able to better capture this population over time and provide invaluable information on the role of social support amongst more vulnerable members of the aging population.

Limitations: Study 2

Study 2 looked at the longitudinal relationship between baseline social support and later executive function. In addition to the overall limitation that longitudinal analyses could only include those who were retained in the study (and not those who had a significant cross-sectional association at baseline), this sample was dramatically reduced as it was necessary to limit only to those who completed their follow-up 2 (T3) assessments pre-COVID-19. This created a fairly small sample and limited the degree to which analyses could be stratified to further investigate the effect of other variables such as marital status or education. Future analyses could be streamlined to exclude some covariates, covariates could be collapsed, or alternative samples could be identified that would better allow for the exploration of how different characteristics such as marital status may alter the association between social support and executive function.

As an addition to the analyses in Study 2, an attempt was made to explore the role of trajectories of social support and other social variables (e.g., marital status, loneliness). This process ran into several issues (e.g., much of the sample reports consistent high social support) and there were complications due to the self-reported data (e.g., for marital status, participants would report impossible patterns such as being widowed, single/never married, and then divorced). Yet, while this process was abandoned due to scope and data issues, future work looking at trajectories of social support and executive function would provide a much clearer idea of how the two interact and would help to account for bidirectionality in the association.

While there were not statistically significant differences between women and men for the longitudinal association between social support and executive function (Study 2), the directions of the associations (i.e., indicating a positive association for women and a negative one for men) are consistent with the literature. Current thinking is that reporting high social support is an indication that men are struggling and already using those resources for support

(e.g., Pillemer et al., 2019). Yet, in these analyses (and others completed by the dissertation author as part of their MSc thesis; Rutter et al., 2019), low social support was associated with executive function, which, while not in disagreement with the former conclusions about males and social support, has different implications. That social support is negatively associated with low executive function implies that reporting low social support is beneficial for executive function score in males. There would be a benefit to further research exploring exactly what the relationship between social support and cognitive health looks like in men.

Limitations: Study 3

For Study 3, the COVID-19 pandemic provided a unique opportunity to explore how the association between social support and executive function might change in the face of major environmental changes. Unfortunately, using the CLSA's Comprehensive cohort for these analyses presents a major limitation in that it is not possible to say whether the changes seen in the relationship between social support and executive function pre/post COVID-19 protocol changes are a result of living in the societal upheaval of a global pandemic and/or due to the change in testing conditions (i.e., over the phone vs in person). Some tests of executive function may not be as effective in a home setting vs a research setting (Cristofori et al., 2019). It is possible that the *learning effect* (Twisk, 2013) was lost for those who completed their testing post-COVID-19 protocol changes, and that was enough for their executive function scores to dip. Yet, a decline in one's executive function score does not necessarily explain why executive function would suddenly become significantly associated with social support. It may be that the small drop in scores post-COVID-19 restrictions was evidence of participants struggling to adjust to the new normal and that this struggle was sufficiently draining on cognitive function that social resources finally became helpful for this very healthy sample. Given these analyses were cross-sectional and temporality cannot be established, there are limited conclusions one can make beyond the fact that the relationship between social support and executive function changed pre/post-COVID-19 restrictions. Future work using the Tracking cohort of the CLSA or using later data collected during the COVID-19 pandemic would be helpful to further explore how social support may have helped cognitive function during this time.

When the analyses in Study 3 were further divided into subtypes of functional social support, emotional/informational support (e.g., having someone you can turn to for advice)

was significantly associated with executive function for those who completed their assessments prior to the COVID-19 restrictions. This association did not change for those tested pre- or post-COVID-19 restrictions. These results conflict with the results of Study 1, which found that those who were retained in the sample for all three waves of the CLSA did not have a baseline cross-sectional relationship between social support and executive function. The exact reason for this change is not clear from the analyses, but one possibility is that by T3 the CLSA sample is reaching a tipping point where enough of the sample is getting older and more vulnerable to changes in health and needs, leaving room for social support to play a role in cognitive health. This sample has been so cognitively healthy that social support and many other variables have not been needed to support their cognitive scores. Yet, T3 may be the start of a shift in the sample, such that social support may become increasingly more important with each subsequent wave of the CLSA. While these are merely suggestions, future work exploring how the cross-sectional association between social support subtypes and executive function changes as the Comprehensive cohort continues to age would provide useful information on how this relationship is impacted by health and age-related changes over the lifespan.

Additional future analyses could further explore different assessments of the key variables. The overall score of executive function was limited to combined scores using two (MAT and AFT) or five (MAT, AFT, Stroop, TMT, COWAT) cognitive tests. When participants were required to have all five tests of executive function, a large number of participants were excluded due to missing data. How this would change if participants were allowed to miss one cognitive test could be considered, with exploration of which cognitive tests can or cannot be removed, and what combinations of tests would still test the same aspects (e.g., cognitive flexibility, working memory, and inhibition) of executive function sufficiently. For social support, the CLSA provides the results of the MOS-SSS as a continuous score out of 100, which could be used to create alternative cut-offs for low social support (e.g., bottom quarter vs top quarter). One limitation with this approach would be that scores on the MOS-SSS are highly skewed with many participants scoring a 5 out of 5, and so specific percentile cut-offs should consider the spread of the data.

Conclusion

Social support may provide an accessible and modifiable area of intervention to support the cognitive health of the aging population. This dissertation demonstrated that both the cross-sectional and longitudinal relationships between social support and executive function are complex and that conclusions in this research area may be influenced by attrition (among other methodological and context specific factors) in longitudinal studies. The results of Study 1 indicated that the cross-sectional association between social support and executive function was significant for those who participated at baseline only but not for those who were retained in the study after baseline assessment, providing some evidence for attrition effects. In Study 2, the longitudinal association between social support and executive function was not statistically significant, consistent with conclusions from Study 1 that those who were retained in the study did not have a statistically significant relationship at any point, versus those who had been lost after baseline. Study 3 analyses, in contrast, indicated that the cross-sectional association between social support and executive function in those retained in the study varied before vs after COVID-19 social restrictions (with parallel changes in methodological approaches), with some subtypes of support only becoming significant for those who completed their tests post-COVID-19 restrictions. Despite findings that those with the strongest association between social support and executive function were also those most likely to be lost to attrition after baseline, participants at T3 (who had never had a statistically significant association between social support and executive function) developed a significant association during the COVID-19 restrictions.

While the long-term impact of social support on cognitive health is best investigated using longitudinal studies, these samples are vulnerable to biases which can lead to generalizations that do not reflect the broader population. Of greatest concern is that those who are lost to these studies over time may be those who would most benefit from cognition and health research as they appear to be those more likely to experience struggles in their social and cognitive health. While this dissertation specifically discusses the association between social support and executive function, attrition in samples represented here have wide-spread implications for longitudinal research on aging. Future research considering the long-term impact of exposures on cognitive health over the lifespan should actively investigate how attrition may impact their samples and findings.

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Appendix

Appendix A: Introduction

Appendix A.1. Medical Outcomes Study: Social Support Survey (MOS-SSS)

People sometimes look to others for companionship, assistance, or other types of support. How often is each of the following kinds of support available to you if you need it? Choose one number from each line.

Emotional/informational support

1. Someone you can count on to listen to you when you need to talk
2. Someone to give you information to help you understand a situation
3. Someone to give you good advice about a crisis
4. Someone to confide in or talk to about yourself or your problems
5. Someone whose advice you really want
6. Someone to share your most private worries and fears with
7. Someone to turn to for suggestions about how to deal with a personal problem
8. Someone who understands your problems

Tangible support

9. Someone to help you if you were confined to bed
10. Someone to take you to the doctor if you needed it
11. Someone to prepare your meals if you were unable to do it yourself
12. Someone to help with daily chores if you were sick

Affectionate support

13. Someone who shows you love and affection
14. Someone to love and make you feel wanted
15. Someone who hugs you

Positive social interactions

16. Someone to have a good time with
17. Someone to get together with for relaxation
18. Someone to do something enjoyable with

Additional item

19. Someone to do things with to help you get your mind off things

Appendix B: Background

Appendix B.1. Tests of executive function in the Canadian Longitudinal Study on Aging

The Animal Fluency Test (AFT) gives participants 60 seconds to list as many animals as possible. This work utilized the second, more lenient, scoring technique for the AFT, in which all valid animal responses are accepted (Strauss, Sherman, & Spreen, 2006; Crossley et al., 1997; Goodglass & Kaplan, 1972).

The Mental Alternation Test (MAT), a test of cognitive flexibility, has participants count from 1 to 20, recite the alphabet, then alternate between numbers and letters, beginning with "1A, 2B" and so on, for 30 seconds. A score was calculated for the MAT out of 51 and standardized (Teng, 1995; Billick et al., 2001)

The Controlled Oral Word Association Test (COWAT) has three sessions during which participants have 60 seconds to list words beginning with a single letter (F, A, S). Participants received a point for each unique word. Scores on each of the three sessions will be combined and standardized for an overall COWAT score (Strauss et al., 2006; Benton & Hamsher, 1978).

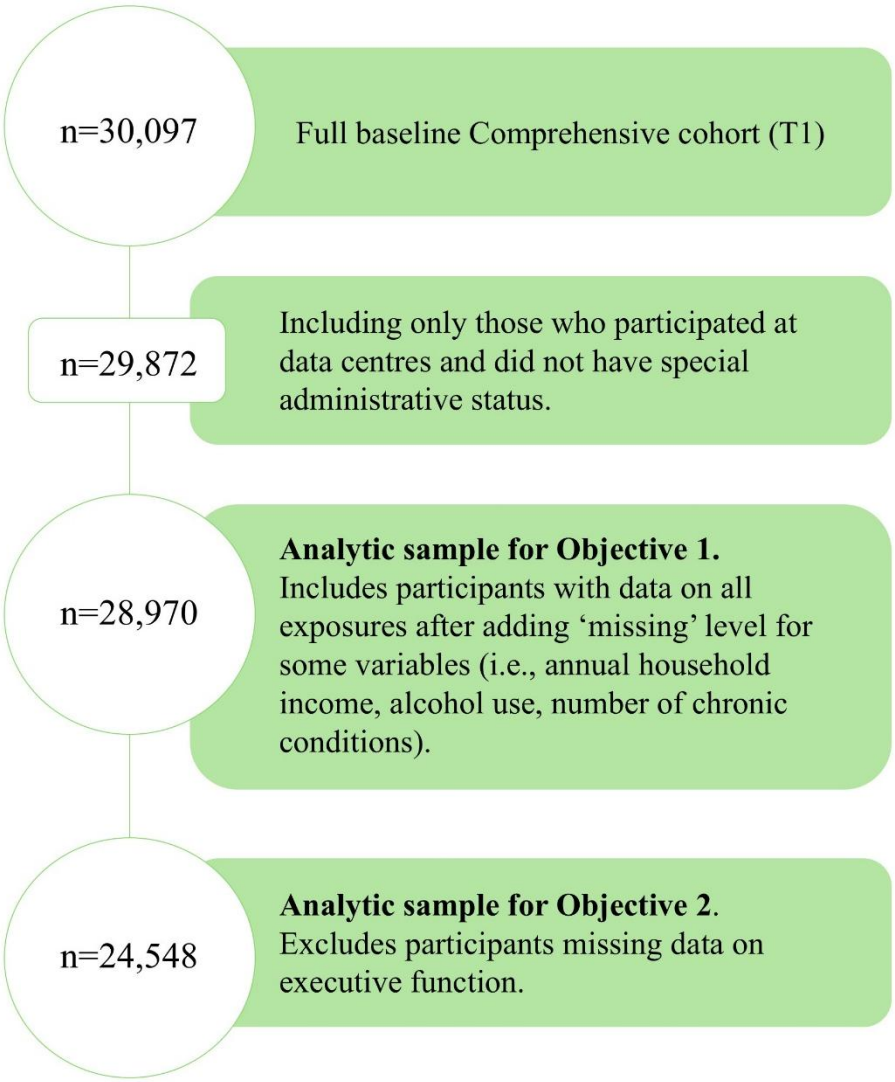
The Time-Based Prospective Memory Test (TMT) requires participants to complete a task at a predetermined time and assesses the working memory and inhibition subtypes of executive function (Mioni & Stablum, 2014). Participants are rated from 0 to 3 on intention to perform, accuracy of response, and need of reminders, with an overall score being calculated out of 9, which is then standardized (Hernandez Cardenache et al., 2014; Loewenstein & Acevedo, 2004).

The Victoria Stroop Neurological Screen Test (Stroop) is divided into three tasks during which participants are required to say the colour of the ink printed on stimulus cards. The cards in the first task contain coloured dots, while the second task contain common words printed in the coloured ink (Spreen & Strauss, 1998; Strauss et al., 2006; Troyer et al., 2006; Bayard et al., 2009; Moroni & Bayard, 2009; Bayard et al., 2011). For the final task, colour words (e.g., blue, yellow) are printed in ink of a conflicting colour. Scores are calculated as an average length of response in seconds for each task. An interference score is calculated by dividing the score on the final task (colour words) by the score on the first task (coloured dots) (Graf, Uttl, & Tuokko, 1995). The interference score is then standardized. The Stroop was modified for use in the CLSA (Tuokko et al., 2017; CLSA, n.d. [Technical document #1122]).

Appendix C: Chapter 4

Appendix C.1: Analytic sample creation for Chapter 4

Figure C.1. The creation of the analytic sample for Chapter 4 analyses using the Canadian Longitudinal Study on Aging



Appendix C.2 The association between subtypes of functional social support and attrition

Models were divided by subtype of support to identify if attrition had a stronger impact on any specific form of functional support. As presented in **Chapter 4 (Table 2)**, low overall functional social support was significantly associated with completing only the baseline assessment of the CLSA (RR = 1.02, 95% CI = 1.00-1.04), and with not participating at all three time points (RR=0.97, 0.95-0.99). Low positive social interactions remained significant for participation at baseline-only after the inclusion of all covariates (RR=1.01, 95% CI=1.00-1.02), while emotional/informational (RR=1.01, 95% CI=0.998-1.03), affectionate (RR=1.01, CI=0.99-1.02), and tangible support (RR=1.01, 95% CI=0.999-1.02) were all marginally significant. The effect of social support was very small for all subtypes (**Table C.1.,** using modified Poisson).

This was also true for the association between the social support subtypes and participation at all time points (**Table C.1.,** using modified Poisson**).** Low overall low social support (RR=0.97, 95% CI = 0.95-0.99) as well as low positive social interactions (RR=0.97, 95% CI=0.96-0.99), emotional/informational (RR=0.98, 95% CI=0.96-0.997), affectionate (RR=0.98, 95% CI=0.97-1.00) and tangible support (RR=0.98, 95% CI=0.97-1.00) were associated with a lower risk of participating at all time points in unadjusted models, with only the positive social interactions and emotional/informational support subtypes remaining significant after the inclusion of all covariates.

Table C.1. The association between low functional social support subtypes (T1) and participation at 1) baseline assessment only and 2) participation at all time points after accounting for sociodemographic, health, lifestyle, and social characteristics in the Canadian Longitudinal Study on Aging (n=29,970)

	Participation at baseline only (T1)	**Participation at all time points (T1, T2, T3)**
Social support (exposure)	RR (95% CI)	RR (95% CI)
Overall social support		
Low vs high	**1.02 (1.00-1.04)**	**0.97 (0.95-0.99)**
Positive social interactions		
Low vs high	**1.01 (1.00-1.02)**	**0.97 (0.96-0.99)**
Emotional/Informational		
Low vs high	1.01 (0.998-1.03)	**0.98 (0.96-0.997)**
Affectionate		
Low vs high	1.01 (0.99-1.02)	0.98 (0.97-1.00)
Tangible		
Low vs high	1.01 (0.999-1.02)	0.98 (0.97-1.00)

Significant results are **bolded.**
Final model includes social support, sociodemographic (sex, education, annual household income, province), health and lifestyle (chronic conditions, clinical depression, self-rated health, ever smoker, alcohol consumption) and social (marital status, loneliness, living alone) variables

Looking at the cross-sectional association between social support subtypes and executive function, the same pattern emerges as was seen with overall support, with the strongest (and statistically significant) association in the fully adjusted model being in those who only participated at baseline (**Table C.2.**). Low positive social interactions and low emotional/informational support were significantly associated with executive function for those lost after baseline assessment, and not for those who participated further in the study. Low affectionate and tangible support were not significantly associated with low executive function for any participation cohort.

Table C.2. Summary of the cross-sectional, baseline association between low functional social support subtypes and low executive function, stratified by participation cohort in the Canadian Longitudinal Study on Aging (n=29,970)

	Participation cohort: Baseline-only	Participation cohort: All-timepoints
	Executive function (Low vs normal)	**Executive function (Low vs normal)**
Social support (exposure)	OR (95% CI)	OR (95% CI)
Positive social interactions Low vs high	**1.47 (1.01-2.14)**	1.10 (0.91-1.34)
Emotional/informational Low vs high	**1.68 (1.16-2.44)**	1.04 (0.85-1.26)
Affectionate Low vs high	1.34 (0.89-2.03)	1.04 (0.84-1.29)
Tangible Low vs high	1.06 (0.73-1.55)	1.03 (0.84-1.25)

Significant results are **bolded.**

Final model includes social support, sociodemographic (sex, education, annual household income, province), health and lifestyle (chronic conditions, clinical depression, self-rated health, ever smoker, alcohol consumption) and social (marital status, loneliness, living alone) variables

Appendix D: Chapter 5

Appendix D.1: Variation in the association between functional social support and low executive function by subtype of support

Many subtypes of functional social support appear to have a positive association with cognitive function. *Emotional/informational* support (e.g., having someone you can turn to for advice; Zahodne et al., 2014; Frith & Loprinzi, 2017; La Fleur & Salthouse, 2017; Rutter et al., 2024; Zahodne et al., 2021), *affectionate* support (e.g., having someone who provides love and attention; Rutter et al., 2024*)*, *positive social interactions* (e.g., having someone to relax or have fun with; Liao and Scholes, 2017; Rutter et al., 2024) and *tangible* support (e.g., having someone to prepare meals if one was sick in bed) have all been positively associated with executive function. Tangible support, though, has also been associated with worse performance on measures of executive function (Dickinson et al., 2011, Liao & Scholes, 2017) and longitudinal analyses indicate that high levels of tangible support may actually be associated with the development of cognitive impairment (Pillemer et al., 2019). If there are conflicting relationships between the subtypes of functional social support and executive function (e.g., emotional/informational vs tangible), analyses using a combined measure of overall social support could be biased toward the null.

To assess whether there were differences in the association between functional social support and low executive function by subtype of support, modified Poisson regression models were run separately with each of the functional social support subtypes included as the key social support exposure. There were no differences in the association between any of the social support subtypes and executive function in final models accounting for all covariates. Baseline (T1) low positive social interactions (RR=1.01, 95% CI=0.99-1.03), emotional/informational (RR=1.01, 95% CI=0.98-1.03), affectionate (RR=1.00, 95% CI=0.98-1.02) and tangible support (RR=1.01, 95% CI=0.99-1.03) were not significantly associated with later low executive function (T3).

Appendix D.2: Variation in the association between functional social support and low executive function when stratified by sex

Sex has been identified as an effect modifier in the association between social support and cognitive function, as the type and level of support available to men and women differ and change over time (Gurung et al., 2003), and some subtypes of support, such as emotional support, may only be beneficial to cognitive function in women (e.g., Pillemer & Holtzer, 2016; Lee & Waite, 2018). Reporting higher or increased levels of support may be indicators of different outcomes for men and women. Despite possibly receiving more tangible support than women (Bourne et al., 2007), men reporting higher levels of this form of support may be experiencing or at a greater risk of cognitive decline (Pillemer et al., 2019) and dementia (Murata et al., 2019).

Final model results for sex-stratified analyses are included in **Table D1**, while a summary of stepwise models is included in **Table D2**. Modified Poisson models were unable to run due to small cell sizes following stratification. As such, logistic regression models were used (females n=4,955, males n=4,344). Social support (T1) was not significantly associated with executive function (T3) for females (OR=1.42, 95% CI=0.86-2.36) or males (OR=0.78, 95% CI=0.40-1.51; Table A1).

Table D1. The longitudinal association between low social support (T1) and low executive function (T3) in the Canadian Longitudinal Study on Aging stratified by sex

	Executive function (Low vs normal)	
	Females	**Males**
	OR (95% CI)	OR (95% CI)
Functional social support (T1)		
Low vs high	1.42 (0.86-2.36)	0.78 (0.40-1.51)
Age group (vs 45–54 years)		
55–64 years	**1.80 (1.05-3.08)**	**2.65 (1.45-4.84)**
65–74 years	**5.66 (3.36-9.54)**	**6.42 (3.51-11.74)**
75 years and over	**11.79 (6.74-20.62)**	**16.23 (8.72-30.19)**
Education (vs post-secondary degree/diploma)		
Some post-secondary	1.06 (0.66-1.72)	1.10 (0.64-1.88)
High school graduate	1.41 (0.97-2.05)	1.37 (0.88-2.14)
Less than high school	**2.44 (1.60-3.72)**	**2.68 (1.60-4.50)**
Annual household income (vs < $20,000)		
≥ $20,000 and < $50,000	0.72 (0.43-1.19)	0.53 (0.25-1.13)
≥ $50,000 and < $100,000	**0.57 (0.33-0.99)**	**0.39 (0.18-0.84)**
≥ $100,000	**0.23 (0.12-0.46)**	**0.31 (0.14-0.70)**
Missing	**0.47 (0.24-0.91)**	**0.40 (0.14-1.04)**

Province (vs Ontario)		
Alberta	0.86 (0.52-1.42)	1.46 (0.85-2.53)
British Columbia	0.70 (0.48-1.05)	1.36 (0.88-2.09)
Manitoba	0.73 (0.45-1.17)	1.28 (0.77-2.11)
Newfoundland and Labrador	0.88 (0.51-1.53)	1.70 (0.97-2.98)
Nova Scotia	1.27 (0.83-1.97)	1.29 (0.78-2.13)
Quebec	0.85 (0.56-1.29)	1.39 (0.88-2.16)
Chronic condition (vs no conditions)		
1 condition	**1.49 (1.02-2.17)**	0.83 (0.56-1.21)
2 conditions	1.39 (0.91-2.11)	1.29 (0.87-1.91)
3+ conditions	**2.11 (1.36-3.28)**	1.51 (0.98-2.32)
Missing	**2.74 (1.45-5.16)**	1.73 (0.83-3.59)
Clinical depression (vs no)	1.01 (0.72-1.41)	0.81 (0.50-1.32)
Self-rated health (vs poor/fair)		
Good	0.87 (0.54-1.39)	0.83 (0.49-1.40)
Very good	0.63 (0.39-1.02)	0.68 (0.40-1.15)
Excellent	0.60 (0.35-1.03)	0.66 (0.37-1.19)
Ever smoked (vs no)	0.97 (0.75-1.26)	1.30 (0.98-1.74)
Alcohol consumption (vs non-user)		
Occasional drinker	0.94 (0.61-1.43)	**2.40 (1.35-4.26)**
Regular drinker	0.62 (0.43-0.89)	0.89 (0.56-1.43)
Missing	0.76 (0.34-1.67)	1.52 (0.55-4.22)
Marital status (vs married/common-law*)*		
Single/never married	0.58 (0.30-1.10)	1.36 (0.63-2.96)
Widowed	0.76 (0.46-1.27)	**2.16 (1.07-4.36)**
Divorced/separated	0.37 (0.21-0.65)	0.83 (0.39-1.73)
Loneliness (vs not lonely)	1.11 (0.82-1.50)	0.89 (0.62-1.28)
Living alone (vs not living alone)	0.98 (0.61-1.57)	0.83 (0.44-1.58)

Significant results are **bolded.**

Table D2. The longitudinal association between low social support (T1) and low executive function (T3) in the Canadian Longitudinal Study on Aging stratified by sex, stepwise models

	Executive Function (T3) (Low vs normal)			
	Model A OR (95% CI)	Model B OR (95% CI)	Model C OR (95% CI)	Final model OR (95% CI)
Females				
Baseline (T1) social support (low vs high)	**1.92 (1.24-2.98)**	1.48 (0.92-2.38)	1.23 (0.77-2.03)	1.42 (0.86-2.36)
Males				
Baseline (T1) social support (low vs high)	0.94 (0.52-1.70)	0.81 (0.43-1.53)	0.72 (0.38-1.37)	0.78 (0.40-1.51)

Significant results are **bolded**.
Model A: Social support; Model B: Model A plus sociodemographic variables (age, sex, education, annual household income, province); Model C: Model B plus health and lifestyle variables (chronic conditions, clinical depression, self-rated health, ever smoker, alcohol consumption); Final Model: Model C plus social variables (marital status, loneliness, living alone)

Appendix D.3: Variation in the association between functional social support and low executive function when stratified by age

Age has a strong impact on cognitive function, and most individuals will experience some level of decline in overall cognitive abilities as they age (Salthouse, 2010). Whether this change in cognitive function impacts the association between social support and executive function across age groups is unclear. Seeman et al. (2011) identified that the association between social support and executive function may be stronger in younger adults compared to older adults. Older adults can experience a trimming of their social networks over time as they focus on their most beneficial relationships; however, this reduction does not necessarily decrease the level of perceived social support they receive (Gurung et al., 2003). To explore if age modifies the longitudinal relationship between social support and incident executive function, objective 1 analyses (i.e., baseline social support, executive function at T3) were stratified by age groups (i.e., 45–54 years, 55–64 years, 65-74 years, and 75 years and over). After inclusion of all covariates, the longitudinal association between social support and executive function was not significant for any age group (**Table D3**).

Table D3. The longitudinal association between low social support (T1) and low executive function (T3) in the Canadian Longitudinal Study on Aging stratified by age

	Executive function (Low vs normal)
	RR (95% CI)
45–54 years	
Social support (low vs high)	1.00 (0.97-1.03)
55–64 years	
Social support (low vs high)	0.98 (0.95-1.01)
65–74 years	
Social support (low vs high)	1.06 (0.98-1.15)
75 years and over	
Social support (low vs high)	1.01 (0.91-1.11)

Significant results are **bolded.**
Final model includes overall social support, sociodemographic (sex, education, annual household income, province), health and lifestyle (chronic conditions, clinical depression, self-rated health, ever smoker, alcohol consumption) and social (marital status, loneliness, living alone) variables

Appendix D.4: The longitudinal association between low social support (T1) and low executive function at follow-up 1 (T2) in the Canadian Longitudinal Study on Aging: The impact of length of follow-up

Given there was no significant association found between baseline (T1) social support and follow-up 2 (T3) executive function, it was worth considering that the follow-up period of approximately six years between T1 and T3 may simply be too long for any effects of baseline social support to still be impacting executive function. To assess the impact of time to follow-up on the relationship between social support and executive function, analyses were run with executive function at follow-up 1 (T2) as the outcome. This created a follow-up period of three years (T1 to T2) vs the six (T1 to T3) years in the primary analyses. If there were a relationship between social support and later executive function in this population, the shorter follow-up would theoretically increase the strength of the association compared to the longer follow-up period (3 years vs 6 years). Results for the association between baseline (T1) social support and follow-up 1 (T2) social support adjusting for all sociodemographic, health, lifestyle and social covariates are included in **Table D4**. Consistent with findings for analyses utilizing T3 executive function, there was not a significant relationship between functional social support and executive function (T2).

Table D4. The longitudinal association between low social support (T1) and low executive function (T2) in the Canadian Longitudinal Study on Aging (n=9299)

	Executive Function (Low vs normal)
	RR (95% CI)
Low functional social support (vs high)	1.00 (0.98-1.02)
Age group (vs 45–54 years)	
55–64 years	1.01 (0.998-1.01)
65–74 years	**1.03 (1.02-1.04)**
75 years and over	**1.08 (1.06-1.11)**
Female (vs male)	0.997 (0.99-1.01)
Education (vs post-secondary degree/diploma)	
Some post-secondary	1.00 (0.98-1.02)
High school graduate	**1.02 (1.00-1.04)**
Less than high school	**1.06 (1.01-1.10)**
Annual household income (vs < $20,000)	
≥ $20,000 and < $50,000	0.996 (0.96-1.04)
≥ $50,000 and < $100,000	0.96 (0.93-1.00)
≥ $100,000	**0.96 (0.93-0.997)**
Missing	0.98 (0.94-1.02)

Province (vs Ontario)	
Alberta	0.99 (0.97-1.00)
British Columbia	0.99 (0.98-1.01)
Manitoba	0.99 (0.98-1.01)
Newfoundland and Labrador	1.01 (0.997-1.03)
Nova Scotia	1.01 (0.99-1.03)
Quebec	1.00 (0.99-1.02)
Chronic condition (vs no conditions)	
1 condition	1.01 (0.997-1.02)
2 conditions	0.99 (0.98-1.01)
3+ conditions	**1.03 (1.01-1.05)**
Missing	1.02 (0.99-1.06)
Clinical depression (vs absence)	0.999 (0.99-1.01)
Self-rated health (vs poor/fair)	
Good	0.98 (0.95-1.00)
Very good	**0.97 (0.95-0.998)**
Excellent	**0.96 (0.94-0.99)**
Ever smoker (vs not)	1.00 (0.99-1.01)
Alcohol consumption (vs non-user)	
Occasional drinker	0.996 (0.97-1.02)
Regular drinker	0.99 (0.98-1.01)
Missing	1.04 (0.99-1.09)
Marital status	
(vs married/common-law)	
Single/never married	0.98 (0.96-1.00)
Widowed	0.99 (0.97-1.02)
Divorced/separated	0.99 (0.97-1.00)
Loneliness (vs not lonely)	0.999 (0.99-1.01)
Living alone (vs not living alone)	0.999 (0.98-1.02)

Significant results are **bolded.**

Appendix D.5: **The longitudinal association between low social support (T1) and low executive function (T3) in the Canadian Longitudinal Study on Aging: Models run using logistic regression**

Models were run using logistic regression instead of modified Poisson regression to assess whether the analytic methods impacted the association between social support and executive function. Using logistic regression, social support was significantly associated with low executive function in the crude Model A (OR=1.42, 95% CI=1.00-2.02 (**Table D5**), but did not remain statistically significant after the inclusion of additional variables (OR=1.13, 95% CI=0.76-1.68).

Table D5. The longitudinal association between low social support (T1) and low executive function (T3) in the Canadian Longitudinal Study on Aging (n=9299)

	Executive Function (T3) (Low vs normal)			
	Model A OR (95% CI)	Model B OR (95% CI)	Model C OR (95% CI)	Final Model OR (95% CI)
Low social support (vs high)	**1.42 (1.00-2.02)**	1.15 (0.79-1.68)	0.997 (0.68-1.46)	1.13 (0.76-1.68)
Age group (vs 45–54 years)				
55–64 years		**2.28 (1.54-3.39)**	**2.22 (1.49-3.30)**	**2.19 (1.47-3.27)**
65–74 years		**6.27 (4.29-9.18)**	**6.14 (4.17-9.05)**	**6.05 (4.09-8.96)**
75 years and over		**14.49 (9.82-21.39)**	**13.83 (9.27-20.64)**	**13.35 (8.86-20.12)**
Female (vs male)		0.90 (0.75-1.08)	0.88 (0.72-1.06)	0.91 (0.74-1.10)
Education (vs post-secondary)				
Some post-secondary		1.15 (0.81-1.63)	1.10 (0.77-1.56)	1.10 (0.77-1.56)
High school graduate		**1.50 (1.13-1.98)**	**1.43 (1.08-1.90)**	**1.39 (1.05-1.85)**
Less than high school		**3.06 (2.24-4.19)**	**2.89 (1.95-3.70)**	**2.51 (1.81-3.47)**
Annual household income (vs < $20,000)				
≥ $20,000 and < $50,000		0.67 (0.45-1.01)	0.73 (0.49-1.10)	0.66 (0.44-1.01)
≥ $50,000 and < $100,000		**0.53 (0.36-0.80)**	**0.64 (0.43-0.96)**	**0.52 (0.34-0.81)**
≥ $100,000		**0.31 (0.20-0.48)**	**0.40 (0.25-0.63)**	**0.31 (0.19-0.51)**

Missing	**0.50 (0.29-0.83)**	**0.55 (0.32-0.93)**	**0.47 (0.27-0.81)**
Province (vs Ontario)			
Alberta	1.06 (0.74-1.53)	1.04 (0.72-1.50)	1.04 (0.72-1.51)
British Columbia	0.93 (0.70-1.24)	0.94 (0.71-1.25)	0.95 (0.71-1.27)
Manitoba	0.93 (0.67-1.31)	0.96 (0.68-1.34)	0.97 (0.69-1.34)
Newfoundland and Labrador	1.27 (0.86-1.86)	1.18 (0.80-1.74)	1.18 (0.80-1.74)
Nova Scotia	1.34 (0.99-1.87)	1.29 (0.93-1.78)	1.27 (0.92-1.76)
Quebec	1.00 (0.74-1.35)	1.03 (0.76-1.39)	1.06 (0.79-1.44)
Chronic condition (vs no conditions)			
1 condition		1.11 (0.85-1.45)	1.11 (0.85-1.45)
2 conditions		1.31 (0.99-1.74)	1.31 (0.98-1.74)
3+ conditions		**1.67 (1.24-2.26)**	**1.69 (1.23-2.29)**
Missing		**2.20 (1.38-3.51)**	**2.19 (1.37-3.51)**
Clinical depression (vs no)		0.91 (0.69-1.19)	0.93 (0.71-1.23)
Self-rated health (vs poor/fair)			
Good		0.84 (0.60-1.19)	0.84 (0.60-1.19)
Very good		**0.64 (0.45-0.90)**	**0.65 (0.46-0.92)**
Excellent		**0.62 (0.42-0.91)**	**0.63 (0.43-0.94)**
Ever smoked (vs no)		**1.09 (0.90-1.31)**	1.10 (0.91-1.33)
Alcohol consumption (vs non-user)			
Occasional drinker		1.35 (0.96-1.90)	1.34 (0.96-1.89)
Regular drinker		**0.71 (0.53-0.94)**	0.70 (0.53-0.93)
Missing		1.00 (0.54-1.87)	0.96 (0.52-1.79)
Marital status (vs married/common-law)			
Single/never married			0.85 (0.52-1.57)
Widowed			1.04

	(0.69-1.57)
Divorced/separated	**0.51**
	(0.33-0.79)
Loneliness (vs not lonely)	1.05
	(0.84-1.32)
Living alone	0.93
(vs not living alone)	(0.64-1.36)

Significant results are **bolded**.
Model A: Social support; Model B: adds sociodemographic variables (age, sex, education, annual household income, province); Model C: adds health variables (chronic conditions, clinical depression, self-rated health, ever smoker, alcohol consumption); Final Model: adds social variables (marital status, loneliness, living alone)

Appendix E: Chapter 6

Appendix E.1: Full stepwise models for the association between low overall functional social support and low executive function, pre- and post-COVID-19 restrictions

Table E1: The cross-sectional (T3) association between low functional social support and low executive function pre-COVID-19 restrictions, in the Canadian Longitudinal Study on Aging (n=10,786)

	Low executive function (T3)			
	Model A (crude) OR (95% CI)	Model B OR (95% CI)	Model C OR (95% CI)	Final model OR (95% CI)
Social support (low vs high)	**1.87 (1.45-2.43)**	**1.42 (1.08-1.87)**	1.30 (0.99-1.72)	1.18 (0.89-1.57)
Over 65 (vs 45–64 years)		**3.93 (3.19-4.85)**	**3.85 (3.10-4.76)**	**3.84 (3.10-4.77)**
Female (vs male)		0.99 (0.85-1.14)	0.96 (0.82-1.11)	0.94 (0.81-1.10)
Education (vs post-secondary)				
Some post-secondary		1.25 (0.95-1.64)	1.21 (0.92-1.60)	1.21 (0.92-1.60)
High school graduate		**1.55 (1.25-1.92)**	**1.54 (1.24-1.91)**	**1.55 (1.24-1.93)**
Less than high school		**3.64 (2.87-4.63)**	**3.27 (2.57-4.18)**	**3.30 (2.58-4.21)**
Annual household income (vs < $20,000)				
≥ $20,000 and < $50,000		0.69 (0.51-0.93)	0.75 (0.55-1.01)	0.76 (0.56-1.04)
≥ $50,000 and < $100,000		**0.44 (0.33-0.60)**	**0.51 (0.38-0.70)**	**0.54 (0.39-0.75)**
≥ $100,000		**0.29 (0.21-0.40)**	**0.36 (0.26-0.51)**	**0.38 (0.27-0.55)**
Missing		0.92 (0.65-1.31)	1.02 (0.71-1.46)	1.06 (0.73-1.53)
Province (vs Ontario)				
Alberta		0.99 (0.76-1.31)	0.99 (0.75-1.30)	0.99 (0.75-1.29)
British Columbia		0.73 (0.58-0.91)	0.73 (0.58-0.92)	0.74 (0.58-0.93)
Manitoba		0.79 (0.60-1.04)	0.81 (0.62-1.07)	0.80 (0.61-1.06)
Newfoundland and Labrador		0.95 (0.70-1.28)	0.93 (0.69-1.26)	0.94 (0.69-1.27)

Nova Scotia	1.03 (0.79-1.33)	1.01 (0.78-1.30)	0.99 (0.77-1.29)
Quebec	0.82 (0.65-1.03)	0.85 (0.68-1.06)	0.84 (0.67-1.06)
Chronic condition (vs no conditions)			
1 condition		0.94 (0.71-1.24)	0.93 (0.71-1.23)
2 conditions		1.14 (0.86-1.51)	1.14 (0.86-1.51)
3+ conditions		1.16 (0.88-1.55)	1.15 (0.87-1.53)
Missing		1.26 (0.98-1.62)	1.25 (0.97-1.61)
Clinical depression (vs no)		0.97 (0.75-1.25)	0.93 (0.72-1.21)
Good or greater self-rated health (vs poor/fair)		**0.63 (0.52-0.78)**	**0.66 (0.53-0.81)**
Alcohol consumption in last year (vs non-user)			
Occasional user (consumed less than once per month)		0.84 (0.66-1.07)	0.83 (0.65-1.06)
Regular user (consumed at least once per month)		**0.64 (0.53-0.77)**	**0.63 (0.52-0.76)**
*Marital status (*married/common-law vs not*)*			1.02 (0.77-1.33)
Loneliness (vs not lonely)			**1.37 (1.16-1.62)**
Living alone (vs not living alone)			1.03 (0.78-1.35)

Significant results are **bolded**.

Table E2: The cross-sectional (T3) association between low functional social support and low executive function post-COVID-19 restrictions in the Canadian Longitudinal Study on Aging (n=10,786)

	Low executive function (T3)			
	Model A (Crude) OR (95% CI)	Model B OR (95% CI)	Model C OR (95% CI)	Final model OR (95% CI)
Social support (low vs high)	**2.69 (2.05-3.54)**	**1.75 (1.30-2.36)**	**1.59 (1.17-2.15)**	**1.61 (1.17-2.20)**
Over 65 (vs 45–64 years)		**3.71 (2.90-4.75)**	**3.51 (2.73-4.51)**	**3.51 (2.73-4.51)**
Female (vs male)		0.95 (0.80-1.14)	0.90 (0.75-1.08)	0.91 (0.76-1.10)
Education (vs post-secondary degree/diploma)				
Some post-secondary		1.30 (0.96-1.77)	1.26 (0.92-1.71)	1.25 (0.92-1.71)
High school graduate		**1.78 (1.38-2.30)**	**1.72 (1.33-2.23)**	**1.72 (1.33-2.23)**
Less than high school		**3.54 (2.63-4.77)**	**3.38 (2.50-4.57)**	**3.36 (2.49-4.54)**
Annual household income (vs < $20,000)				
≥ $20,000 and < $50,000		0.84 (0.57-1.23)	0.92 (0.62-1.35)	0.89 (0.60-1.32)
≥ $50,000 and < $100,000		**0.51 (0.34-0.75)**	**0.59 (0.39-0.88)**	**0.56 (0.37-0.85)**
≥ $100,000		**0.33 (0.21-0.50)**	**0.40 (0.26-0.63)**	**0.38 (0.24-0.61)**
Missing		1.38 (0.89-2.12)	1.52 (0.98-2.36)	1.47 (0.94-2.30)
Province (vs Ontario)				
Alberta		1.06 (0.76-1.49)	1.05 (0.75-1.47)	1.04 (0.74-1.46)
British Columbia		1.02 (0.79-1.33)	1.04 (0.80-1.36)	1.04 (0.80-1.36)
Manitoba		1.00 (0.68-1.45)	0.98 (0.67-1.44)	0.98 (0.67-1.44)
Newfoundland and Labrador		**1.53 (1.08-2.17)**	**1.56 (1.09-2.22)**	**1.55 (1.09-2.21)**
Nova Scotia		1.09 (0.78-1.51)	1.11 (0.80-1.54)	1.10 (0.79-1.53)
Quebec		0.88 (0.67-1.16)	0.91 (0.69-1.20)	0.91 (0.69-1.19)

Chronic condition (vs no conditions)		
1 condition	1.04 (0.75-1.45)	1.05 (0.75-1.45)
2 conditions	0.86 (0.60-1.24)	0.86 (0.60-1.24)
3+ conditions	**1.51 (1.09-2.09)**	**1.51 (1.09-2.10)**
Missing	**1.37 (1.01-1.87)**	**1.37 (1.01-1.86)**
Clinical depression (vs no)	0.91 (0.68-1.22)	0.90 (0.67-1.21)
Good or greater self-rated health (vs poor/fair)	**0.74 (0.58-0.94)**	**0.75 (0.59-0.95)**
Alcohol consumption in last year (vs non-user)		
Occasional user (consumed less than once per month)	0.85 (0.63-1.13)	0.85 (0.64-1.13)
Regular user (consumed at least once per month)	**0.65 (0.52-0.80)**	**0.65 (0.52-0.80)**
*Marital status (*Married/common-law vs not*)*		1.08 (0.80-1.47)
Loneliness (vs not lonely)		1.07 (0.87-1.31)
Living alone (vs not living alone)		0.99 (0.73-1.34)

Significant results are **bolded**.

Appendix E.2: Fully adjusted models for the association between functional social support subtypes and low executive function, pre- and post-COVID-19 restrictions

Table E3: The cross-sectional (T3) association between low functional social support subtypes and low executive function pre-COVID-19 restrictions in the Canadian Longitudinal Study on Aging (n=10,786)

	Positive social interactions[a]	Emotional/ informational support[a]	Tangible support[a]	Affectionate support[a]
	Executive function (T3) (Low vs normal)	**Executive function (T3) (Low vs normal)**	**Executive function (T3) (Low vs normal)**	**Executive function (T3) (Low vs normal)**
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Social support (low vs high)[a]	1.16 (0.91-1.47)	**1.38 (1.10-1.73)**	1.14 (0.86-1.51)	1.09 (0.85-1.41)
Over 65 (vs 45–64 years)	**3.84 (3.10-4.76)**	**3.85 (3.10-4.77)**	**3.49 (2.71-4.49)**	**3.84 (3.10-4.76)**
Female (vs male)	0.94 (0.81-1.10)	0.95 (0.82-1.11)	0.89 (0.74-1.07)	0.94 (0.80-1.10)
Education (vs post-secondary degree/diploma)				
Some post-secondary	1.22 (0.92-1.60)	1.21 (0.92-1.60)	1.25 (0.92-1.70)	1.21 (0.92-1.60)
High school graduate	**1.55 (1.24-1.93)**	**1.55 (1.24-1.92)**	**1.72 (1.33-2.23)**	**1.55 (1.24-1.92)**
Less than high school	**3.30 (2.59-4.22)**	**3.29 (2.58-4.20)**	**3.38 (2.50-4.56)**	**3.29 (2.58-4.20)**
Annual household income (vs < $20,000)				
≥ $20,000 and < $50,000	0.76 (0.56-1.04)	0.76 (0.56-1.04)	0.86 (0.58-1.27)	0.76 (0.56-1.03)
≥ $50,000 and < $100,000	**0.54 (0.39-0.75)**	**0.54 (0.39-0.75)**	**0.53 (0.35-0.81)**	**0.54 (0.39-0.74)**
≥ $100,000	**0.38 (0.27-0.55)**	**0.39 (0.27-0.56)**	**0.36 (0.23-0.58)**	**0.38 (0.26-0.55)**
Missing	1.05 (0.73-1.53)	1.06 (0.73-1.53)	1.40 (0.90-2.19)	1.06 (0.73-1.53)
Province (vs Ontario)				
Alberta	0.99 (0.75-1.30)	0.99 (0.75-1.30)	1.03 (0.74-1.07)	0.99 (0.75-1.29)
British Columbia	**0.74 (0.58-0.93)**	**0.73 (0.58-0.93)**	1.05 (0.81-1.37)	**0.74 (0.58-0.93)**

Manitoba	0.81 (0.61-1.06)	0.81 (0.62-1.07)	0.97 (0.66-1.42)	0.80 (0.61-1.06)
Newfoundland and Labrador	0.94 (0.67-1.27)	0.94 (0.69-1.27)	**1.53 (1.08-2.19)**	0.94 (0.69-1.27)
Nova Scotia	0.99 (0.77-1.29)	0.99 (0.77-1.29)	1.09 (0.78-1.51)	0.99 (0.77-1.29)
Quebec	0.85 (0.67-1.06)	0.84 (0.67-1.06)	0.92 (0.70-1.21)	0.84 (0.67-1.06)
Chronic condition (vs no conditions)				
1 condition	0.93 (0.71-1.23)	0.94 (0.71-1.23)	1.05 (0.75-1.46)	0.93 (0.71-1.23)
2 conditions	1.14 (0.86-1.51)	1.14 (0.86-1.52)	0.86 (0.60-1.24)	1.13 (0.85-1.51)
3+ conditions	1.16 (0.87-1.54)	1.16 (0.87-1.54)	**1.51 (1.09-2.10)**	1.15 (0.87-1.53)
Missing	1.25 (0.97-1.61)	1.25 (0.97-1.61)	**1.37 (1.01-1.87)**	1.25 (0.97-1.61)
Clinical depression (vs no)	0.93 (0.72-1.21)	0.92 (0.71-1.20)	0.91 (0.67-1.22)	0.94 (0.72-1.21)
Good or greater self-rated health (vs poor/fair)	**0.66 (0.54-0.81)**	**0.67 (0.54-0.82)**	**0.73 (0.58-0.93)**	**0.66 (0.53-0.81)**
Alcohol consumption in last year (vs non-user)				
Occasional user (consumed less than once per month)	0.83 (0.65-1.06)	0.83 (0.65-1.06)	0.84 (0.63-1.13)	0.83 (0.65-1.06)
Regular user (consumed at least once per month)	**0.63 (0.53-0.76)**	**0.63 (0.53-0.77)**	**0.64 (0.52-0.79)**	**0.63 (0.52-0.76)**
*Marital status (m*arried/common-law vs not*)*	1.02 (0.78-1.34)	1.02 (0.78-1.34)	1.07 (0.79-1.45)	1.02 (0.78-1.34)
Loneliness (vs not lonely)	**1.36 (1.15-1.62)**	**1.33 (1.13-1.58)**	1.10 (0.89-1.35)	**1.38 (1.17-1.63)**
Living alone (vs not living alone)	1.03 (0.78-1.35)	1.02 (0.78-1.35)	1.01 (0.75-1.38)	1.03 (0.79-1.36)

[a]Models were run separately with each subtype of functional social support as the social support exposure.
Significant results are **bolded**.

Table E4: The cross-sectional (T3) association between low functional social support subtypes and low executive function post-COVID-19 restrictions in the Canadian Longitudinal Study on Aging (n=10,786)

	Positive social interactions[a]	Emotional/ informational support[a]	Tangible support[a]	Affectionate support[a]
	Executive function (T3) (Low vs normal)	**Executive function (T3) (Low vs normal)**	**Executive function (T3) (Low vs normal)**	**Executive function (T3) (Low vs normal)**
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Social support (low vs high)[a]	**1.43 (1.09-1.87)**	**1.40 (1.05-1.89)**	1.14 (0.86-1.51)	**1.38 (1.04-1.83)**
Over 65 (vs 45–64 years)	**3.48 (2.71-4.48)**	**3.48 (2.70-4.47)**	**3.49 (2.71-4.49)**	**3.51 (2.73-4.52)**
Female (vs male)	0.90 (0.75-1.08)	0.90 (0.75-1.09)	0.89 (0.74-1.07)	0.91 (0.75-1.09)
Education (vs post-secondary degree/diploma)				
Some post-secondary	1.26 (0.93-1.72)	1.25 (0.92-1.71)	1.25 (0.92-1.70)	1.25 (0.92-1.71)
High school graduate	**1.72 (1.33-2.23)**	**1.72 (1.33-2.23)**	**1.72 (1.33-2.23)**	**1.73 (1.33-2.24)**
Less than high school	**3.38 (2.50-4.56)**	**3.37 (2.49-4.55)**	**3.38 (2.50-4.56)**	**3.37 (2.49-4.55)**
Annual household income (vs < $20,000)				
≥ $20,000 and < $50,000	0.88 (0.59-1.30)	0.88 (0.59-1.29)	0.86 (0.58-1.27)	0.87 (0.59-1.28)
≥ $50,000 and < $100,000	**0.55 (0.36-0.83)**	**0.55 (0.36-0.83)**	**0.53 (0.35-0.81)**	**0.54 (0.36-0.82)**
≥ $100,000	**0.37 (0.24-0.59)**	**0.37 (0.24-0.59)**	**0.36 (0.23-0.58)**	**0.37 (0.23-58)**
Missing	1.45 (0.93-2.26)	1.44 (0.92-2.24)	1.40 (0.90-2.19)	1.42 (0.91-2.22)
Province (vs Ontario)				
Alberta	1.04 (0.74-1.46)	1.03 (0.74-1.45)	1.03 (0.74-1.45)	1.04 (0.74-1.45)
British Columbia	1.04 (0.80-1.36)	1.05 (0.80-1.36)	1.05 (0.81-1.36)	1.05 (0.81-1.36)
Manitoba	0.99 (0.68-1.45)	0.98 (0.67-1.44)	0.97 (0.66-1.42)	0.98 (0.67-1.44)

Newfoundland and Labrador	**1.55 (1.09-2.21)**	**1.54 (1.08-2.20)**	**1.53 (1.08-2.19)**	**1.56 (1.09-2.22)**
Nova Scotia	1.09 (0.79-1.52)	1.10 (0.79-1.52)	1.09 (0.78-1.51)	1.10 (0.79-1.53)
Quebec	0.92 (0.70-1.22)	0.91 (0.69-1.19)	0.92 (0.70-1.21)	0.92 (0.70-1.20)
Chronic condition (vs no conditions)				
1 condition	1.05 (0.76-1.47)	1.04 (0.75-1.45)	1.05 (0.75-1.46)	1.05 (0.76-1.46)
2 conditions	0.87 (0.60-1.25)	0.86 (0.60-1.24)	0.86 (0.60-1.24)	0.87 (0.60-1.25)
3+ conditions	**1.52 (1.09-2.11)**	**1.51 (1.09-2.10)**	**1.52 (1.09-2.10)**	**1.52 (1.10-2.11)**
Missing	**1.37 (1.01-1.86)**	**1.36 (1.00-1.85)**	**1.37 (1.01-1.87)**	**1.38 (1.01-1.87)**
Clinical depression (vs no)	0.91 (0.67-1.22)	0.91 (0.68-1.22)	0.91 (0.67-1.22)	0.90 (0.67-1.22)
Good or greater self-rated health (vs poor/fair)	**0.75 (0.59-0.95)**	**0.74 (0.58-0.94)**	**0.73 (0.58-0.93)**	**0.74 (0.58-0.93)**
Alcohol consumption in last year (vs non-user)				
Occasional user (consumed less than once per month)	0.85 (0.64-1.14)	0.85 (0.64-1.13)	0.84 (0.63-1.13)	0.85 (0.64-1.13)
Regular user (consumed at least once per month)	**0.65 (0.52-0.81)**	**0.65 (0.52-0.80)**	0.64 (0.52-0.79)	0.64 (0.52-0.80)
*Marital status (*married/common-law vs not*)*	1.09 (0.81-1.48)	1.08 (0.80-1.46)	1.07 (0.79-1.45)	1.11 (0.82-1.50)
Loneliness (vs not lonely)	1.06 (0.86-1.30)	1.08 (0.88-1.32)	1.10 (0.89-1.35)	1.07 (0.87-1.32)
Living alone (vs not living alone)	1.01 (0.74-1.37)	1.02 (0.75-1.38)	1.01 (0.75-1.38)	1.01 (0.75-1.38)

[a]Models were run separately with each subtype of functional social support as the social support exposure.
Significant results are **bolded**.

Appendix E.3. The cross-sectional (T3) association between functional social support and executive function by number of tests of executive function

After March 16, 2020, the CLSA's data collection protocol was updated in response to the COVID-19 pandemic (see *Methods*). This change in data collection method had a profound impact on the testing of executive function in particular, with only two tests of executive (AFT, MAT) being collected after COVID-19 restrictions and with testing occurring over the telephone (post-COVID-19 restrictions) vs in-person (pre-COVID-19). In order to compare the post-COVID-19 restrictions sample to the pre-COVID-19 sample, the pre-COVID-19 sample's overall score of executive function was calculated using only those assessments available both pre- and post-COVID-19 restrictions (i.e., AFT, MAT). As such, additional analyses were conducted to compare the association between social support and executive function pre-COVID-19 when overall combined executive function was calculated using two tests of executive function vs all five available tests.

Results for the cross-sectional, pre-COVID-19 association between functional social support and executive function using two tests vs five tests are included in **Table E5**. Consistent with pre-COVID-19 results on the association between low social support and low executive function restricted to the MAT and AFT (OR=1.18, 95% CI=0.89-1.57; **Table 3**), low overall functional social support was not significantly associated with low executive function when using all five assessments available for executive function pre-COVID-19 (OR=0.98, 95% CI=0.72-1.35). Minor differences were found with covariates, with clinical depression (OR=0.59, 95% CI=0.44-0.81) and having any chronic conditions (vs none) being significantly associated with low executive function only when five tests of executive function were used.

Analyses considering subtypes of functional social support were also consistent pre-COVID-19 regardless of number of assessments (two vs five) used to calculate overall executive function, with only emotional/informational social support being significantly associated with low executive function pre-COVID-19 whether the outcome was calculated using two (OR=1.38, 95% CI=1.10-1.73) or five tests of executive function (OR=1.41, 95% CI=1.10-1.80; **Table E6).**

Table E5: The cross-sectional (T3) association between low functional social support and low executive function pre-COVID-19 restrictions, in the Canadian Longitudinal Study on Aging: The impact of using two (n=10,786) vs five tests (n=10,124) of executive function

	Executive function (T3) (Low vs normal) assessed using MAT & AFT	**Executive function (T3) (Low vs normal)** assessed using MAT, AFT, STROOP, COWAT & TMT
	OR (95% CI)	**OR (95% CI)**
Social support (low vs high)	1.18 (0.89-1.57)	0.98 (0.72-1.35)
Over 65 (vs 45–64 years)	**3.84 (3.10-4.77)**	**4.12 (3.26-5.20)**
Female (vs male)	0.94 (0.81-1.10)	**0.72 (0.61-0.85)**
Education (vs post-secondary degree/diploma)		
Some post-secondary	1.21 (0.92-1.60)	1.21 (0.91-1.62)
High school graduate	**1.55 (1.24-1.93)**	**1.37 (1.08-1.74)**
Less than high school	**3.30 (2.58-4.21)**	**3.81 (2.95-4.91)**
Annual household income (vs < $20,000)		
≥ $20,000 and < $50,000	0.76 (0.56-1.04)	0.76 (0.55-1.05)
≥ $50,000 and < $100,000	**0.54 (0.39-0.75)**	**0.49 (0.35-0.69)**
≥ $100,000	**0.38 (0.27-0.55)**	**0.37 (0.25-0.55)**
Missing	1.06 (0.73-1.53)	0.85 (0.57-1.27)
Province (vs Ontario)		
Alberta	0.99 (0.75-1.29)	1.12 (0.84-1.50)
British Columbia	0.74 (0.58-0.93)	1.01 (0.79-1.29)
Manitoba	0.80 (0.61-1.06)	0.98 (0.73-1.32)
Newfoundland and Labrador	0.94 (0.69-1.27)	1.22 (0.89-1.67)
Nova Scotia	0.99 (0.77-1.29)	**1.43 (1.10-1.88)**
Quebec	0.84 (0.67-1.06)	0.82 (0.64-1.06)
Chronic condition (vs no conditions)		
1 condition	0.93 (0.71-1.23)	**1.39 (1.01-1.92)**
2 conditions	1.14 (0.86-1.51)	**1.85 (1.33-2.58)**
3+ conditions	1.15 (0.87-1.53)	**1.98 (1.43-2.76)**
Missing	1.25 (0.97-1.61)	**2.28 (1.69-3.07)**
Clinical depression (vs no)	0.93 (0.72-1.21)	**0.59 (0.44-0.81)**
Good or greater self-rated health (vs poor/fair)	**0.66 (0.53-0.81)**	**0.66 (0.53-0.82)**
Alcohol consumption in last year (vs non-user)		
Occasional user (<once per month)	0.83 (0.65-1.06)	0.89 (0.69-1.15)
Regular user (≥once per month)	**0.63 (0.52-0.76)**	**0.62 (0.51-0.75)**
*Marital status (*married/common-law vs not*)*	1.02 (0.77-1.33)	0.82 (0.62-1.09)
Loneliness (vs not lonely)	**1.37 (1.16-1.62)**	**1.22 (1.02-1.47)**
Living alone (vs not living alone)	1.03 (0.78-1.35)	0.95 (0.72-1.27)

Significant results are **bolded**.

Table E6. The cross-sectional (T3) association between low functional social support subtypes and low executive function pre-COVID-19 restrictions in the Canadian Longitudinal Study on Aging: The impact of using two (n=10,786) vs five tests (n=10,124) of executive function

	Five tests of executive function	Two tests of executive function (MAT & AFT)
	Executive function (Low vs normal)	**Executive function (Low vs normal)**
	OR (95% CI)	OR (95% CI)
Positive social interactions Low vs high	1.20 (0.93-1.54)	1.16 (0.91-1.47)
Emotional/informational Low vs high	**1.41 (1.10-1.80)**	**1.38 (1.10-1.73)**
Affectionate Low vs high	0.99 (0.77-1.27)	0.98 (0.77-1.24)
Tangible Low vs high	1.13 (0.86-1.47)	1.09 (0.85-1.41)

Significant results are **bolded**.

Fully adjusted models for each type of social support (overall and subtypes, run separately) include social support, age, sex, education, annual household income, province, chronic conditions, clinical depression, self-rated health, alcohol consumption, marital status, loneliness, living alone.

Appendix E.4: The longitudinal association between social support (T1) and executive function (T3) in the Canadian Longitudinal Study on Aging (CLSA) pre- and post-COVID-19 restrictions

Results for the longitudinal association between functional social support at baseline (T1) and executive function pre- and post-COVID-19 restrictions (T3) are included in **Table E7.** The longitudinal association between social support (overall and subtypes) and executive function was not significant for participants either pre- or post-COVID-19 restrictions.

Table E7. Summary of the longitudinal association between low social support (Overall and subtypes, T1) and low executive function (T3) pre- and post-COVID-19 restrictions in the Canadian Longitudinal Study on Aging

	Pre-COVID-19 Restrictions	Post-COVID-19 Restrictions
	Executive function [a] (Low vs normal)	**Executive function [a] (Low vs normal)**
	OR (95% CI)	OR (95% CI)
Positive social interactions Low vs high	0.94 (0.68-1.30)	1.23 (0.87-1.75)
Emotional/informational Low vs high	1.05 (0.77-1.44)	1.39 (0.98-1.98)
Affectionate Low vs high	0.81 (0.57-1.15)	0.78 (0.54-1.13)
Tangible Low vs high	0.95 (0.71-1.29)	1.39 (0.96-2.01)
Overall social support Low vs high	1.10 (0.76-1.59)	1.41 (0.95-2.12)

Significant results are **bolded**.
Fully adjusted models for each type of social support (overall and subtypes, run separately) include social support, age, sex, education, annual household income, province, chronic conditions, clinical depression, self-rated health, alcohol consumption, marital status, loneliness, living alone.
[a] Executive function was assessed using the AFT and MAT for both the pre- and post-COVID-19 restriction samples. Assessments were completed in-person pre-COVID-19 and via telephone interviews post-COVID-19 restrictions