PhD Thesis

Current Life Complexity and Its Relationship with Task-Switching Function in Young and Older Adults

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A thesis submitted for the degree of Doctor of Philosophy (Psychology) of The Australian National University.

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Declarations

I hereby declare that this thesis is my own original work, except where referenced and acknowledged, and has not been submitted for any other degree or qualification at this and any other university. The conceptualisation, methodology development, data collection, analysis and investigation, and the writing of the thesis were undertaken primarily by myself, with guidance, advice, feedback and support from my supervisory panel, and with suggestions provided by individuals acknowledged in the following section.

I would also like to declare that ChatGPT (Version 3.5) was used to generate equations based on text descriptions of calculation processes for current life complexity scores, and to debug R code in the process of data analysis and figure production. ChatGPT (Version 3.5) and Claude (Sonnet 4) were used for editorial assistance in alignment with Australian standards for editing practice, and restricted to Standard D, specifically for clarity of expression, voice and tone, and grammar and word usage. All outputs were reviewed, modified, and substantially refined by myself and my supervisory panel. No substantive work was undertaken by AI. I take full responsibility for this work.

Xuanning He

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"Principles for the Development of a Complete Mind: Study the science of art. Study the art of science. Develop your senses—especially learn how to see. Realise that everything connects to everything else."

—Leonardo da Vinci

Abstract

Globally, the proportion of people aged 60 and above is projected to increase from 14% in 2025 to 22% by 2050. Supporting the well-being of this growing older population requires a deeper understanding of cognitive functioning in later-life. The primary aim of the thesis was to gain further understanding of cognitive ageing by investigating the relationship between patterns of engagement in everyday activities and cognitive control in young and older adults. It was hypothesised that self-reported current life complexity and in-laboratory task-switching could be sensitive measures to detect decline under cognitive and behavioural compensation. Current life complexity was a novel concept proposed in this thesis, defined as the level of engagement in everyday activities during daily life that require individuals to invest cognitive resources. Task switching—the ability to alternate between tasks—was selected as an in-laboratory measure of cognitive control. Existing experimental studies showed that older adults were slower, and it was more effortful for them to switch between tasks, compared to young adults. To compensate for age-related changes, older adults tended to maintain accuracy by sacrificing speed of responding.

The most appropriate measure of current life complexity was sought through a conceptual literature review of pre-existing self-report instruments. This indicated no existing instrument was fit-for-purpose in assessing current life complexity. Consequently, a self-report Current Life Complexity Questionnaire (CLCQ) was developed by modifying an existing instrument, followed by evaluation through online-survey studies (Chapter Two; $N = 384$). The findings indicated there was adequate face validity for online participation, and meaningful scores could be extracted for assessing current life complexity.

The task-switching paradigms were selected by conducting a systematic review of task-switching in ageing (Chapter Three), which revealed substantial variability in task-switching paradigms and reporting of results. Two experimental studies, comparing two paradigms chosen on the basis of the systematic review, were undertaken in healthy young and older adults (Chapter Four). The first study ($N = 44$) involved a within-subject comparison of task-switching performance using a digit-based task-switching paradigm and a letter-based task-switching paradigm. The second study ($N = 86$) involved a between-subject comparison of task-switching performance with difficult-letter stimuli and easy-letter stimuli. Findings indicated that digit-based paradigms best captured reliable task-switching performance across age groups.

Having established the CLCQ through online-survey studies, and identified an appropriate task-switching paradigm through the systematic review and experimental studies, a third experimental study (Chapter Four) examined the association between current life complexity and cognitive control as measured by the digit-based task-switching paradigm in young ($N = 36$) and older ($N = 40$) adults. The final experimental study found no significant association between current life complexity as measured by the CLCQ, and task-switching function ($b = -3.73$, $t(34) = -1.18$, $p = 0.25$ for young participants; $b = -0.34$, $t(38) = -0.15$, $p = 0.88$ for older participants).

This thesis included a systematic review, the proposal of the novel concept of current life complexity, and the development and initial validation of the CLCQ. This theoretical groundwork facilitated the investigation of the relationship between current life complexity and in-laboratory task-switching. While the hypothesised relationship was not supported, this

work highlighted the importance of incorporating participant feedback in the development of self-report questionnaires and experimental procedures. These insights and measures provide a foundation for future research into patterns of engagement in everyday activities and cognitive control in ageing.

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Abbreviations and Glossary

Abbreviations

ACQ: Activities Characteristics Questionnaire

APA: American Psychology Association

CLCQ: Current Life Complexity Questionnaire

DDM: Diffusion Decision Model

EZ-DM: EZ-Diffusion Model

FCAS: Florida Cognitive Activity Scale

IADL: Instrumental Activities of Daily Living

MCI: Mild Cognitive Impairment

MoCA: Montreal Cognitive Assessment

REML: Restricted Maximum Likelihood

STAC: Scaffolding Theory of Ageing and Cognition

VLS-ALQ: Victoria Longitudinal Study Activity Lifestyle Questionnaire

VOSP: Visual Object and Spatial Perception battery

WHO: The World Health Organisation

Glossary

Base-Task: Two (or more) tasks that participants are required to switch sequentially between in the task-switching paradigm.

Cognitive Control: The control aspect of executive function, focusing on the ability to control thoughts and actions in alignment with internal goals.

Current Life Complexity: The level of engagement in everyday activities during daily life that require individuals to invest cognitive resources.

Digit Paradigm: The digit-comparison and digit-parity task-switching paradigm.

Effectiveness: The appropriateness of using the colour and letter base-tasks in the task-switching paradigm to measure task-switching performance, which will be reused in the subsequent content.

Executive Function: Functions that are intrinsic to the ability to respond in an adaptive manner to novel situations and are also the basis of many cognitive, emotional, and social skills

Functional Ability: The capacity that enable individuals to do what they intend and value to do.

Global-Switch Cost: Reaction time and accuracy differences between pure-block trials and the no-switch trials in the mixed-blocks.

Letter Paradigm: The letter-categorisation and luminance-discrimination task-switching paradigm.

Local-Switch Cost: Reaction time and accuracy differences between no-switch trials and switch trials.

Switch-Rule: It is used to instruct participants about what kind of task-switching will be required in a particular trial.

Switch Cost: Quantifiable measures of the cognitive effort required to make a switch between trials.

Chapter One

General Introduction

Chapter One: General Introduction

In the process of healthy ageing, most people will experience some degree of functional decline in later-life (Ranasinghe & Mapa, 2024). After the age of 60, individuals are more likely to experience neurodegeneration (Chai et al., 2024), cognitive decline (De Jager et al., 2005; Parent et al., 2023), and difficulty performing everyday activities (Ćwirlej-Sozańska et al., 2019). Among the global population, the proportion of people aged 60 and over will grow from 15% in the year 2025 to 22% in the year 2050 (World Health Organisation [WHO], 2025). In later-life, maintaining independent functional ability is a key factor in determining quality of life (Martinez-Martin et al., 2012). The maintenance of functional ability through preventive interventions may result in better performance outcomes in ageing, compared to regaining abilities through rehabilitation after decline has taken place (Berthelot et al., 2019; Hébert, 1997). Given the absence of cure or treatment for regaining functional abilities after decline such as with dementia, preventative interventions developed through identification of modifiable factors (e.g., lifestyle) becomes necessary (Barnett et al., 2015). Understanding age-related changes in functional ability is essential for facilitating early detection of decline, and for maximising opportunities for preventive interventions. This understanding is a crucial aspect in taking care of the ageing population and enhancing the quality of life for older adults.

1.1 Cognitive Ageing

Functional ability in later-life is a very broad concept. This concept can be viewed as the capability to perform activities that support independent and meaningful living, which aligns

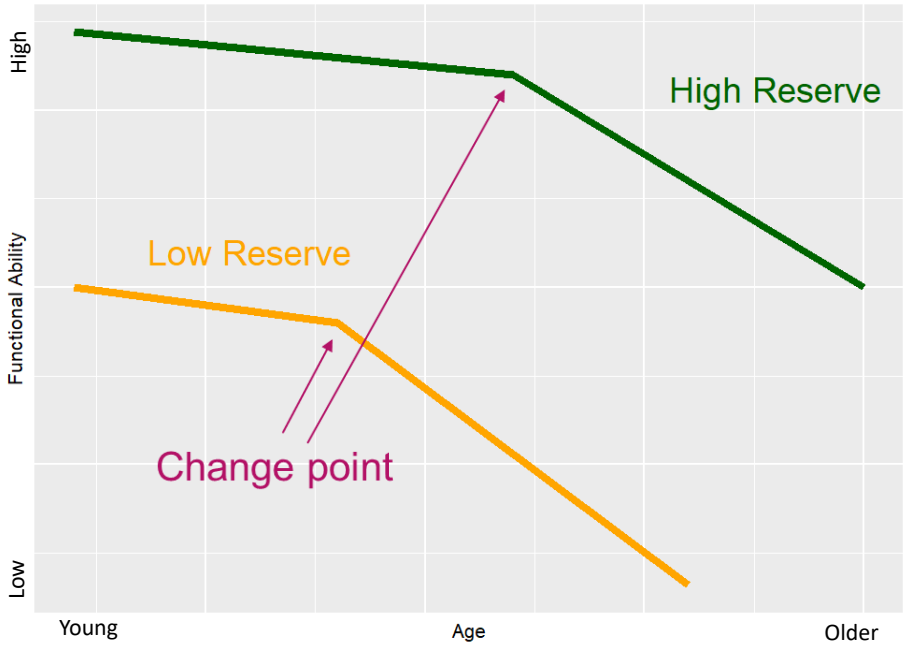
with an individual's values (WHO, 2020). Preserved functional ability can be represented by maintaining: capability of undertaking basic tasks such as getting dressed without assistance (Imoh Udoh et al., 2024; Katz, 1963); independence in living (Bezdicek et al., 2016; Lawton & Brody, 1969); friendships, contributing to a community and continuing to learn (Nishio et al., 2024); and sustained engagement in daily activities (Rowe & Kahn, 1997). As noted in Lezak et. al. (2012), three components of human behaviour that underpin complex functioning are cognition, emotionality, and executive functioning. Cognition refers specifically to information processing, emotionality to feeling and motivation, and executive functioning to the behavioural expression of intention (Lezak et al., 2012). Cognitive functioning is fundamental for later-life independence and quality of life (Song et al., 2023), as it refers to people's ability to think, learn, remember, and make decisions (American Psychological Association [APA], 2018a).

The lifespan perspective of ageing frames the age-related changes in later-life as part of the lifelong developmental process, which reflects the impact from lifetime neurological (Fjell, 2024), cognitive (Francis, 2021; Long et al., 2018), and socio-cultural factors (Kuwayama et al., 2024). The idea of lifelong development enables the incorporation of not only age-related decline, but also growth, adaptation, and change in later-life (Baltes, 1987). There are substantial individual differences in trajectories of cognitive functioning in ageing, arising from genetic factors (Reuter-Lorenz & Park, 2014), lived environment (Hertzog et al., 2008; Reuter-Lorenz & Park, 2014), education (Clouston et al., 2020), socioeconomic status (Skoblow et al., 2024), physical health (Wei et al., 2025), and attitude towards independence in later-life (Hertzog et al., 2008). Still, the typical trajectory of cognitive functioning in

ageing begins with gradual, normative, age-associated decline in later-life, which becomes more dramatic when it reaches a specific threshold (i.e., the "change point"; Figure 1.1). This "change point" can be represented as the point of the emergence of a pathological illness, but is often not a simple and direct reflection of a single causal source of decline (Barulli & Stern, 2013).

Figure 1.1

Model of the Trajectory of Cognitive Ageing in Functional Ability with the Effect of High/Low Cognitive Reserve; Adapted from Barulli and Stern (2013)



Note. This figure is a representation of age-related changes in functional ability. High Reserve = higher level of cognitive reserve. Low Reserve = lower level of cognitive reserve. Change point = a representation of various routes of experience in ageing. It can represent the point of the emergence of a pathological illness, or a failure in compensatory mechanisms, where physical decline cannot be overridden.

Compensatory mechanisms were incorporated into the explanation of the adaptation and maintenance of behavioural performance, in the face of age-related structural or functional changes in later-life (Baltes & Baltes, 1993; Martins et al., 2015). The APA (2018b) defined compensatory mechanisms as active or passive processes that are employed to counteract the decline, so as to achieve the goal of maintaining performance. Compensation can occur at the neural level, via cognitive strategies, and also through behaviours. In neural degeneration, compensation occurs by increasing neural activity, shifting which brain regions are activated, recruiting larger brain regions, and/or altering neural processes or networks (Bunzeck et al., 2024; Cabeza et al., 2018; Morcom & Johnson, 2015). A common strategy in older adults experiencing age-related reductions in cognitive resources is to sacrifice speed of processing to maintain accuracy of performance (e.g., Van Asselen & Ridderinkhof, 2000). As a consequence, older adults may perform a task as accurately as young adults, but more slowly. This can be seen in laboratory tasks, such as task-switching (Kray & Lindenberger, 2000) and mental rotation (Hertzog et al., 1993). It can also be seen in real-world behaviours, such as language comprehension (Silagi et al., 2015) and responding to traffic lights while driving (Salvia et al., 2016). A neurocognitive study conducted based on a perceptual decision-making task suggested that this age-related speed-accuracy trade-off was the result not only of strategy choices, but also of the structural limitations of the cortex (Forstmann et al., 2011). When this compensatory mechanism fails, and the sacrifice in speed is no longer sufficient to compensate for maintaining performance accuracy, the “change point” is reached and an apparently sudden decline in functioning can be observed. There are a number of factors that can influence the point at which decline in

cognitive ageing begins, and the capacity for successful compensation is reached.

The brain reserve theory emphasises the biological and neurological aspects of cognition, and suggests a larger brain volume and a greater number of neuronal connections can be beneficial in maintaining functional ability under physical decline (Stern et al., 2020). Cognitive reserve theory suggests that there is a protective effect of life experience, characterised by involvement in cognitively-demanding activities, emphasising the protective effect obtained from previous history but also acknowledging the protective effect obtained from experience in the current state of functioning (Stern et al., 2020). Higher cognitive reserve can result in a higher baseline level of functional ability, and/or more efficient compensatory mechanisms, which can delay the "change point" in the trajectory of decline in cognitive functioning (Barulli & Stern, 2013). Hence, preceding life experience is an important factor to consider in understanding the current state of functional ability under the context of successful ageing.

Successful ageing is a multi-dimensional concept that has received extensive research (e.g., see Daffner, 2010; Mana & Bezdicek, 2022). It involves the application of biomedical, psychological, and social approaches in order to understand how people adapt to age-related changes, and maintain functional ability in later-life (Urtamo et al., 2019). From the perspective of cognitive functioning, successful ageing is defined as maximising cognitive ability and maintaining engagement in active life (Estebsari et al., 2020). The revised Scaffolding Theory of Ageing and Cognition (i.e., the revised STAC model; Reuter-Lorenz & Park, 2014) and the Enrichment Effect model (Hertzog et al., 2008) fit within the broader conceptualisation of successful ageing. The STAC model draws from a neuropsychological

perspective, and in its revised form suggests two pathways that may operate beneficially and protectively: neural resource enrichment, where brain structure and function is directly enhanced through efficient neural connectivity; and life course enrichment factors (Reuter-Lorenz & Park, 2014). Factors such as engagement in activities and education can increase the compensatory scaffolding, which potentially introduces new neural connections to scaffold the pre-existing networks (Oosterhuis et al., 2023; Reuter-Lorenz & Park, 2014; Wook Yoo et al., 2015). The Enrichment Effect model (Hertzog et al., 2008) draws on a behavioural perspective, and is focused on behavioural influences on cognitive changes (e.g., Mao et al., 2023). The source of these changes includes focused cognitive interventions, mentally-enhancing activities (i.e., engaged lifestyle, or complex lifestyle) and other sources that provide opportunities for improving (i.e., enriching) mental and/or physical abilities through practice; thus allowing for the development of strategies and a more efficient distribution of cognitive resources (Hertzog et al., 2008).

1.2 From Cognitive Lifestyle to Current Life Complexity

Lifestyle is a complex concept with both commonsense and technical definitions, but broadly describes an individual's pattern of life choices (for reviews on the definition of lifestyle, see Brivio et al., 2023; Schwarzinger et al., 2024; Veal, 1993). Due to the role of voluntary choices, lifestyle is a reflection of an individual's habits, values, beliefs, physical and cognitive state. The focus of this thesis is on the cognitive aspects of lifestyle, which can be conceptualised and measured in a number of ways.

The Instrumental Activities of Daily Living (IADL) is a measure of real-world life

management tasks, including shopping, preparing meals, using the telephone, and using transportation within the community (Vaughan & Giovanello, 2010). Lower scores in IADL have been associated with accelerated cognitive decline in older adults (Rajan et al., 2013). In their systematic review, which focused on performance-based instrumental activities of daily living, Romero-Ayuso et al. (2021) suggested that worse performance was associated with deficits in executive functions and prospective memory.

Naturalistic multi-tasking tests, such as the Day-Out Task (McAlister & Schmitter-Edgecombe, 2013) involves a number of distinct tasks with goals and clear end points, such as preparing change for a bus fare while also dressing to leave the house. Participants are asked to multi-task and mix the tasks, in a way that they feel is most natural and most efficient. The outcomes of these tasks provide insight into current functional abilities, and either voluntary or automatic choices of real-life compensatory strategies. Schmitter-Edgecombe et al. (2012) found that participants experiencing Mild Cognitive Impairment (MCI) took more time to complete the day-out task, and with poorer accuracy, than participants experiencing healthy ageing.

The concept of engagement in daily activities (often referred to as activity engagement) is grounded in the idea of "use it or lose it" (see Bielak & Gow, 2023, for a review), where regular engagement in cognitively-demanding activities constitutes a form of practice that can result in preserving functional ability in later-life. Daily activity engagement is typically captured by self-report questionnaires, asking participants to indicate their frequency of being involved in a given activity for a given period of time. Support for the relationship between daily activity engagement and specific domains of cognitive functioning is mixed. Weaver

and Jaeggi (2021) reported a non-significant relationship between daily activity engagement and global cognitive functioning, which was measured by combining scores from working memory, episodic memory, and processing speed. In a longitudinal study, higher levels of leisure activity engagement were related to slower decline in memory among participants with Mild Cognitive Impairment (MCI; Armstrong et al., 2022). Bielak et al. (2019) found a significant association between the variety and frequency of daily activity engagement with performance of fluid intelligence. Rather than evaluating each of the daily activities individually, Bielak et al. (2019)'s approach focused on the relationship between the variety and frequency of daily activity engagement, and cognitive performance. This approach reflects the conceptualisation of lifestyle as a summary of patterns in life. Accordingly, strategic and behavioural compensation may be detectable through lifestyle, and assessed by the variety and frequency of daily activity engagement. This approach allows individuals to make compensatory adjustments according to their personal needs.

The Cognitive Reserve Questionnaire and measures of daily activity engagement move beyond a focus on basic daily functioning, and instead frame cognitive lifestyle more strongly within a lifespan perspective of successful ageing. The Cognitive Reserve Questionnaire is a proxy measure of current and lifetime engagement, including eight elements (years of education, years of parents' education, occupation, number of training courses, musical training, number of languages spoken, reading activity, and involvement in intellectual games; Garcia-Gorro et al., 2019). Higher scores on this measure were thought to reflect both a better chance, and a greater strength in preserving cognitive function in later-life (Garcia-Gorro et al., 2019; Nogueira et al., 2022). Higher cognitive reserve scores were also

associated with neural compensation, especially in a much later stage of ageing (Anthony & Lin, 2018).

The concept of selective optimisation with compensation suggests that individuals select categories in which they invest energy, time, and cognitive resources to acquire knowledge and experience (Baltes & Baltes, 1993). Individuals cannot develop knowledge and experience in all domains due to limitations in cognitive resources. In the process of cognitive ageing, the level of investment a person can make across categories of activities can reflect a combined result of the extent of their available cognitive resources, their current state of cognitive functional ability, and the efficiency of their compensatory mechanisms. The complexity of current lifestyle is a real-life representation of the level of investment. Although the existence of a connection between the complexity of current lifestyle and cognitive functioning has been supported by daily activity engagement literature (Bielak & Gow, 2023), the nature and the underlying mechanism of this connection remains unexplained. Changes in the complexity of individual's current lifestyle can reflect either the results of age-related cognitive changes, the cause of the cognitive changes, or both the results and the cause of the cognitive changes. Under either of these possible connections, compensatory mechanisms can be in effect and mask the direct relationship between cognitive functioning and cognitive lifestyle. Hence, there is clear scope for investigation of the relationship between cognitive lifestyle and current cognitive status, and the identification of cognitive and behavioural compensation.

To quantify the complexity of current lifestyle, this thesis introduces the multi-dimensional concept "current life complexity", defined as the level of engagement in

everyday activities during daily life that require individuals to invest cognitive resources. Cognitive investment is a combination of the breadth of involvement (i.e., the number of activity categories a person invests in), and the depth of involvement (i.e., the time and energy invested into each of the activity categories). More activity categories and greater depth of involvement indicate a more complex lifestyle. Current life complexity describes the overall complexity of the pattern of investment in categories, rather than focusing on the engagement with any given category. When cognitive resources are sufficient, it is proposed that people are more likely to maintain a complex life. When cognitive resources become insufficient and compensation is needed, reduction in life complexity might be a way to preserve functioning. A person's life complexity may be reduced in two ways. First, an individual can choose to reduce the number of categories of activities they are involved in, to preserve the level of performance in other categories. Second, an individual can also reduce the depth of involvement in each selected category, to preserve the total number of categories engaged in. Such behavioural compensation is conceptually similar to speed-accuracy trade-offs seen in cognitive tests in ageing. Furthermore, both forms of compensation relate to cognitive control.

1.3 Executive Function and Cognitive Control

Executive function (also known as cognitive control) is defined by Lezak et al. (2012) as "functions that are intrinsic to the ability to respond in an adaptive manner to novel situations and are also the basis of many cognitive, emotional, and social skills" (p.38). There are a number of competing conceptualisations and definitions of executive function (e.g.,

Diamond, 2013; Lezak et al., 2012) arising from different research traditions. Definitions with a neurobiological focus primarily consider both neurotransmitter and brain structure, those with a psychological focus primarily consider behaviours, and those with a computational focus primarily on the connection between neural networks and behavioural structures (Banich, 2009). The current investigation follows Lezak et. al. (2012)'s definition, due to its wide use in relevant literature (e.g., Franzen et al., 2020; Gruters et al., 2022; Sokolovič et al., 2023), and because the psychological and behavioural focus align well with considerations of cognitive processing and daily functioning.

Executive function is important for making plans and carrying out intentional activities, and is thus crucial in maintaining independence even under conditions of cognitive decline (Lezak et al., 2012). Independence is also suggested to be an effective indicator of quality of life (Martinez-Martin et al., 2012). The maintenance of a cognitively-demanding lifestyle, as is the case in a person with a more complex current life, requires sufficient executive functioning across the sub-domains of executive function outlined by Lezak et al. (2012): volition, planning and decision making, purposive action, and effective performance.

Volition (Haggard, 2019), planning and decision-making (Yang et al., 2018) are processes that are responsible for mental processing and intention formation before carrying out the actual performance (Lezak et al., 2012). This relies on an understanding of individuals' current environment, their relationship with it, and potential changes in status as the results of the action, requiring impulse control, sustained attention, and a clear perception of reality. Purposive action and effective performance are two of the components that are responsible for connecting and transforming the intention into actual behaviour (Lezak et al.,

2012). This relies on recognising, identifying, and adjusting responses according to mistakes in behaviour, necessary for adapting to dynamically changing circumstances (e.g., Chiu et al., 2021). Both effective functioning in purposive action and effective performance are crucial for maintaining independence in living, as both functions enable individuals to manage and adapt to unexpected changes (Lezak et al., 2012). This has been assessed with a performance-based task by Lahav and Katz (2020), where participants were asked to plan for their weekly calendar.

Self-regulation is required for constructing sensible connections between intention to act, and action (Lezak et al., 2012). This requires flexibility, the capacity to shift one's thoughts and actions in response to changing situational requirements, which connects with the concept of effective performance, where behaviours are monitored and corrected when necessary (Lezak et al., 2012). This is similar to cognitive flexibility as outlined by Diamond (2013), and "cognitive control". Although at times "executive function" has been used interchangeably with "cognitive control", cognitive control focuses specifically on the ability to control thoughts and actions in alignment with internal goals (Friedman & Robbins, 2022). It involves the active maintenance of task-relevant information and the suppression of task-irrelevant information or habitual responses. Flexibility as explained by Lezak et. al. (2012), cognitive flexibility as explained by Diamond (2013), and cognitive control as explained by Friedman and Robbins (2022) are the conceptual components of executive function as viewed from different perspectives. However, they are similar in their importance, in allowing an individual to efficiently carry out intentional behaviours and adapt to changes. The flexibility component of executive function was found to be directly associated with instrumental

activities of daily living, which was an important indication of living independently (Verreckt et al., 2022).

In conclusion, all four of the executive function sub-domains categorised by Lezak et al. (2012), as well as flexibility within self-regulation, are crucial elements in the process of efficiently carrying out intentional behaviours, and are potentially related to the capacity and management of the investment of cognitive resources in lifestyle. This is of direct relevance to the maintenance of current life complexity, especially in later-life when cognitive resources become limited and people need to adapt to this change in cognitive capacity.

1.4 Task-Switching

Task-switching is the in-laboratory executive function that directly reflects the ability to adapt to changes. Sometimes known as set-shifting or cognitive flexibility, task-switching is the ability to alternate between multiple tasks sequentially (Ging-Jehli & Ratcliff, 2020; Jersild, 1927). While classically measured in controlled laboratory tasks in a short timeframe with highly simplified task scenarios, task-switching is also common in situations where a person must "adapt to changes" in daily life. For example, preparing for a meal (one component of the IADL), requires individuals to switch between tasks such as cutting ingredients, to operating a stove, and boiling water.

Task-switching paradigms were first developed by Jersild in 1927 (Jersild, 1927; Spector & Biederman, 1976), but became more widely used in the mid-1990s. The paradigm is characterised by requiring participants to switch between two (or more) tasks where the rules for switching differ between different tasks. The costs of switching, commonly named as

switch costs, are most often measured by differences in accuracy or reaction time between switch and no-switch trials (or blocks). Larger switch costs are seen as requiring more effort when switching between tasks.

There have been a number of studies exploring the association between task-switching performance and real-world functioning. Vaughan and Giovanello (2010) reported a significant association between task-switching and instrumental activities of daily living. Better task-switching performance was associated with a higher level of physical activity in both young (Kamijo & Takeda, 2010) and older adults (Dai et al., 2013). Mas-Herrero et al. (2021) suggested that the unique cognitive experience created by bilingualism was associated with better performance in task-switching in young participants. However, Chen and Yow (2023) found this association between bilingualism and task-switching only in cognitively healthy older participants, not older participants with cognitive impairments.

When participants were given voluntary control in task-switching decisions, older adults demonstrated a preference for avoiding task-switching rather than choosing to switch between tasks (Butler & Weywadt, 2013). This strategy reduces the cognitive demands associated with adapting to changes in the experimental setting. However, as demonstrated by Van Asselen and Ridderinkhof (2000), when task-switching is a requirement of the experiment, older adults compensate by prioritising accuracy over speed. These findings reflect a consistent compensatory principle: older adults prioritise accuracy and quality over speed and quantity when cognitive resources become limited. Specifically, they compensate for cognitive resource constraints by reducing task complexity to maintain performance quality on remaining activities. This shared compensatory principle provides a theoretical

foundation for linking real-world lifestyle patterns (i.e., current life complexity) with in-laboratory experimental measures (i.e., task-switching performance).

1.5 Link Between Current Life Complexity and Task-Switching

There are two potential ways that current life complexity might relate to control mechanisms: a direct relationship and a compensatory relationship. First, in the direct relationship, slowing and simplification in daily functions may be related to slowing and simplification in control mechanisms. For instance, age-related decline in speed of reacting and capacity for multi-tasking can result in impaired driving performance, and consequently the loss of a driver's license (Wechsler et al., 2018, Wetton et al., 2011). Second, in the compensatory relationship, there is decline in one or more domains of cognitive control mechanisms that is compensated for through increased effort or reduction of engagement in other domains. For example, consider an older adult, whose main daily cognitive tasks were driving to shops, shopping, and cooking meals. Ability to complete these tasks successfully relies to some degree on preserved task-switching ability (Wechsler et al., 2018; Park, 2022; and Wang et al, 2011 respectively). Due to age-related changes in cognitive functional ability, this older adult may experience cognitive decline, including reduced task-switching ability, which makes it difficult to maintain their prior level of lifestyle complexity. Instead of driving, shopping, and cooking, this older adult might choose to take a bus to the shops, and use the effort and time saved from driving to continue shopping and cooking as much as before. However, after the change point (illustrated in Figure 1), when compensatory mechanisms fail, the association between current life complexity and control mechanisms

might become a direct relationship, and this older adult may now give up shopping and cooking and instead order from food delivery services.

Lifestyle patterns we conceptualised in this thesis go beyond activity engagement, by focusing on investment in different activities. Stine-Morrow and Manavbasi (2022) provided a theoretical framework suggesting that engagement is not a simple construct but a multi-dimensional investment of personal resources into one's ecosystem. This investment consists of distinct but interrelated forms: time investment, deep cognitive investment, relationship-focused investment, and investment that is influenced by personal experience and individual differences. Stine-Morrow and Manavbasi proposed that these forms of investment operated based on trade-offs between adapting to changes and novelty, and developing stable, efficient expertise (i.e., specialisation). This ecosystem perspective assumes that individuals can actively construct their cognitive ageing trajectory by making choices in how to invest their resources into different forms of cognitive engagement. This aligns with characteristics of the concept of current life complexity, where the breadth of involvement, the depth of involvement, and the variability across the involvement are important to consider in the investigation of the role of current life complexity in cognitive ageing. Cognitive reserve represents the historical experience of the individual, and is another important component of the ecosystem because it serves as the basis for how individuals make choices in their current state. This historical experience needs to be taken into account, for the purpose of gathering a comprehensive understanding of the current lifestyle pattern. Consistent with Stine-Morrow and Manavbasi' framework, Brown et al. (2023) provided critical evidence that the diversity of daily activities, capturing both the variety and frequency of engagement, is associated with

better cognitive functioning in later-life. They concluded that the cognitive benefits of an "active lifestyle" were tied to the cognitive demands of managing and shifting between varied goals and environments. Their idea of managing and shifting between varied goals and environments align with the underlying mechanisms of the “adapt to changes” component of executive function.

The ability to “adapt to changes”, as represented by task-switching performance, may only be one of the factors influencing current lifestyle patterns in older adults. Other factors that could influence lifestyle patterns include financial concerns (Stalling et al., 2022), available social support (Lewis et al., 2022), and physical accessibility (Witten et al., 2012). However, these factors are either based on the physical status of the individual, or they rely on the external environment, hence they are less able to be controlled by the individual. To gather a comprehensive understanding that informs healthy ageing, it is important to investigate the role of external factors for making changes to lifestyles in older age. While the effects of the physical and environmental factors on activity patterns are well-established, variations in individual differences remain unaccounted for, leading to a potential knowledge gap in the literature. The relevance of environmental factors to lifestyle patterns varies across individuals with different physical needs, and living in different environments (Annear et al., 2014; Belachew et al., 2024). Cognitive constructs, such as executive functions (e.g., task-switching), as well as compensatory mechanisms, represent predictors of functional ability that are shared across all individuals (Cepeda et al., 2001; Hall & Marteau, 2014). Accordingly, the investigation of the potential association between lifestyle patterns and task-switching performance offers a pathway to generate explanations with potential

generalisability across different populations of older adults.

The potential link between current life complexity and task-switching was assumed to exist and be in effect over an extended period of time, rather than at a daily or momentary level. A shorter timeframe was not considered to be adequate, due to the potential effect of temporary state-dependent fluctuations in task-switching performance and daily activity engagement, as a result of transient states, such as fatigue (Zhong et al., 2022), acute stress (Morava et al., 2023), or changes to routine such as holidays (Olds et al., 2019). Similarly, activity enjoyment can vary seasonally (Ferguson, 2021).

A one-year observation period provides a more reliable assessment of cognitive functional ability, avoiding the possibility of drawing erroneous conclusions from a non-representative timeframe. Longitudinal studies on task-switching (Hasanzadeh et al., 2025) suggest that sustainable changes in task-switching function can be observed over a period of one year. In people with Mild Cognitive Impairment (MCI, Tabatabaei-Jafari et al., 2017), individuals can progress to more serious decline or revert back to their normal cognitive functioning within one year. Longitudinal studies on lifestyle changes (Hughes et al., 2018) have had the common practice of following up on the timescale of years. For example, VLS-ALQ studies (Hultsch et al., 1999) recorded participants' activity engagement covering two years of time, with a focus on measuring precision over a period of a year.

1.6 Overview of the Thesis

The primary aim of this thesis was to investigate the relationship between current life complexity and task-switching function in young and older adults. In later-life, compensation

can be assessed by both current life complexity and task-switching performance, using indicators such as reduced breadth/depth in current life complexity, and speed-accuracy trade-offs in task-switching, respectively. If these indicators of compensation arise from shared underlying age-related changes in the flexibility aspect of executive function, then the compensation observed in current life complexity should correlate with compensation in task-switching performance. It was hypothesised that individuals demonstrating higher current life complexity would also exhibit better performance on in-laboratory task-switching tasks. When individuals are experiencing cognitive decline, compensatory strategies should be present at the level of current life complexity and in-laboratory task-switching. Further, due to the increased need for compensation in older adults with cognitive decline, this association is proposed to be stronger in older adults, compared to young adults. The outcome of these studies could inform the selection of sensitive measures to detect decline alongside cognitive and behavioural compensation. This investigation also could provide further understanding of cognitive lifestyles that support early detection of cognitive decline as well as maintenance of later-life functional abilities.

The thesis begins with a general introduction introducing and reviewing relevant concepts of current life complexity and task-switching (Chapter One: the current chapter).

Real-life current life complexity is assessed by a questionnaire newly developed and validated in this thesis. Chapter Two contains a literature review of pre-existing self-report instruments designed to capture cognitive lifestyle or daily activity engagement. Consequently, a self-report Current Life Complexity Questionnaire (CLCQ) was developed by modifying the Victoria Longitudinal Study Activity Lifestyle Questionnaire (VLS-ALQ;

Hultsch et al., 1999), followed by evaluation through online-survey studies. This chapter contains three sub-studies: a pilot study investigating the usability of a Likert Scale versus a Slider Scale in young participants, a test-retest study on young participants and older participants comparing the initial modification of the VLS-ALQ versus the CLCQ, and finally, a norming study on an online sample of Australian adults to evaluate the quality of the CLCQ.

In-laboratory experimental task-switching function was assessed using one of the commonly used paradigms in laboratory settings, the task-switching paradigm developed by Jersild (1927) almost a century ago. Before using the task-switching paradigm to investigate the relationship between task-switching function and cognitive lifestyle, it was important to understand how the task switching paradigm as used with older participants had evolved over time. Following best practice in understanding the history and current state of evidence (Siddaway et al., 2019), existing systematic reviews on task-switching in ageing were consulted. Meta-analyses suggested compensation was detectable, in that older adults responded to the tasks more slowly than young adults in task-switching paradigm (e.g., Wasylyshyn et al., 2011). However, Chen and Hsieh (2023) found that the evidence provided in the current literature was not sufficient to confirm that the cost of switching was significantly larger in older adults. There was also no existing literature regarding the evolution of the task-switching paradigm. Chapter Three presents a systematic review focusing on summarising modifications of task-switching paradigms that have been tested in older adults, and selecting the most appropriate task-switching paradigm that could be used in young and older adults.

Experimental studies were conducted to further identify the most suitable measure of task-switching, by modifying and comparing task-switching paradigms (see Chapter Four). Finally, combining the results of these two approaches, the associations between current life complexity and the task-switching function in both young and older adults were investigated. The fourth chapter contains three sub-studies:

1) Study 1 was a comparison of paradigm effectiveness between two task-switching paradigms (selected on the basis of findings from the systematic review in Chapter Three).
2) Study 2 was a comparison between easy and difficult letter stimuli in a task-switching letter paradigm to examine the impact of stimulus difficulty.
3) Study 3 was an investigation of the relationship between current life complexity and task-switching function in young and older adults.

The thesis concludes with Chapter Five (General Discussion), which summarises and evaluates the findings of the whole thesis, and suggests further directions for studies in the area of cognitive ageing, cognitive lifestyle, and executive function.

Chapter Two

Development and Initial Validation of the Current Life Complexity Questionnaire

Development and Initial Validation of the Current Life Complexity Questionnaire

2.1 Introduction

2.1.1 Life Complexity and Cognitive Capacity

The multi-dimensional concept "current life complexity" is defined as the level of engagement in everyday activities during daily life that require individuals to invest cognitive resources. The dimensions of the concept are represented by the breadth of involvement across activity categories (i.e., the number of activity categories a person invests in) and the depth of involvement in these activity categories (i.e., the time and energy invested into each of the activity categories), with more activity categories and greater depth of involvement indicating a more complex lifestyle. Current life complexity describes overall complexity of the pattern of investment in categories, rather than focusing on the engagement with any given category. When cognitive resources are sufficient, people are more likely to maintain a complex life. When cognitive resources become insufficient, and compensation has to take place, reducing life complexity might be a way of protecting the efficiency of the more important categories. A person's life complexity may reduce in two ways. First, an individual can choose to reduce the number of categories of activities they are involved in, to preserve the level of performance in other categories. Second, an individual can also reduce the depth of involvement in each selected category, to preserve the total number of categories engaged in. The purpose of the current study is to establish a "current life complexity" self-report questionnaire.

2.1.2 Challenges in The Measurement of Current Life Complexity

2.1.2.1 General Challenges in Self-Report

The measurement of current life complexity faces multiple methodological challenges, several of which are general challenges of self-report measurements, as discussed in DeVellis and Thorpe (2022). Face validity is the extent to which the meaning of a questionnaire is apparent, or whether extended explanation is necessary for participants to understand the meaning of the questions as intended by the questionnaire developer (Haynes et al., 1995). High face validity could lead to better participant experience and enhanced engagement with a measure (Kemper, 2017). Poor face validity could lead to collecting data with unsatisfactory quality and thus lead to potentially misleading findings (Allen et al., 2023). It could also lead to unnecessarily burdensome survey-taking experiences for participants. Poor face validity could arise from confusingly constructed questions, and/or an attempt to investigate a complex concept with limited numbers of questions (Allen et al., 2023). Current life complexity is a multi-dimensional concept, in a way that may impact face validity. Understanding questions asked about daily life might be easy, but the underlying reasons for asking might create uncertainty for participants.

Due to its multi-dimensional nature, it is unlikely that the concept of current life complexity could be captured by a single, or even a few questions. Response burden has long been a concern that could harm the quality of data collected by questionnaires (Yan & Williams, 2022). Extended length of a questionnaire could lead to intolerable burden for participants. However, to obtain a comprehensive overview of participants' lifestyle, multiple questions needed to be asked. The appropriate length of life complexity questionnaires needs

further exploration.

Current life complexity requires reflection on activities that have been previously undertaken. Even without intentional deception, the human memory can introduce errors when answering retrospective recall questions (Öztaş Ayhan & Işiksal, 2005). The required recalled time frame for answering any given questionnaire is an important factor that influences the level of recall bias (Bhandari & Wagner, 2006). The selection of the most suitable questionnaire for measuring current life complexity also needs to address this issue appropriately.

2.1.2.2 Challenges Specific to Measuring Cognitive Lifestyle

Lifestyle is an overarching concept that has been used to describe a number of different aspects of living (Jensen, 2009). The concept of lifestyle as discussed in the current work is multi-dimensional, and cognition-focused. It summarises people's patterns of activities over days, weeks and months (e.g., Zhang et al., 2021), which can be used to make inferences about people's current cognitive state. There are large variations in lifestyle across different countries, generations, occupations, personalities, and other individual characteristics (e.g., O'Donoghue et al., 2018). Within the same individual, the meaningful domains of lifestyle could change over time, and across different circumstances. An individual's lifestyle at school age might differ largely from the same person's lifestyle after entering the work force. Some aspects of lifestyle are more self-selected and interest-based (e.g., reading), and other less self-selected but function-based (e.g., driving). As the result of this large variation across individuals, an exhaustive list of daily activities within the concept of lifestyle has not been

established or agreed upon. Instead, it is common practise in the lifestyle literature to group activities into meaningful categories, such as physical activities or social activities (e.g., Marr et al., 2021).

2.1.2.3 Challenges with Validating the Measurement of Current Life Complexity

The concept of current life complexity is derived from the concept of lifestyle. It inherits the multi-dimensional nature of lifestyle, but rather than summarising activities it focuses on the breadth, the depth, and the variability of the involvement in activities across different categories. As with lifestyle, any measurement of current life complexity needs to be as inclusive as possible in terms of capturing all the possible meaningful categories of daily activities for different people. Adequate measurement needs to capture variability within and between categories of activities, and within and between participants, as well as the breadth and the depth of engagement with activities across meaningful categories. This focus on "complexity" means that traditional scale construction techniques such as factor analysis cannot be utilised. For example, factor analysis aims to reduce the number of dimensions, instead of measuring or representing it. These issues need to be addressed in the selection or development of the appropriate current life complexity instrument.

2.1.3 Existing Measures of Current Lifestyle

We evaluated existing measures of lifestyle to identify the most appropriate measure for of the concept of current life complexity.

2.1.3.1 Cognitive Reserve

Cognitive reserve refers to the brain's resilience to cognitive decline, typically associated with ageing (Stern, 2002; Tucker & Stern, 2011). The concept of cognitive reserve is different from cognitive lifestyle (which is a long-term, self-selected living pattern) and current life complexity (which places emphasis on the breadth and depth of daily involvement in cognitively-demanding activities). The measurement of cognitive reserve focuses on the life course history of cognitive experiences. The Cognitive Reserve Index Questionnaire (CRIq; Nucci et al., 2012) asks about previous education, occupation, leisure activity undertaken at one's peak in life. The Cognitive Reserve Questionnaire (Garcia-Gorro et al., 2019) includes eight elements (years of education, years of parent's education, occupation, number of training courses, musical training, number of spoken languages, reading activity, and involvement in intellectual games). Higher scores on this measure are associated with preserved executive function (Garcia-Gorro et al., 2019). While the concept of cognitive reserve is relevant to life complexity, the focus is much less on current involvement of cognitively-demanding activities, and therefore, not suitable for our purpose of assessing current life complexity.

2.1.3.2 Instrumental Activities of Daily Living (IADL)

The IADL was developed to assess instrumental competence, defined by the authors as the level of everyday independent functioning competence on real-world life management tasks, including telephone use, shopping, preparing meals, and using transport within the community (Vaughan & Giovanello, 2010). The IADL typically generates a single score that

represents the participants' independent functioning competence, with higher scores associated with computer-based measures of executive functioning, including task-switching (Vaughan & Giovanello, 2010). This is similar to current life complexity in the way that both measurements are focused on relatively demanding daily activities. However, the IADL is distinct from current life complexity as the IADL is not measuring a long-term living pattern, and does not capture the breadth and depth of daily involvement in cognitively-demanding activities.

2.1.3.3 Naturalistic Tests (The Day-Out Task)

The day-out task was developed based on discussion of the ecological validity of in-lab executive function tests (Burgess et al., 1998), so as to provide a measurement that more closely mimics the daily environment that requires executive functions (Schmitter-Edgecombe et al., 2012). It requires participants to complete tasks to prepare for a day out (e.g., McAlister & Schmitter-Edgecombe, 2013), asking them to multi-task and interweave sub-tasks whenever they prefer, in the most comfortable and efficient way from the perspective of participants. Researchers then are able to observe and analyse how individuals prioritise and switch between tasks in this naturalistic setting.

The day-out task was originally used to assess the everyday functioning of patients with Mild Cognitive Impairment (MCI), who took more time to complete the day-out task and with poorer accuracy than the non-MCI control group (Schmitter-Edgecombe et al., 2012). McAlister and Schmitter-Edgecombe (2013) suggested that compared with young adults, older adults take longer to compete all of the day-out tasks, and are less efficient in

completing the tasks.

The description of the day-out task, and how it is used, are generally consistent. This task provides a direct observation of everyday performance under cognitively-demanding realistic situations, which can be used in a controlled experimental study. However, this task is an intensive and short-term measurement of real-time behaviours, so does not capture long-term patterns and daily involvement in activities needed to assess current life complexity.

2.1.3.4 Time-Use Record

The measurements in the time-use records are either an experience sampling method, which asks participants to keep a diary of their daily schedule, or a self-report method, which asks participants to recall their 24-hour time-use for a typical weekday and a typical weekend day retrospectively (Day Reconstruction Method Study; Möwisch et al., 2019). The time-use record methods were first developed in the 19th century, and were used for monitoring economics and labour (for a narrative review, see Bauman et al., 2019). In the field of psychology, previous investigations used the time-use record to assess the relationship between daily activity patterns and well-being (e.g., Tomczyk et al., 2021). Time-use records are appropriate to capture the concept of current life complexity. For example, Jarosz (2023) used time-use records to investigate age-related changes in lifestyle complexity, and concluded that complexity decreased with age.

In the analysis of time-use records, a group of studies (Lee et al., 2020, Lee et al., 2023) calculated daily activity engagement scores using the Shannon's entropy index, ranging between 0 and 100. A score close to 0 indicates low diversity in activity engagement, whereas

a score close to 100 indicates high diversity in activity engagement. The Shannon's entropy approach of assessing activity diversity is aligned with the breadth of involvement aspect of the concept of current life complexity.

The level of detail provided comes at the cost of high participant burden, is rarely used for measuring lifestyle pattern over an extended period of time, and requires data be collected prospectively. Participants' willingness to take part in in an extended experience sampling study can be hard to manage, alongside a high potential time and financial cost for the researcher. This makes time-use records challenging to use with larger sample sizes.

2.1.3.5 Florida Cognitive Activities Scale (FCAS)

The FCAS is a cognitive activity engagement measurement developed for the Charlotte Country Healthy Ageing Study (CCHAS, Schinka et al., 2005). This is similar to the concept of current life complexity in the way it works as it is an attempt to quantify and access the "simulation provided by everyday cognitive and social activities" (Schinka et al., 2005, p.108). Schinka et al. (2005) indicated that a higher FCAS score was associated with higher education level and better cognitive performance. A higher FCAS score was also found in healthy older individuals, compared to individuals with mild cognitive impairment and early-stage Alzheimer's disease (Schinka et al., 2010).

However, the investigation of simulation of activities in the FCAS studies focuses on the most cognitively-demanding activities and the maintenance of activities over time, which are distinct from the focus of complexity in the concept of current life complexity. Due to this distinction, the FCAS does not align with the requirement of containing a vast variety of daily

activities for measuring current life complexity. The same limitation applies to other activity engagement measurements (e.g., Weaver & Jaeggi, 2021), with the exception of the Activities Characteristics Questionnaire (ACQ; Bielak, 2017). However, the ACQ focuses intensively on the activity patterns within a day, which does not align with investigating long-term patterns and daily involvement in activities required for assessing current life complexity.

2.1.3.6 Lifestyle Activity Questionnaire (LAQ)

The LAQ is a lifestyle activity developed by Carlson et al. (2012). This questionnaire utilised a composite engagement score—multiplying the time spent on each of a possible 20 activities by a score given by experts—that reflected the activity's cognitive demand. A higher expert-rated score for an activity was an indication of the activity being more cognitively-demanding. This practice resonates with the "depth of involvement" aspect in the concept of current life complexity. A score for variety and a score for frequency were also extracted from the LAQ, which resonate with the "breadth of involvement" and "depth of involvement" aspects in the concept of current life complexity. A greater variety of lifestyle activities was associated with a significant 8-11% reduction in the risk of verbal memory and global cognitive impairment. This relationship was more strongly predicted by the variety of participation than by the frequency of activities, or the degree of cognitive challenge (Carlson et al., 2012). A similar method of scoring activity engagement was used in Soldan et al. (2021), who found that greater cognitive activity engagement was associated with higher connectivity within the dorsal attention network.

The expert-led approach used in developing LAQ was reliable, but limited in its

ecological validity. The list of 20 activities might not capture the full breadth of daily activities that would be relevant across diverse populations and temporal contexts, and the perspectives of the experts might reflect cultural and generational biases. Specifically, the list of activities and the cognitive demand weights used in Carlson et al. (2012) may be less applicable and relevant to people's current lifestyle in 2025, particularly given advancements in technology that can reduce cognitive demand across a number of domains.

2.1.3.7 Victoria Longitudinal Study Activity Lifestyle Questionnaire (VLS-ALQ)

The VLS-ALQ is an activity lifestyle measurement developed for the Victoria Longitudinal Study (Hultsch et al., 1999). It is described by the authors as measuring the "engaged lifestyle", defined as "participation in cognitively-demanding activities" (Hultsch et al., 1999, p. 246). This is similar to the concept of current life complexity in the way that both concepts focus on cognitively-demanding activities, and capture the depth of involvement in those activities.

The VLS-ALQ has undergone substantial modification over time. The original full version (Hultsch et al., 1999) included 70 items covering six domains including physical activities (e.g., jogging), self-maintenance activities (e.g., preparing a meal), social activities (e.g., talking to a friend), hobbies and home maintenance activities (e.g., playing a card game and doing household repairs), passive information processing (e.g., watching TV), and novel information processing (e.g., learning a new skill). Participants were instructed to rate their frequency of involvement in the listed activities using a 9-point Likert Scale from Never to Daily (9-points includes: Never, Less than once a year, About once a year, Two/three times a

year, About once a month, Two or three times a month, About once a week, Two/three times a week, Daily). A shorter 57-item version of the VLS-ALQ was validated by Jopp and Hertzog (2010). Later, in the 62-item version modified by Marr et al. (2021), three items from the original 70-item version (listening to radio, attending concert/play, attending sports events), and two new items that were not included in the original questionnaire were included (going to galleries/museums, going to pubs/social clubs).

The description of the VLS-ALQ measures, and how it is used, varies across the literature. It has been used to explore the association between: "engaged lifestyle" and cognitive performance (Hultsch et al., 1999); "lifestyle activities" and injuries in ageing (Rivan et al., 2021); "lifestyle activities" and successful ageing (Vanoh et al., 2019); "overall activity level" and wellbeing (Shryock, 2022). In analyses, the VLS-ALQ is typically deconstructed into sub-scales which are used as separate scores, either together (e.g., social activity, physical activity, and cognitive activity, as in Brown et al., 2016), or as subscales administered and analysed separately (e.g., just social engagement, as in Casazza et al., 2023; or just physical activities, as in Thibeau et al., 2019). In some instances, individual activities are the unit of analysis (e.g., Vanoh et al., 2019). This analysis approach captures the depth of involvement in the activities, but the breadth of involvement required by the concept of current life complexity has not been explored to date.

2.1.3.8 A Summary and Comparison across Measurements

As indicated in Table 2.1, compared to other available measures, the VLS-ALQ is the most viable basis for assessing current life complexity.

Table 2.1

A Comparison Between Potential Measures of Current Life Complexity (CLC)

Measures	General Comment	Cognitive Lifestyle	Life Complexity
Cognitive Reserve Measurements	Valid Measure, but is a measure of a construct distinct from the CLC.	Not a measure of current lifestyle.	Not a measure of current lifestyle.
IADL	Valid Measure, but is a measure of a construct distinct from the CLC.	Focus is on the functional aspect of lifestyle.	Can be modified to fulfill the need to measure complexity.
Naturalistic Tests	Valid Measure, but needs a naturalistic setting and scoring scheme.	Not a measure of current lifestyle.	Not a measure of current lifestyle.
Time-Use Record	Valid Measure, but requires an extended period of participants' time.	A comprehensive representation of the current lifestyle.	Can be modified to fulfill the need to measure complexity.
FCAS	Valid Measure, but needs to pay attention to retrospective recall bias.	Can capture the multi-dimensional nature of CLC.	Reduces the number of activities instead of assessing complexity.
VLS-ALQ	Valid Measure, but needs to pay attention to retrospective recall bias.	Can capture the multi-dimensional nature of CLC.	Can be modified to fulfill the need to measure complexity.

Note. CLC: Current Life Complexity. IADL: Instrumental Activities of Daily Living. FCAS: Florida Cognitive Activities Scale. VLS-ALQ: Victoria Longitudinal Study Activity Lifestyle Questionnaire.

2.2 Pilot Study: Update of the VLS-ALQ

The original items of the VLS-ALQ were developed over a decade ago in Canada, accordingly an update was necessary to capture the lifestyle of Australians in 2024. The aim of pilot testing was to explore participant experience and performance of an updated VLS-ALQ.

2.3 Pilot Study: Methods

2.3.1 Declarations

This study's design and its analysis were not preregistered. The calculated required sample size when assuming small, medium, and large effect sizes were: 327, 54, and 23, the sample size of study 1 and 2 were decided accordingly. All the statistical analyses were conducted using R (version 4.3.2; R Core Team, 2023) and RStudio (version 2023.9.1.494; Posit Team, 2023), all the utilised packages can be found in the Appendix A. We reported data exclusions, and all measures in the manuscript.

2.3.2 Participants

Twenty young adults (age mean = 26.00, age *SD* = 3.08, age range = 20–30; 14 women, 5 men, 1 non-binary) currently studying psychology at the undergraduate level at an Australian university participated in return for course credit. All participants provided informed consent. The ethical aspects of this and subsequent studies were approved by the Australian National University Human Research Ethics Committee (protocol 2023/555).

2.3.3 Materials

2.3.3.1 Demographic Questions

Participants reported age, gender, education level, occupation, handedness preferences, and self-reported language(s) history.

2.3.3.2 Updated VLS-ALQ

We based our updated questionnaire on the 62-items version of VLS-ALQ, as validated by Jopp and Hertzog (2010; 57 items) and further modified by Marr et al. (2021; 62 items). We retained the ten-category structure of the questionnaire, but added new items within domains reflecting more modern technologies such as smartphones and online services, and locally relevant activities such as "going for a walk". For each category, we also added "Please specify other [category] related activities". We removed two activities associated with religion ("Attending church service/synagogue" and "Engaging in prayer or meditation") due to ethical concerns regarding the sensitivity of requesting participants to report on their religious activities. Example items from the updated VLS-ALQ can be found in Appendix B. The full list of activities that were asked in the different versions of the questionnaire are reported in Appendix C.

2.3.3.3 Survey-Taking Experience

Participants were monitored by a researcher while they completed the updated VLS-ALQ, and open-ended questions were included at the end of the questionnaire for participants to provide self-reported descriptions of their experiences. Upon completion, some of the participants also provided verbal feedback on the experience of responding to the questionnaire.

2.3.4 Procedure

The updated VLS-ALQ and demographic questions were completed as a part of a larger

task-switching experimental study (see Chapter Four). The updated VLS-ALQ was taken at the end of a 1.5-hour session for all of the participants. Breaks were offered before starting the updated VLS-ALQ. All of the participants individually completed the online version of the updated VLS-ALQ on the online survey platform Qualtrics, on a lab-based computer.

2.3.5 Analysis

Inductive qualitative analysis was carried out to characterise participant experience of completing the questionnaire based on both written and verbal feedback. Quality of response data was explored via evidence of disengagement with the task, such as straight-lining (i.e., uniform responses resulting in a standard deviation of 0 across activities), and poor face validity (i.e., a participant indicating infeasibly frequent/infrequent engagement across all ten domains). The time taken to complete the questionnaire was also investigated. Missing responses were also evaluated to infer whether participants had problems understanding the questionnaire.

2.4 Pilot Study: Results

Following administration of the modified VLS-ALQ to the first ten participants, it became apparent that they found the questionnaire confusing to complete. This was due to:

- Burden of thinking about the extensive list of individual items and overlap between activities (e.g., running, exercise and outdoor activities).
- Poor face validity arising from confusion surrounding how questions were asked.
- Difficulty of reporting frequency of each specific activity in detail for the past year

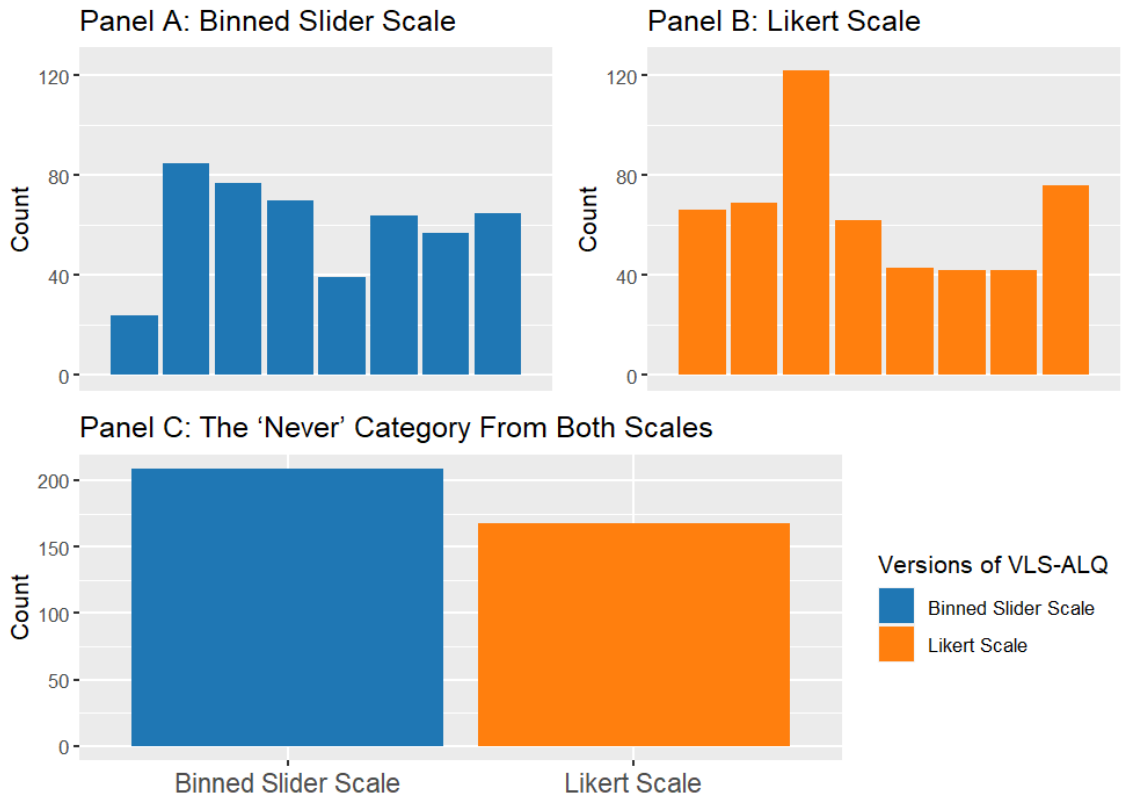
with the given VLS-ALQ frequency categories.

Based on participant feedback regarding difficulty estimating frequency of non-regular activities (e.g., infrequent ad-hoc swimming versus fortnightly swimming class), we modified the response format from a Likert response to the given frequency categories (never/less than once a year/about once a year/two or three times a year/about once a month/two or three times a month/about once a week/two or three times a week/daily) to a continuous visual analogue slider scale between 0 days (leftmost) to 365 days (rightmost). This version was then administered to another ten pilot participants.

According to participant feedback, both the original VLS-ALQ and modified VLS-ALQ had similar levels of difficulty for completion. No large response differences were found between the frequency category version of the VLS-ALQ and the analogue sliding scale version of the VLS-ALQ (see Figure 2.1). However, we note that the analogue sliding scale was able to capture the whole spectrum (i.e., 365 days) with even emphasis at all frequencies of activity engagement. The frequency categories scale had more emphasis on the most frequent end of the spectrum (e.g., daily, two/three times a week) and the least frequent end of the spectrum (e.g., never, less than once a year), thus overlooking the frequencies in between the two extremes.

Figure 2.1

Comparison Between the Slider Scale Version and the Likert Scale Version of the VLS-ALQ



Note. In the pilot study, 10 participants completed the modified Slider scale version, and 10 participants completed the original Likert scale version of the VLS-ALQ. Responses from the Slider scale version were grouped according to the cutoff points of the nine frequency categories used in the Likert scale version. Panels A and B display eight of the nine frequency categories (from left to right: less than once a year, about once a year, two or three times a year, about once a month, two or three times a month, about once a week, two or three times a week, and daily). The 'Never' category from both scales is shown separately in Panel C, using a different y-axis scale for clearer visualisation.

Further planned analyses of the modified VLS-ALQ, including the time taken to compete the questionnaire, missing responses, were not carried out due to concerns regarding poor data quality arising from participant confusion.

2.5 Pilot Study: Conclusions

Pilot testing indicated that the modified VLS-ALQ was not fit for the purpose of measuring lifestyle complexity due to heavy participant burden and confusion regarding question wording, which is likely to undermine the quality of data collected. This might partly be due to the difference in the mode of delivering the questionnaire. In the Victoria Longitudinal study, the VLS-ALQ was collected in face-to-face group interview sessions (Hultsch et al., 1999), whereas the current pilot study provided an online version of the questionnaire for participants to complete individually in a lab setting.

The number of questions for each of the activities (activity categories in the case of the CLCQ), and the approach taken to obtain the information required in relation to understanding the breadth and depth of activity involvement, were different across the VLS-ALQ and the CLCQ. In the case of completing the VLS-ALQ, the format of asking one question about each activity resulted in participants needing to have more precision for each of the activities, but fewer details of activity involvement were needed. In the case of completing the CLCQ, because questions were asked in the unit of activity category, the participants needed to have less precision for any single activity, but more details of activity involvement were needed. Hence, participants might perceive the difficulty of completing the VLS-ALQ and the CLCQ differently.

When looking at the response format, results suggested that both the Likert format and Slider format of the VLS-ALQ obtained similar patterns of activity selection and frequencies. While the visual analogue scale response format was not successful in reducing participant burden, it had the beneficial property of allowing participants to report activity frequency

more precisely, and was retained in further scale development. This aligns with the findings of Kemper and colleagues (2020), who compared the response differences between the Likert, Slider and Text-Entry format of the questions on the same topic. When participants were asked about their exercise level, the Likert and Slider format extracted similar responses, whereas the responses extracted by the Text-Entry format were significantly lower than the Likert and Slider formats. When participants were asked about their alcohol composition level, the Slider format extracted information with the strongest reliability, relative to the Likert and Text-Entry format. We proceeded to develop a modified version of the VLS-ALQ—The Current Life Complexity Questionnaire (CLCQ).

2.6 Study 1

The aim of Study 1 was to establish the CLCQ as a more participant-friendly, and fit-for purpose instrument for assessing current life complexity, compared with the pilot modification of the VLS-ALQ, henceforth “VLS-ALQ (modified)”.

The purpose of developing the CLCQ was to capture the breadth and complexity of current lifestyle, hence the commonly used dimension-reduction practice of scale validation (e.g., factor analysis) did not align with the principle of the CLCQ. However, it was necessary to obtain evidence of the validity of the CLCQ. The concept of convergent validity was used as the fundamental principle of this validation, where a strong correlation with a scale that assessed the same or highly similar construct would support the validation of the scale under evaluation. Convergent validity was one of the components that needed to be considered when validating questionnaires (e.g., Watson et al., 2008). Padovani et al. (2025)

applied this principle as a part of the evidence to validate the Boston Cognitive Assessment (BOCA). Adapting this practice, the validity of the CLCQ was assessed through evaluating the consistency between responses obtained from the CLCQ and responses obtained from the VLS-ALQ.

2.7 Study 1: Methods

2.7.1 Participants

There were two participant groups, chosen to represent two distinct phases of life: young adults (inclusion criterion, 18–40 years; henceforth referred to as "young participants") and older members of the local community (inclusion criterion, older than 60 years; henceforth referred to as "older participants"). Thirty older members of the community re-contacted following participation in a related study (see Chapter Four). The older participants were not provided with a further incentive in addition to their first participation. The incentive for young adults depended on how they were recruited: students currently studying psychology at the undergraduate level recruited as part of their undergraduate research participation requirement received course credit. Young volunteers responding to posters and snowball sampling within the general community received no incentive.

2.7.2 Materials

2.7.2.1 Demographic Questions

The online questionnaire included questions asking participants' age, gender, education level, longest occupation, handedness preference, place of residence, barriers to accessing

activities, and self-reported language(s) proficiency.

2.7.2.2 CLCQ

The CLCQ is based on the VLS-ALQ (modified) described in the pilot study. Our first modification aimed to address participant burden associated with the extensive list of individual items, and perceived overlap between some items in the VLS-ALQ. Rather than asking about frequency of undertaking each activity from a long list of specific activities within each category (as in the original VLS-ALQ), we asked participants to select which activities they have engaged in at least once in the past year, and then report on frequency of engaging in that activity category as a whole. Our second modification was intended to address the insensitivity of the original VLS-ALQ to duration of activities. Some activities could be undertaken frequently for short periods of time, or infrequently for longer durations (e.g., daily one-minute walks versus one occasion of a six-hour walk). We asked participants to use a visual analogue scale, with 0 hours at the leftmost anchor and 24 hours at the rightmost anchor, to report the duration of activity in hours for a typical day, a day with the least involvement in the category of activities (i.e., minimum), and a day with the most involvement in the category of activities (i.e., maximum). This enables the instrument to capture indications of depth of involvement in any given activity (time spent), consistency or inconsistency in this depth of involvement, and the frequency of switching between different activity categories on a typical day. One item (“reading”) that occurred in more than one category from the VLS-ALQ (modified) was removed from the CLCQ. Example items from the CLCQ can be found in Appendix B. The full list of activities that were asked in the

different versions of the questionnaire are reported in Appendix C.

2.7.2.3 Survey-Taking Experience

The duration of completing each version of the questionnaire was recorded. Open-ended questions were asked at the end of each version of the questionnaire to collect participants' self-reported experience of survey-taking. Participants were asked to report how difficult they thought it was to complete the questionnaire, and rated their certainty of the reported activity frequency from 0 (not at all certain) to 100 (completely certain). The time taken to complete the questionnaire was also investigated.

2.7.3 Procedure

Every participant completed two versions of the lifestyle questionnaire—VLS-ALQ (modified) and CLCQ—in Qualtrics, on two separate days. The order of the activity categories and the order of activities within each category were randomised in both the VLS-ALQ (modified) and the CLCQ.

Half of the young participants were randomly assigned first to complete the VLS-ALQ (modified), and the other half first to complete the CLCQ. There was a 7- to 14-day gap between the two sessions.

All of the returning older participants completed the Qualtrics version of the CLCQ first, in-lab with other tasks of a computer-based experiment. After a 112- to 318-day gap, they were then invited to complete the VLS-ALQ (modified) second, as a follow-up study.

2.7.4 Analysis

Analysis of consistency focused on comparing the correspondence of items between the VLS-ALQ (modified) and the CLCQ. Correspondence between activities selected when undertaking the VLS-ALQ (modified) and the CLCQ was descriptively expressed as a percentage of consistency. The percentage of consistency was the count of activities selected in both questionnaires, divided by the total number of selected activities, calculated within each activity category. The overall consistency measure was the mean percentage of consistency across ten activity categories.

Quantitative analyses were conducted on a novel variable developed for the purpose of quantifying current life complexity, the composite complexity score. It is the sum of the number of activities selected plus the sum of the number of other activities reported. Histograms were used to compare the distribution of the composite complexity score captured by the VLS-ALQ (modified) and the CLCQ (see Appendix D for a scoring manual). The Shapiro-Wilk normality test was carried out to examine whether our data met the assumption of normality. Pearson's correlation coefficients were calculated to understand the consistency between the two versions of the questionnaire. The Bland-Altmen analysis was conducted to assess the test-retest reliability of the two versions of the questionnaire.

The time taken to complete the two versions of the questionnaire, and self-reported certainty in responses were compared as part of the survey-taking experience analysis. Qualitative analyses were conducted on the participants' open-ended responses regarding survey-taking experience. Major themes were extracted from participants' responses to the open-ended questions that asked for their experience when completing each version of the

questionnaire. Representative quotes from each of the themes were extracted.

2.8 Study 1: Results

The participants consisted of 26 psychology undergraduates, 12 community based young participants and 26 returning older participants. A total of 14 participants were excluded from the study (13 of the psychology undergraduates only completed the first part of the test-retest; 1 older participant did not complete the whole follow-up questionnaire). Of the remaining 50 participants included in analysis, there were 25 young participants (age mean = 22.52, age *SD* = 3.73, age range = 19–31; 20 women, 4 men, 1 preferred not to say), and 25 older participants (age mean = 71.20, age *SD* = 6.47, age range = 61–87; 15 women, 10 men).

2.8.1 Consistency Between Two Versions

2.8.1.2 Consistency of Activity Selection

In young participants, a mean of 85.74% (*SD* = 10.80, range = 56.67%–100%, median = 87.50%) of activities were selected consistently when comparing the responses from the VLS-ALQ (modified) and the CLCQ. The lowest mean consistency was found in the developmental activities category (59.53%, *SD* = 32.75) and the highest mean consistency was found in the private social activities category (98.43%, *SD* = 5.65).

In older participants, a mean of 79.87% (*SD* = 11.35, range = 54.58%–100%, median = 94.00%) of activities were selected consistently when comparing the responses from the VLS-ALQ (modified) and the CLCQ. The lowest mean consistency was found in the developmental activities category (32.67%, *SD* = 40.10) and the highest mean consistency

was found in the physical activities category (97.67%, *SD* = 8.16).

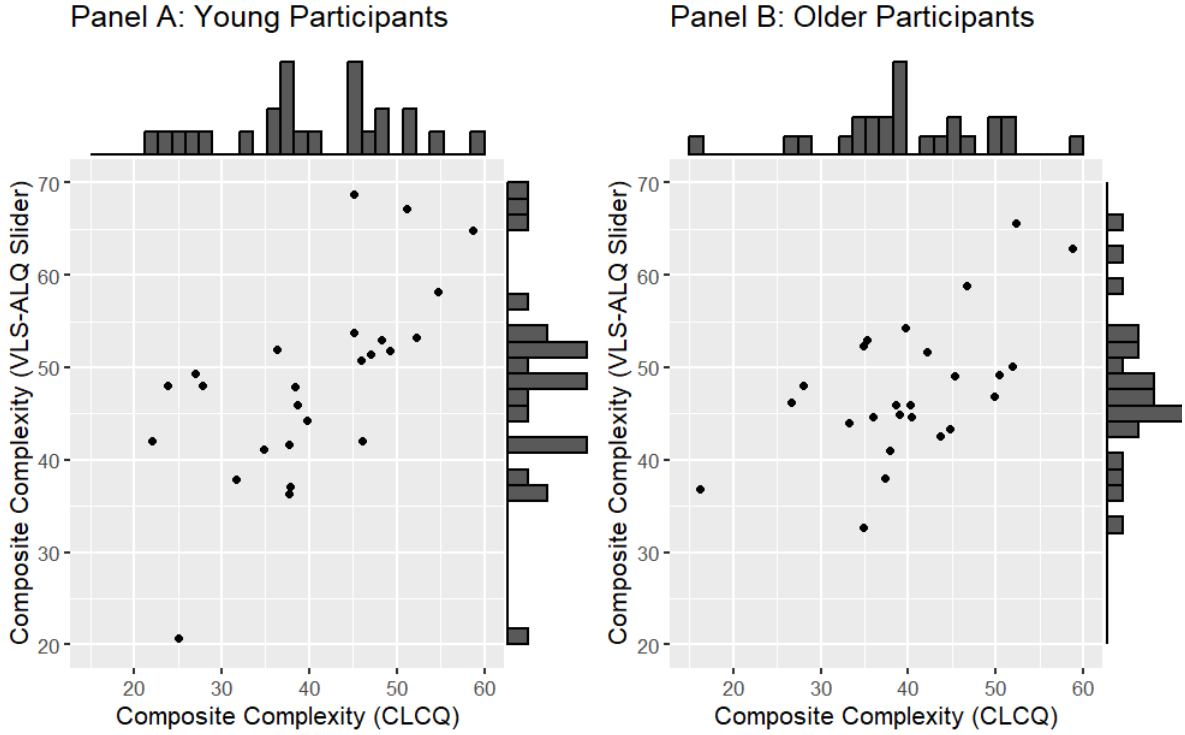
2.8.2 Correlations of Composite Complexity Scores

The consistency between the VLS-ALQ (modified) and CLCQ were also reflected in the correlation between the scores. In young participants (Figure 2.2, Panel A), the composite complexity scores calculated based on responses for the VLS-ALQ (modified) had a mean of 48.28 (SD = 10.40, range = 21–69), and the composite complexity scores calculated based on responses for the CLCQ had a mean of 40.76 (SD = 10.01, range = 22–59). The Pearson's correlation coefficient was 0.65, indicating a moderate positive correlation.

In older participants (Figure 2.2, Panel B), the composite complexity scores calculated based on responses for the pilot modification of the VLS-ALQ (modified) had a mean of 47.76 (SD = 7.55, range = 33–66), and the composite complexity scores calculated based on responses for the CLCQ had a mean of 40.16 (SD = 9.15, range = 16–59). The Pearson's correlation coefficient was 0.59, indicating a moderate positive correlation.

Figure 2.2

Correlation and Distribution of the Composite Complexity Scores Calculated Based on the VLS-ALQ and the CLCQ for Young and Older Participants



Note. Figure presents the correlation (central scatter plots) and distribution (marginal histograms) of the Composite Complexity Scores for the VLS-ALQ and CLCQ for young participants (Panel A) and older participants (Panel B). VLS-ALQ: Victoria Longitudinal Study Activity Lifestyle Questionnaire. CLCQ: Current Life Complexity Questionnaire.

Shapiro-Wilk's normality test suggested that all composite complexity scores were normally distributed (Young: VLS-ALQ (modified) $W = 0.96$, $p = 0.40$, CLCQ $W = 0.97$, $p = 0.57$; Old VLS-ALQ (modified) $W = 0.96$, $p = 0.41$, CLCQ $W = 0.97$, $p = 0.71$).

2.8.3 Test-Retest Reliability

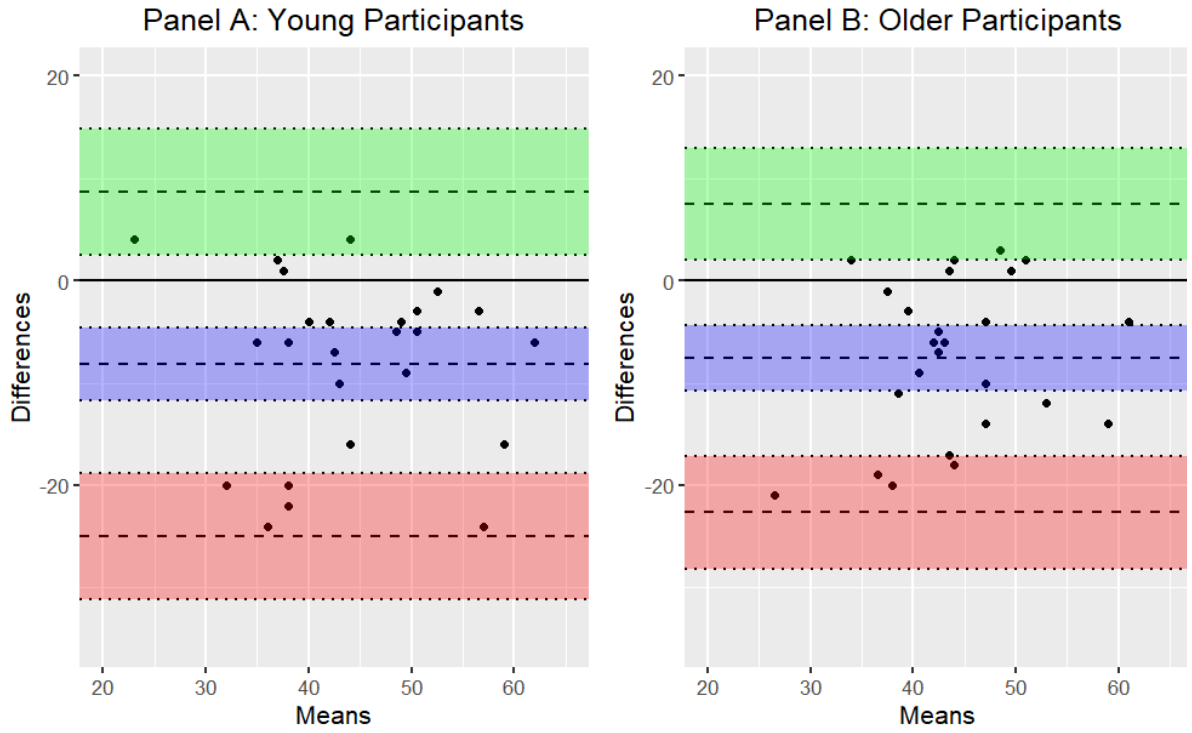
A Bland-Altman plot (Figure 2.3 Panel A) showed there was a systematic bias introduced by different versions of the questionnaire in young participants with a mean

difference (bias) of -8.16 (t = -4.74, df = 24, p <0.001, *95% confidence interval [CI]* = [-11.71, -4.61]). The limits of agreement were -25.02 to 8.70.

Similarly, there was a systematic bias in older participants (Figure 2.3 Panel B), mean difference (bias) of -7.60 (t = -4.94, df = 24, p <0.001, *95% confidence interval [CI]* = [-10.78, -4.42]). The limits of agreement were -22.68 to 7.48. These results suggested that in both young and older participants, differences in scores were found between the two versions of the questionnaire.

Figure 2.3

Bland-Altman Plots Comparing the Pilot Modification of the VLS-ALQ and the CLCQ in Young and Older Participants



Note. Figure presents mean difference (bias) and the limits of agreement (mean difference ± 1.96 *SD*) are shown by dashed lines in young participants (Panel A) and older participants (Panel B). Each point represents an individual observation. The figure indicates that there were systematic differences found between the composite complexity scores obtained in the VLS-ALQ (modified) and the CLCQ.

2.8.4 Survey-Taking Experience

2.8.4.1 Duration

In young participants, the VLS-ALQ (modified) took an average of 25.72 (*SD* = 34.85) minutes to complete, and the CLCQ took an average of 23.42 (*SD* = 15.78) minutes to complete. In older participants, the VLS-ALQ (modified) took an average of 27.75 (*SD* = 18.04) minutes to complete, and the CLCQ also took an average of 25.67 (*SD* = 8.38) minutes to complete.

2.8.4.2 Certainty

In young participants, self-reported certainty in their answers had an average of 66.36 (range = 50–100, *SD* = 19.39) out of 100 for the VLS-ALQ (modified), and an average of 62.96 (range = 50–93, *SD* = 16.06) out of 100 for the CLCQ. In older participants, the self-reported certainty in their answers had an average of 70.68 (range = 10–98, *SD* = 14.45) out of 100 for the VLS-ALQ (modified), and an average of 64.52 (range = 10–100, *SD* = 21.32) out of 100 for the CLCQ.

2.8.4.3 Difficulty

In young participants, 12 out of 25 participants commented on the difficulty and potential improvement of the VLS-ALQ (modified) in qualitative feedback, the other participants either did not respond (including responded with NA) to the question (*N* = 7) or suggested the VLS-ALQ (modified) was not difficult to complete (*N* = 7). Six out of 25 participants commented on the difficulty and potential improvement of the CLCQ, the other participants either did not respond to the question (*N* = 11) or suggested the CLCQ was not difficult to complete (*N* = 8).

In older participants, 15 out of 25 participants commented on the difficulty and potential improvement of the VLS-ALQ (modified), the other participants either did not respond to the question (*N* = 3) or suggested the VLS-ALQ (modified) was not difficult to complete (*N* = 7). Twelve out of 25 participants commented on the difficulty and potential improvement of the CLCQ, 1 participant entered “not sure”, the other participants either did not respond to the question (*N* = 4) or suggested the CLCQ was not difficult to complete (*N* = 8).

Qualitative analysis of both groups of participants' responses on both versions of the questionnaire suggested there were a total of 7 common themes.

Across all age groups and questionnaire types

Theme 1. Participants suggested that recalling the exact number of days for activities over the past year was difficult. Quote: "Just hard to remember what I did in the past year".

Theme 2. A Likert scale categorising the number of days into yearly / monthly / weekly frequency could help with responding to the frequency questions. Quote: "Maybe a rating scale (e.g., from 1–7) of how frequently I complete the activities each week/month/year".

Theme 3. Some participants suggested that completing the questionnaire was not difficult. Quote: "Your suggested methods plus actual counts for specific activities worked well for me".

Specific to the pilot modification of VLS-ALQ

Theme 4. There was overlap between questions. Quote: "Exercise questions seemed to overlap".

Theme 5. There was difficulty recalling frequency of activities that people rarely do. Quote: "Difficult to be precise for activities done sporadically and infrequently".

Specific to the CLCQ

Theme 6. The activity pattern in different days vary largely. Quote: "Life is very variable, so I estimated".

Specific to older participants

Theme 7. A diary could help with completing the questionnaire. Quote: "Keeping a diary of activities but wouldn't want to do that for more than a few weeks".

2.8.4.4 Relevance of Selected Activities

Most of the young and older participants were able to select a range of different activities that they were involved in regularly in their daily life from the provided list. In young participants, 9 out of 25 participants reported at least one other activity that was not listed in the VLS-ALQ, whereas 10 out of 25 people reported other activities that were not listed in the CLCQ. In older participants, 18 out of 25 participants reported at least one other activity that was not listed in the VLS-ALQ, whereas 21 out of 25 people reported other activities that were not listed in the CLCQ. This suggested that the CLCQ could potentially scaffold participants' thoughts to reflect on other activities that were not listed in the questionnaire by building in questions allowing participants to report other relevant activities in each activities category (e.g., other physical activities, other games, etc.).

Commonly mentioned activities (i.e., listed by more than one participant) that were not included in the original activity list for both versions of the questionnaire are listed in Appendix E.1.

2.9 Study 1: Discussion

2.9.1 Questionnaire Quality Evaluation

2.9.1.1 General Challenges in Self-Report

Based on both the quantitative and qualitative aspects, both young and older participants found the CLCQ less difficult, compared to the VLS-ALQ (modified). When participants were asked to comment on the difficulty of completing the questionnaire at the end of the session, they did not report issues in relation to the explanation of the questions, but

commented on the difficulty of precise calculations of the number of days involved in activities over the past year. This aligns with expected challenges of recall bias for retrospective reporting over a year (Öztaş Ayhan & Işiksal, 2005), and suggests that the level of information provided in the questionnaire was appropriate for participants to understand what sort of information we were expecting from them.

2.9.1.2 Challenges Specific to Measuring Cognitive Lifestyle

To address the challenges of appropriate activities selection for measuring cognitive lifestyle, the CLCQ was developed to include common daily activities for an Australian sample in current years (2021–2024). In the process of questionnaire development and modification, balancing the trade-off between comprehensiveness and length had always been an inevitable challenge (Yan & Williams, 2022). The CLCQ was developed with the expectation that it was impossible to obtain an exhaustive list of every single relevant daily activity. Our findings suggested that the questionnaire design of the CLCQ was able to capture more relevant activities by scaffolding participants' reflections and providing opportunities for participants to report activities that were not listed by the questionnaire (e.g., watching movies, drama). Adding new items within domains reflecting more modern technologies (i.e., smartphones and online services) was appropriate and necessary, as these new items were frequently selected by participants and none of the participants mentioned additional activities for this domain.

2.9.2 Comparisons Between the VLS-ALQ (Modified) and the CLCQ

The similarly normal distributions of the composite complexity scores extracted from the VLS-ALQ (modified) and CLCQ, the high percentage of consistent selection of activities, and the correlation between the two versions of the questionnaire could suggest that they were likely measuring the same construct (i.e., current life complexity). However, the outcomes of the Bland-Altman analysis suggested that there were systematic differences between the two version of the questionnaire. Within both young and older individuals, composite complexity scores calculated from the CLCQ were systematically lower than those from the VLS-ALQ (modified). This may be partly because participants undertaking the CLCQ considered (and reported) their daily activity patterns in categories, instead of considering each activity individually as in the VLS-ALQ (modified). This structure helped participants avoid double-reporting due to overlap between activities, a modification made based on the feedback from participants in the pilot study. As the result of this reduced overlap and within-category salience, a reduced number of reported activities, and consequently a lower composite complexity score could be expected.

Response characteristics differed according to age group. In young participants, a larger variation of reported activities was found by the VLS-ALQ, compared to the CLCQ. In older participants, a larger variation of reported activities was found by the CLCQ, compared to the VLS-ALQ. Given the percentages of consistently selected activities in both age groups, this was likely the result of the large number of not-listed activities reported by older participants in the CLCQ. This might need to be taken into considerations when comparing current life complexity of young and older participants.

Results suggested participants experience of the CLCQ was better than that of the VLS-ALQ (modified): the CLCQ was slightly quicker to complete, and fewer participants commented on the difficulty of the CLCQ or indicated potential improvement. However, they responded with slightly less certainty to the CLCQ than the VLS-ALQ, which was acceptable considering the CLCQ asked them to report hours of the days involved in the activities. This finding aligned with Seninde and Chambers (2020)'s investigation on different types of survey questions, namely the Check-All-That-Apply and Check-All-Statements (Yes/No) question formats. They found that the Check-All-That-Apply format was preferred by their participants, while the Check-All-Statements format was better suited to gathering detailed information. The CLCQ response format is closer to the Check-All-That-Apply, while the VLS-ALQ (modified) is closer to the Check-All-Statements.

2.9.3 Conclusions

Study 1 found that the CLCQ was a more participant-friendly and fit-for purpose instrument for measuring current life complexity than the VLS-ALQ (modified). Participants felt the CLCQ was less difficult for answering questions. This was likely because the CLCQ allowed participants to scaffold all the possible daily activities that they were involved in during the past year, rather than reflecting on each activity individually.

However, the VLS-ALQ (modified) provided participants with higher certainty during the process of answering the questions than the CLCQ. We conclude that the CLCQ is fit-for-purpose for capturing daily activity patterns with the intent of measuring current life complexity. Further investigation would be needed to examine the CLCQ's performance in

response to the challenges of modelling/measuring current life complexity.

2.10 Study 2

The pilot test and study 1 described the development of the CLCQ from the VLS-ALQ validated by Jopp and Hertzog (2010). The aim of study 2 was to establish norms for the CLCQ as administered in a general population sample, and demonstrate the scoring and calculation of life complexity measures, described as follows.

2.10.1 Life Complexity Variables

The complete scoring manual of CLCQ can be found in Appendix D.

2.10.1.1 The Composite Complexity Score

The composite complexity score (binomial, possible range between 0 and 136) is the sum of the number of activities selected in each category, plus the sum of the number of other activities reported in each category. The number of other activities has a cut-off the same as the maximum number of the listed 68 activities. A higher composite complexity score indicates that the participant has a more complex current lifestyle.

Equation:

$$Composite\ Complexity\ Score = \sum_{i=1}^{10} (A_i + O_i)$$

- A_i is the number of selected activities in category i
- O_i is the number of other reported activities in category i
- There are a total of 10 categories.

2.10.1.2 The Breadth of Involvement

The breadth of involvement (Count, possible range between 0 and 10) is a count of the number of categories with more than one activity selected and/or reported. A larger breadth of involvement indicates that the participant has a wider range of investment across different activity categories.

Equation:

$$Breadth\ of\ Involvement = \sum_{i=1}^{10} I\ (A_i + O_i \geq 1)$$

- A_i is the number of selected activities in category i
- O_i is the number of other reported activities in category i
- There are a total of 10 categories
- I(·) is an indicator function that equals 1 if the condition inside the parentheses is true (i.e., if the sum of activities in a category is greater than or equal to 1), and 0 otherwise.

2.10.1.3 The Depth of Involvement

Participants directly report the number of days (continuous, possible range between 0 and 365) for each activity category. No further calculations were required. A larger depth of involvement indicates that the participant is deeply invested in the selected activity category.

Equation:

$$Depth\ of\ Involvement = \{D_i\}_{i=1}^{10}$$

- D_i is the number of days reported for activity category i.

2.10.1.4 The Variability in Depth of Involvement

The variability in depth of involvement (possible range being within positive continuous number) is the standard deviation of the number of days involved in the activities across 10 activity categories. A larger variability in depth of involvement indicates that the participant showed greater variation in their level of investment across activity categories.

Equation:

$$Variability\ of\ Time\ of\ Involvement = \sqrt{\frac{1}{10}\sum_{i=1}^{10}(D_i - \overline{D})^2}$$

- D_i is the number of days of involvement in category i
- $\overline{D} = \frac{\sum_{i=1}^{10} D_i}{10}$ is the mean number of days of involvement across the 10 categories.

2.10.1.5 Concentration (Gini Index)

The concentration of activities (Gini Index, possible range between 0 and 1; Gastwirth, 1972) reflects how concentrated each participant's selection of activities is across the 10 activity categories. A concentration score close to 0 means that the participant has equal involvement across activity categories (i.e., low concentration). A concentration score close to 1 means that the participant has focused involvement on a few activity categories (i.e., high concentration). It is calculated based on the normalised proportion.

Equation:

$$Normalised\ Proportion\ (P_i) = \frac{A_i + O_i}{N}$$

- Ai is the number of selected activities in category i
- Oi is the number of other reported activities in category i
- N is the total number of listed activities across all categories.

Equation:

$$Concentration\ (Gini\ Index) = 1 - \frac{\sum_{i=1}^{10} P_i^2}{\left(\sum_{i=1}^{10} P_i\right)^2}$$

The entropy score of concentration (See Appendix E.2) was also calculated and plotted. A similar pattern of results was presented. Here, we only present the concentration scores based on the Gini-index, as it is theoretically closer to its real-word interpretation, which is the level of concentration in activities selected across 10 activity categories.

2.10.1.6 The Inclusiveness of the Activities

The inclusiveness of the activities (continuous, possible range between 0 and 10) could be calculated based on 10 depth of involvement measures, by adding them up and dividing them by 365. A higher score means the participant was more inclusive when involved in the selected activities. A lower score means the participant was less inclusive when involved in the selected activities.

Equation:

$$Inclusiveness\ of\ the\ Activities = \frac{\sum_{i=1}^{10} D_i}{365}$$

- D_i is the number of days reported for activity category i.

2.11 Study 2: Methods

2.11.1 Participants

Participants were recruited via Prolific, an online platform that connects participants with researchers (their official website: https://www.prolific.com/). Adults currently living in Australia with a self-reported fluent level of English were eligible for participation.

2.11.2 Materials

2.11.2.1 Demographic Questions

Participants reported their age, gender, highest education level, occupation, and language background. To disambiguate whether potential outliers reflect genuine unusual current life complexity or if there is some shortcoming of the CLCQ, we also asked questions relating to potential barriers for engaging with desired daily activities (e.g., physical, financial), and rurality of residency.

2.11.2.2 CLCQ

The CLCQ is the same instrument as described in Study 1. The CLCQ included 10 activity categories. In each of the activity categories, we asked participants to select all the activities they have engaged in at least once in the past year, and then report on frequency of engaging in that activity category as a whole. We also asked participants to use a visual analogue scale to report the duration of activity in hours for a typical day, a day with the least involvement in the category of the activities (i.e., minimum), and a day with the most involvement in the category of the activities (i.e., maximum). To avoid order effects, the

activity categories and activities within each of the categories were randomised for each of the participants.

2.11.2.3 Catch Questions

Two types of catch questions were included to access whether participants had paid attention to our questions during the completion process. Both catch questions were developed to mimic the format of core questions in the CLCQ. The first catch question asked participants to select “Apple, Grape and Watermelon” from a list of fruits. The second catch question asked participants to set the slider to a value corresponding to “168”.

2.11.3 Procedure

All participants were provided with the online version of the CLCQ on Qualtrics. The Qualtrics link were automatically provided when participants signed up to the study on Prolific.

Participants were excluded from the analysis if they failed to correctly respond to both catch questions, without providing an explanation to the researcher. They were also excluded from the analysis if their responses did not make logical sense (e.g., the reported typical hours fell outside of the minimum hours and maximum hours range).

2.11.4 Analysis

The CLCQ was characterized through descriptive statistics, and visualisation via histograms, scatter plots, and box plots. The intra-class correlation coefficient was

investigated within and between participants and activity categories. Composite complexity, breadth of involvement, depth of involvement, variability in proportion of involvement, variability of time of involvement, concentration, and exclusiveness scores were calculated. Pearson's Correlation Coefficients were calculated to investigate the association between these extracted variables.

2.12 Study 2: Results

Of the original 330 participants recruited, 18 declined to participate or did not submit the survey, and were replaced with new participants via Prolific. Of the 330 who submitted the questionnaire, sixteen participants did not pass data quality checks. This resulted in a final sample of 314 participants for subsequent analysis.

The 314 participants (age mean = 36.04, age *SD* = 12.02, age range = 18–87) had a relatively good coverage of ages throughout adulthood, with some bias toward young adulthood (*n* = 11 <20, *n* = 110 in 30s, *n* = 61 in 40s, *n* = 25 in 50s, *n* = 8 in 60s, *n* = 4 in 70s and *n* = 2 in 80s). There were 154 participants who identified as women, 154 as men, and 6 identified as non-binary. Of the 314 participants, 113 participants lived in urban areas, 167 lived in suburban areas, 31 lived in rural areas, and 3 reported living in none of those areas. We had a balanced sample of monolinguals (n = 159) and bilinguals/multilinguals (*n* = 154, and 1 did not answer the question). In terms of the highest education, 10 reported secondary school (Year 7–10) qualifications, 60 college (Year 11–12) qualifications, 154 reported having an undergraduate degree, 57 a master's degree, 13 a doctoral degree, and 20 reported other educational attainment.

Of the 314 participants, 232 participants reported no conditions that were a barrier to undertaking daily activities. Of the 82 participants who reported barriers, 61 reported only one barrier, and 21 reported more than one barrier. The most commonly mentioned barriers were financial (n = 26) and physical (n = 26) problems, followed by difficulties with vision (n = 9), hearing (n = 5), and neurological problems (n = 2).

2.12.1 Extracted Variables

The extracted variables aligned with the theoretical expectation of the concept of current life complexity. The descriptive statistics of extracted variables can be found in Table 2.2.

Table 2.2

Theoretical Range and Sample Results of Extracted Variables

Variables	**Theoretical Range**	**Sample Results Mean/Median (SD)[Range]**
Composite Complexity Score	[0–136]	**32.84** (10.74) [3–64]
Breadth of Involvement	[0–10]	**10** [2–10]
Depth of Involvement	[0–365]	[0–365]
Variability in Depth of Involvement	Positive Continues	**123.3** (33.09) [0–186.72]
Concentration	[0–1]	**0.85** (0.05) [0.44–0.89]
Inclusiveness of the Activities	[0–10]	**4.05** (1.30) [0.29–8.39]

Note. To reflect the characteristics of each variable, median was used to measure the central tendency of Breadth of Involvement, and mean was used for all other variables. There are a total of 10 Depth of Involvement measures for each person, corresponding to each of the activity categories.

2.12.1.1 Intraclass Correlation Coefficients

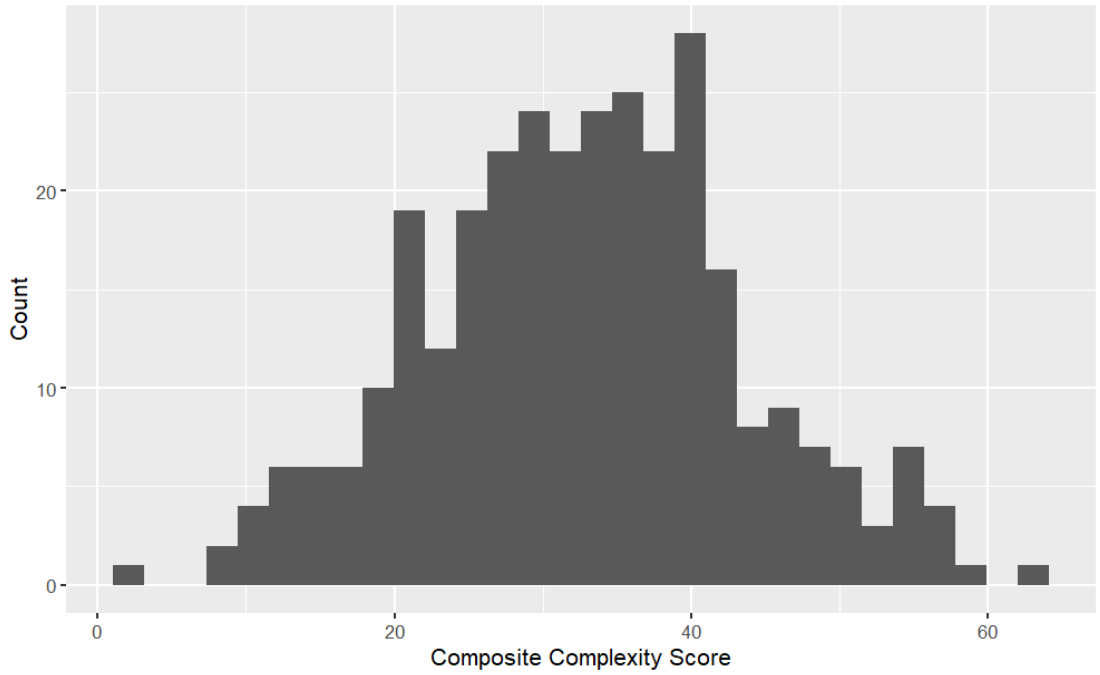
The intraclass correlation coefficients (ICC) of the number of activities (i.e., a count of the number of selected activities) in each category is 0.445, indicating that there was both variability within and between the categories of activities. The ICC of the depth of involvement (i.e., number of days) in each category was 0.359, indicating that there was both variability within and between the categories of activities, but a relatively larger proportion of variability is explained by within category differences. The ICC of the proportion of activities (i.e., a ratio of selected activities out of the total number of listed activities) in each category is 0.287, indicating that there was both variability within and between the categories of activities, but an even larger proportion of variability is explained by within category differences. These results supported the necessity of investigating multiple extracted variables from the CLCQ.

2.12.1.2 Composite Complexity Score (Composite)

In our sample of participants, the mean composite complexity score was 32.84, suggesting that participants were involved in an average of 33 different activities in the past year, with a minimum of 3 activities and a maximum of 64 activities. Figure 2.4 presents the histogram distribution of the composite complexity score, which is normally distributed.

Figure 2.4

Histogram Distribution of the Composite Complexity Score (N = 314)



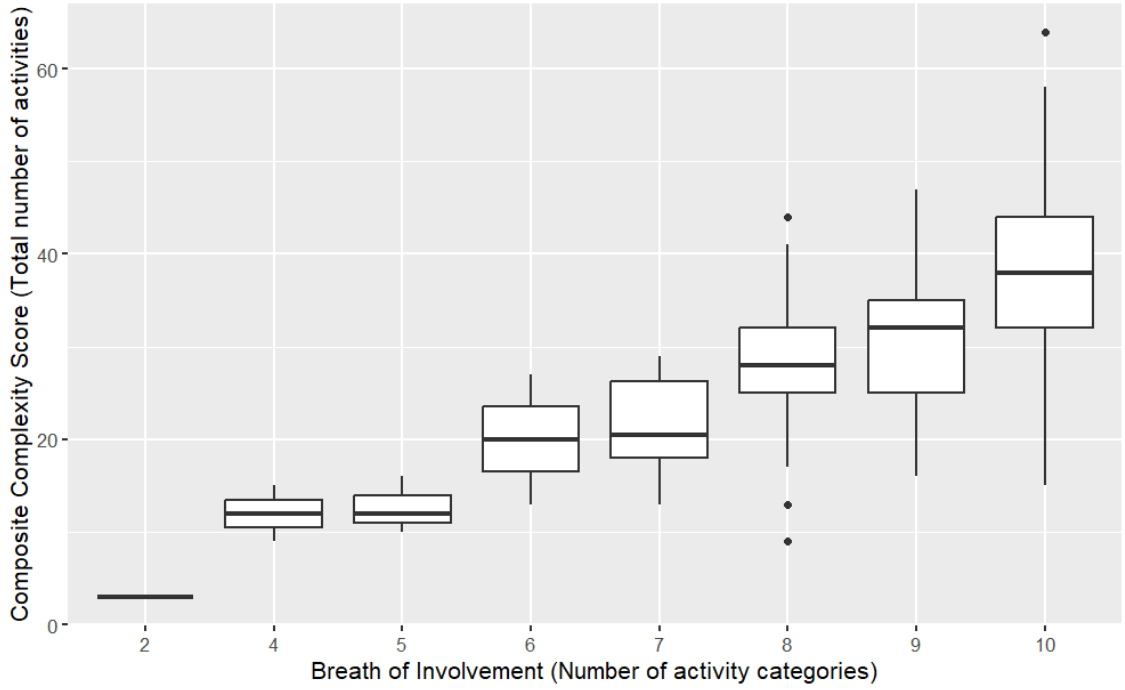
Note. Figure presents the distribution of the composite complexity score in a total of 314 participants. The figure suggests that the composite complexity score is normally distributed in our participants.

2.12.1.3 Breadth of Involvement (Breadth)

The median breadth of involvement (10) indicated that more than half of the participants were involved in all 10 categories of activities in the past year. Figure 2.5 plots the Breadth against the Composite Complexity Score, indicating that although they are positively correlated, participants involved in all 10 categories of activities still vary across the total number of involved activities.

Figure 2.5

Boxplot of the Breadth of Involvement (Number of Activity Categories) Versus the Composite Complexity Score (Total Number of Activities)



Note. The breadth of involvement (2–10) is presented on the x-axis of the figure, and the composite complexity score (3–64) is presented on the y-axis of the figure. As the breadth of involvement increases, the mean and variability of composite complexity score also increases.

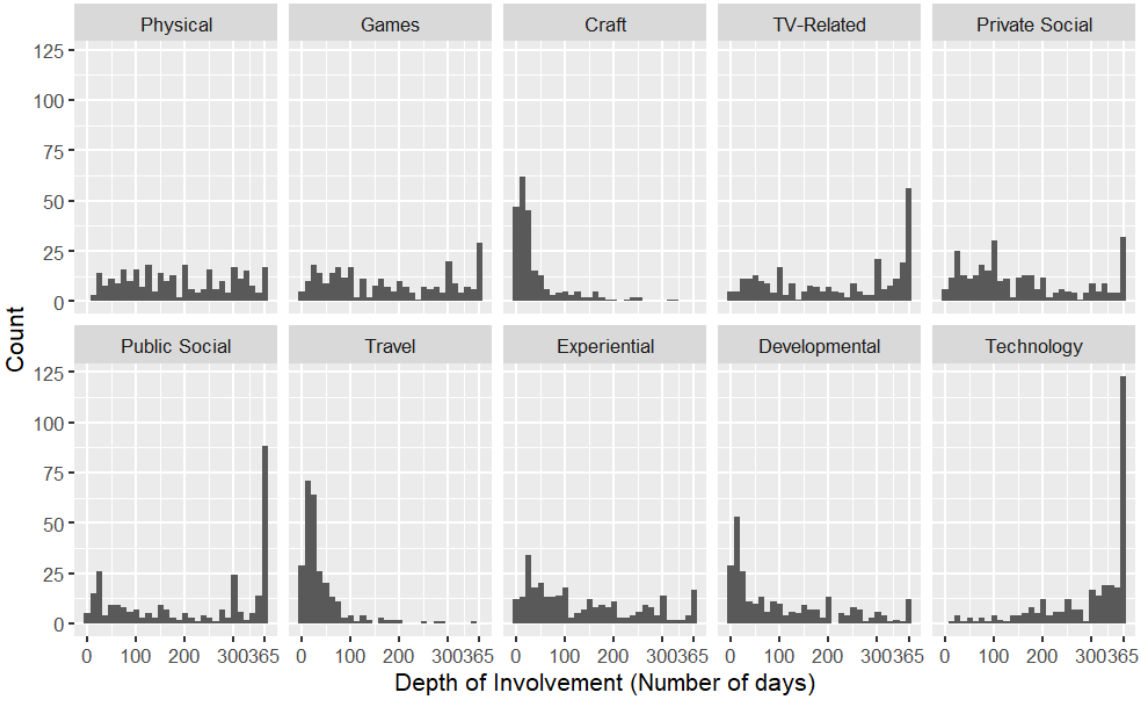
2.12.1.4 Depth of Involvement (Depth)

As indicated by Figure 2.6, our participants were more likely to select involvement frequencies both around 0 and 365, and they were less likely to select involvement frequencies between 100 and 300. This suggested that participants were likely to either report involvement in the activities for only a few days of the year, or report involvement in the activities at close to daily frequency.

Craft, Travel, and Developmental activities were more frequently found with lower depths of involvement (i.e., fewer days over the past year), whereas Public Social and Technology-related activities were more frequently found with greater depths of involvement (i.e., more days over the past year). In contrast, involvement in Physical activities and Games was distributed across all levels of depths of involvement.

Figure 2.6

Histogram Distributions of Number of Days Involved in Each of the Activity Categories



Note. The depth of involvement (0–365 days) is presented on the x-axis of the figure, and frequencies (the frequency of participants selecting the corresponding depth of involvement) are presented on the y-axis. Different activity categories had different patterns in depth of involvement.

2.12.1.5 Variability in Depth of Involvement (Variability)

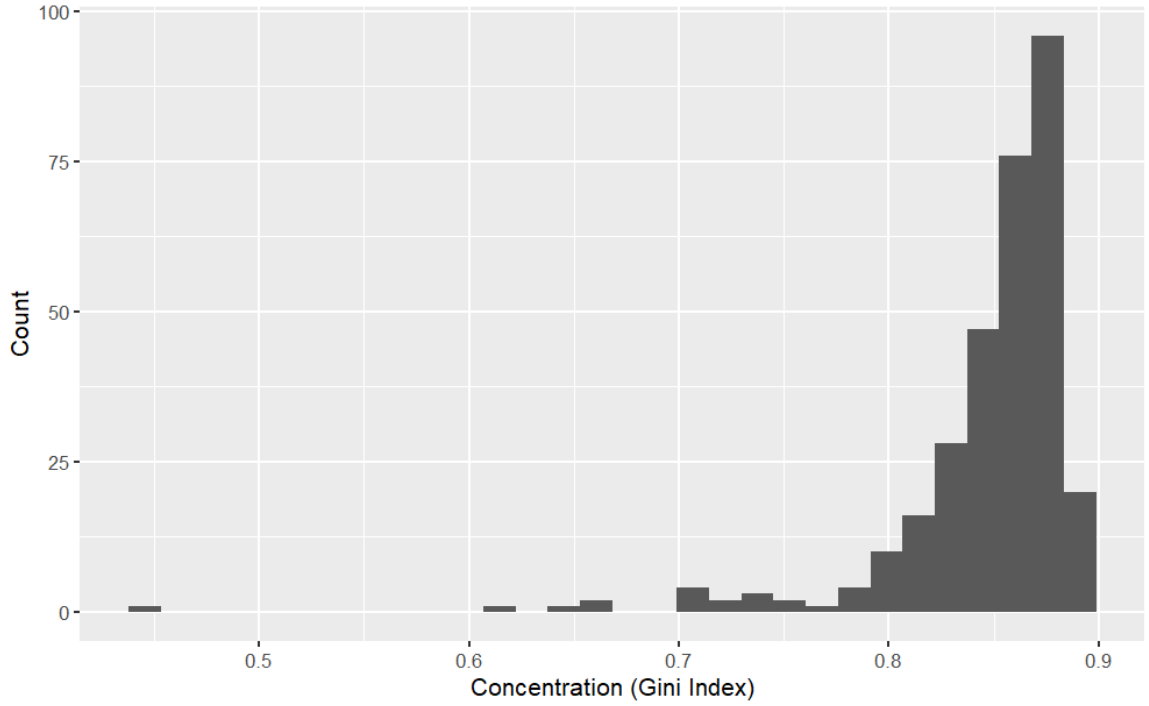
The variability in the depth of involvement had a mean of 123.3, indicating the number of days our participants were involved in different activity categories varied largely. Information regarding the variability in depth of involvement can be found in Appendix E.3.

2.12.1.6 Concentration of Category Selection (Concentration)

The concentration of category selection indicated that our sample of participants had a mean of 0.85, suggesting they had a relatively concentrated selection that focused on a few activity categories of their interest, rather than they were equally involved in all categories. This occurred even though most of the participants selected at least one activity from each of the 10 activity categories. The pattern of distribution is presented in Figure 2.7. The concentration calculated by entropy score provided less extreme results (Shannon, 2001; see Appendix E.2).

Figure 2.7

Histogram Distribution of the Concentration of the Activities Score (Gini Index)



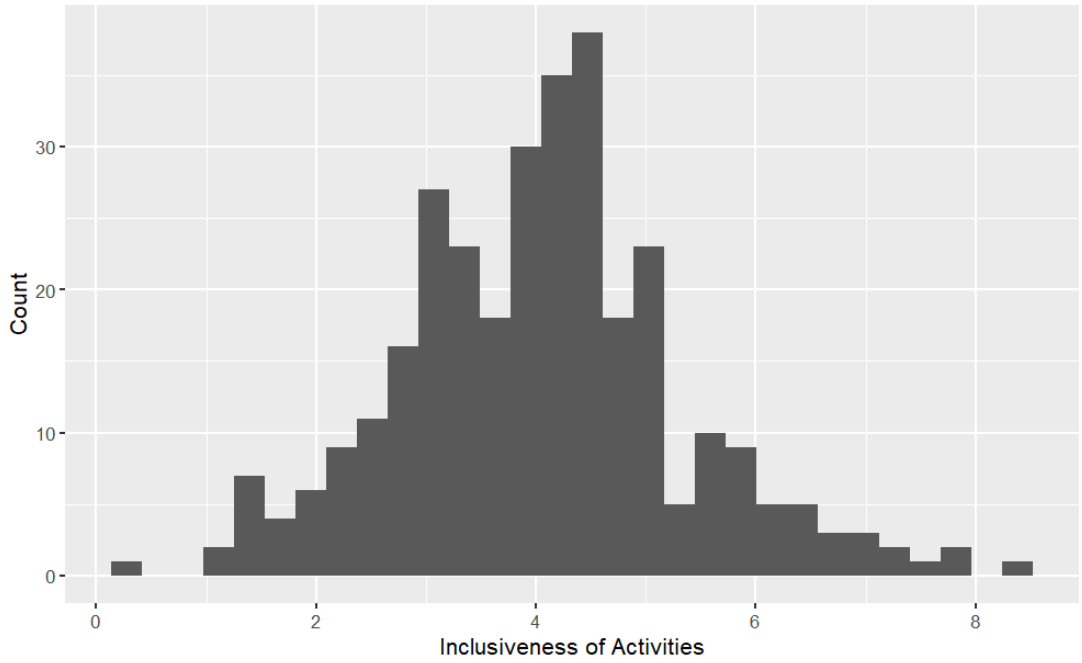
Note. Figure presents the distribution of concentration calculated in a total of 314 participants. Y-axis is an indication of the frequency of participants for each concentration score on the x-axis. The figure suggests that the concentration score is left-skewed in our participants, with a greater number of participants scoring at the higher end of the scale and fewer at the lower end.

2.12.1.7 Inclusiveness of Activities (Inclusiveness)

The inclusiveness of activities indicated that, for our sample of participants, the inclusiveness of activities had a mean of 4.05, with a minimum of 0.29 and a maximum of 8.39. This score suggests that our participants varied across their inclusiveness of being involved in activities, with the majority of participants involved in 3 to 5 different categories of activities within a day in the past year. The pattern of distribution is presented in Figure 2.8, which is normally distributed.

Figure 2.8

Histogram of Distribution of the Inclusiveness of the Activities Score



Note. Figure presents the distribution of inclusiveness of activities in a total of 314 participants. Y-axis is an indication of the frequency of participants for each inclusiveness of activities score on the x-axis. The figure suggests that the inclusiveness of activities score is normally distributed in our participants. The inclusiveness of activities score was calculated based on participants' reported number of days of involvement in activity categories in the past year.

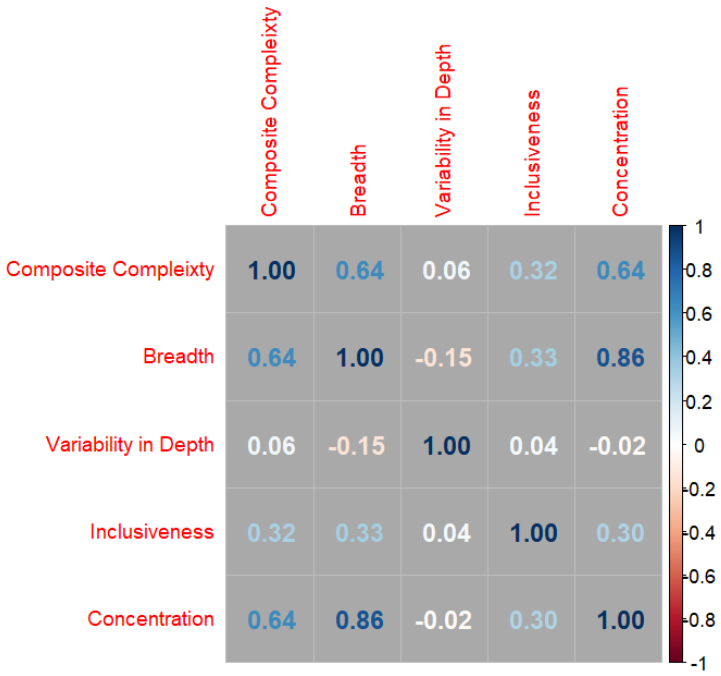
2.12.2 Correlations Between Variables

2.12.2.1 Pearson's Correlation Coefficients

The Peason's correlation coefficients between main variables are presented in Figure 2.9. The concentration of activities is negatively correlated with (or not correlated with) other variables. All other variables are positively correlated with each other, except for the variability in depth of involvement which is negatively correlated with the breadth of involvement, and with concentration of activities.

Figure 2.9

Correlation Matrix of the Main Extracted Variables



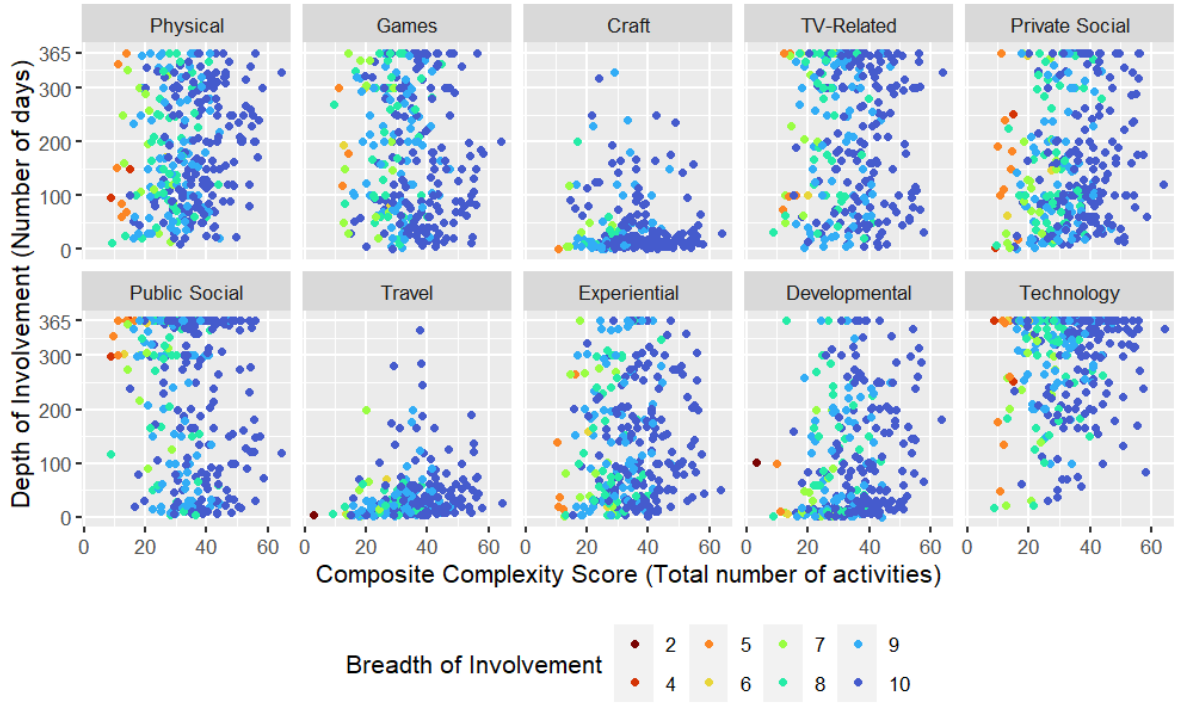
Note. The coefficients in blue indicate positive correlations, and the coefficients in red indicate negative correlations.

2.12.3 Relationship Between Variables

The relationship between depth of involvement and composite complexity revealed differences between some activity categories (Figure 2.10). Craft, Travel and Developmental Activities had relatively lower depths of involvement, whereas Technology, Games and Physical Activities had greater depths of involvement.

Figure 2.10

Composite Complexity Score Versus Depth of Involvement Grouped by the Activity Categories



Note. The composite complexity score (3–64) is presented on the x-axis of the figure, and the depth of involvement (0–365) is presented on the y-axis of the figure. The breadth of involvement is indicated by the colour of the data points, each of which indicates one participant.

2.13 Study 2: Discussion

Study 2 aimed to evaluate the use of CLCQ, and develop meaningful scoring in order to represent the concept of cognitive life complexity. Current life complexity variables were extracted from the questionnaire responses, and initial norms for the variables were established. Results demonstrate adequate face validity and viable participant experience in taking the CLCQ, resulting in usable data. According to the results of both Study 1 and Study

2, we could conclude that the "complexity" aspect of the concept of current life complexity could be represented by the derived variables. All proposed variables for measuring breadth, depth, and variability of current life complexity were theoretically meaningful. The pattern of results implies that the composite complexity score cannot only be explained by the breadth of involvement, but was also likely to reflect other dimensions. A multiple-parameter approach might be ideal to represent participants' responses for their current life complexity.

A limitation of Study 2 was that the majority of the participants were under the age of 60. When considering the characteristics of lifestyle, more specifically activity patterns, differences were expected to exist between young and older adults. Compared to older adults, young adults potentially engage in less variety of activities, because they have less disposable time and are less financially established (Richardson et al., 2018). Also, different activities patterns might be selected depending on people's health conditions (Wang & Yang, 2023) and mobility (Unsworth et al., 2022). Young adults generally had better health conditions and more mobility compared to older adults (Erickson et al., 2024). When applying the results obtained from Study 2 in the context of the current thesis, the hidden effect of age on lifestyle choices needs to be considered. However, from the perspective of participants' experience, the older adults' successful completion of Study 2 provided evidence that responding to the lifestyle questions asked in the CLCQ was achievable. This finding supported the feasibility of future studies to obtain responses for the CLCQ from older (i.e., aged 60 and above) and even old-older (i.e., aged 80 and above) samples. Hence the comparison of current life complexity between young and older participants and the examination of age-related changes in current life complexity, can be conducted with older populations.

2.13.1 Potential Applications of Extracted Variables

A list of hypothetical research questions is provided below as examples of how the extracted variables from the CLCQ may be applied, noting these research questions were not the interest of current study.

1. Does lower education level restrict the number of activities people choose to be involved in during daily living?

   Model:

   $$Composite\ Complexity\ Score = a + b * Education\ Level$$

   - a is the intercept
   - b is the coefficient for Education Level.

2. Does wider breadth of involvement restrict participants' depth of involvement in the most commonly involved activities category (i.e., technology-related activities)?

   Model:

   $$\log\left(\frac{p}{1-p}\right) = a + b * Breadth\ of\ Involvement$$

   - p represents the probability of a higher Composite Depth of Involvement in Technology-Related Activities
   - a is the intercept
   - b is the coefficient for Breadth of Involvement.

3. Is there any age-related difference in people's intention to focus on a smaller number of categories of activities with greater depth (i.e., the concentration of activities in a fewer number of categories)?

   Model:

$$logit\ (\mu) = a + b_1 * Age + b_2 * Breath\ of\ Involvement$$

- μ represents the Concentration of Activities variable, which follows a Beta distribution
- a is the intercept
- b_1 is the coefficient for Age
- b_2 is the coefficient for Breadth of Involvement.

4. Is there any age-related difference in the number of activities people can be involved in within a day (i.e., Inclusiveness of Activities)?

   Model:

$$Inclusiveness\ of\ Activities = a + b * Age$$

- a is the intercept
- b is the coefficient for Age.

2.14 General Discussion

The purpose of these studies was to establish a self-report measure that is capable of capturing the concept of current life complexity. After investigating a number of measurement approaches and instruments, the Victoria Longitudinal Study Activity Lifestyle Questionnaire (VLS-ALQ; Hultsch et al., 1999) was selected and further modified to fulfill the needs of measuring current life complexity, resulting in the development of the Current Life Complexity Questionnaire (CLCQ). Our evaluation of the CLCQ using both qualitative and quantitative methods indicated acceptable face validity, and that participants could respond in the expected way. We suggest a number of meaningful scoring approaches to capture breadth, depth and variability of current life complexity from the CLCQ. The relationship between the VLS-ALQ and CLCQ at the item level and the scale level adds support to the assertion that current life complexity is a real, measurable concept, which is dependent on but different from a summary of lifestyle pattern.

As in other studies exploring daily engagement in categories of activities (e.g., Spissu et al., 2009), we found clear distinctions in the selection and frequency of engagement in different categories of activities in the previous year. Our participants were more deeply involved in technology-related activities than in the other activities. This aligned with Arundell and colleagues' (2021) findings, which suggested that there was an increase in time with screens (i.e., the majority of technology-related activities) following the COVID-19 pandemic in Australia. Also, our participants were less likely to be involved in craft and travel activities than in the other activity categories, and when involved in craft and travel, they spent less time on these activity categories. This may reflect the reduced frequency of

travel in the Australian population found by Butler et al. (2021). We also detected potential clustering in activity preferences, with some participants engaging more regularly with TV-related activities, and others with social activities. This is consistent with research surrounding television viewing habits (Turner, 2021) and social activity engagement (Maness, 2017; Naud et al., 2019). Taken together, engagement within and across activity categories as captured by the CLCQ aligns with existing relevant literature, suggesting the CLCQ can successfully capture meaningful patterns of lifestyle engagement.

The selection of activity categories in the current study was similar to activity categories emphasised by previous time-use survey studies that investigated the complexity of life in later adulthood (e.g., physical activity, TV-related activity, social activity, and travel; Jarosz, 2023). Jarosz (2023) found that complexity of life reduced with age. However, most of our participants endorsed all 10 activity categories, implying that there would be a suitable scope for detecting age-related changes. Accordingly, the CLCQ is likely suitable for detecting how individuals actively select categories in which to invest energy and time, which is the core of the selective optimisation with compensation (Baltes & Baltes, 1993). This process involves activity category selection, investment, compensation, and optimisation. The derived variables of current life complexity (e.g., composite complexity score, breadth of involvement, depth of involvement) can be used to operationalise the theoretical framework established by selective optimisation with compensation. The composite complexity score and the breadth of involvement reflects the actively selected activity categories, so it may be used to measure selective reduction in number of domains engaged with, to optimise lessened cognitive resources. The composite complexity score and the depth of involvement reflects

the invested energy and time, so may be used to measure whether engagement across domains is being maintained by reducing engagement with some (or all) domains. Longitudinal investigations using CLCQ could expand our understanding of age-related changes in activity categories selection, investment, compensation, and optimisation.

2.14.1 Strengths and Limitations

This study has a number of strengths, as well as limitations. The extracted variables from the CLCQ capture not only breadth of involvement, but also depth and variability of involvement across categories of activities. This enables the construction of a multi-dimensional view of an individual's cognitive lifestyle, which allows for a richer exploration into the association between cognitive lifestyle and cognitive outcomes. However, this means traditional measures of internal reliability and consistency used in scale development could not be applied, and the current analysis has focussed primarily on face validity and participant experience.

The CLCQ is a retrospective self-report measure. This allows more scalable and timely data collection than prospective measures, but it means the CLCQ relies on participants' recall of past activities, which is subject to memory biases and inaccuracies (Bhandari & Wagner, 2006; Öztaş Ayhan & Işiksal, 2005). This may result in over- or under-reporting of activities. These biases are likely to differ by activity categories. For instance, in studies exploring self-report accuracy, Quinlan et al. (2021) found evidence of over reporting physical activities, and Wu-Ouyang and Chan (2023) found evidence of under reporting technology-related activities. Additionally, in Study 1, the timeframe of test-retest in older

participants was larger compared to the timeframe of test-retest in young participants. In young participants, the test-retest period was 1–2 weeks, whereas in older participants, the test-retest period was 3–10 months. The recall period for both VLS-ALQ (modified) and the CLCQ was the past year. Hence, the activities patterns recorded by the VLS-ALQ (modified) and the CLCQ had less overlap in terms of timeframe for older participants (2–9 months) compared to young participants (almost 12 months). As established in Chapter One, the expected timeframe for meaningful change in activity patterns was over a year (Hughes et al., 2018). While the longer test-retest period for older participants could introduce larger timeframe effects between the VLS-ALQ (modified) and CLCQ administrations compared to the timeframe effects in young participants, such a confound was anticipated to be limited. Longitudinal studies of ageing typically measure activity lifestyle change over intervals of 4–5 years across 50–90 years of age (e.g., Finkel et al., 2018; Shaw et al., 2010). This established scale of meaningful change in activity patterns suggests that an extended test-retest period could introduce minimal timeframe effects for older adults. To understand the potential magnitude of this bias, future research should compare within-subject consistency between the CLCQ and an experience sampling method such as time-use diary, covering the same time period.

Further, the CLCQ does not account for differences between participants with organised schedules versus those with less stringent schedules, such as those in the workforce versus retired individuals. Regularities and planning are also important aspects of lifestyle that might require investment of cognitive resources (Dexter & Ossmy, 2023; Kliegel et al., 2007). Future research would benefit from examining the association between the CLCQ and

measures that capture the participants' time allocation to different activity categories (e.g., time-use records).

2.14.2 Future Directions

The current study focussed on the measurement of the concept of current life complexity, rather than seeking to explain potential reasons underlying differences in life complexity. Lifestyle choices have been associated with physical abilities (Qiao et al., 2021), socio-economic status (Qiao et al., 2021; Stalling et al., 2022), non-work responsibilities (Dyer et al., 2018) and migrant status (Berasategi Sancho et al., 2023; Dyer et al., 2018). They may also be associated with personality traits such as conscientiousness, openness, or extraversion (Stephan et al., 2018; Wang et al., 2009). Future investigations could build on the current work by exploring the association between these factors and people's choices of living pattern, which could further inform our understanding of lifestyle and its potential effect on people.

There is a large body of research in ageing investigating the association between cognitive ability and historical lifetime experiences (e.g., Almeida-Meza et al., 2021), function in daily activities (e.g., Passler et al., 2020), daily time use (e.g., Jarosz, 2023) and current activity lifestyle (e.g., Hultsch et al., 1999). The CLCQ may be valuable for further investigation of the association between current life complexity and cognitive ageing. Relatedly, the CLCQ can be a suitable tool for exploring compensatory behaviours (e.g., reducing involvement in either breadth or depth, under constraints of energy and/or cognitive

resources). This could be a potential lifestyle signal that informs the early detection of cognitive decline in later-life.

Chapter Three

A Systematic Review of Task Switching in Healthy Older Adults: Paradigm Manipulations and Switch Costs

A Systematic Review of Task-Switching in Healthy Older Adults: Paradigm Manipulations and Switch Costs

3.1 Introduction

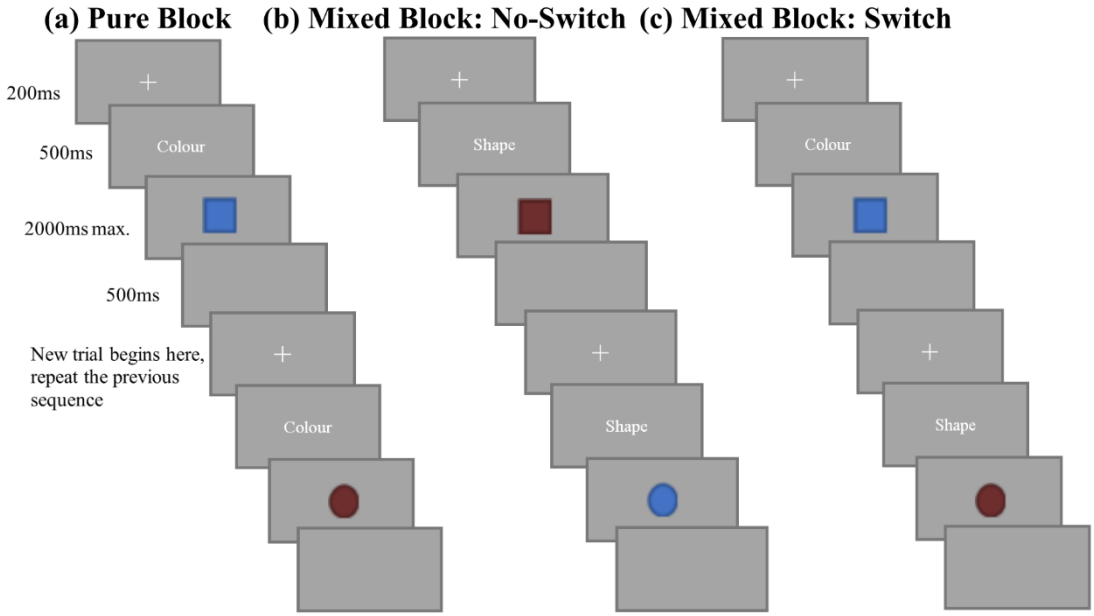
Task-switching, also known as set-shifting or cognitive-flexibility, is the ability to alternate sequentially between multiple tasks (Ging-Jehli & Ratcliff, 2020; Jersild, 1927). To switch tasks successfully, executive control processes are needed to coordinate the inhibition of the old task with the activation of the new task (Allport et al., 1994). This cognitive process has been explored in laboratory settings using tasks including the Wisconsin Card Sorting Test (Berg, 1948) and the Trail Making Test (Caselli et al., 2020), and most commonly through a task-switching paradigm built on the foundational design by Jersild (1927). The task-switching paradigm has evolved greatly since its origin in 1927, but the basic concept and procedures have remained the same. Participants are required to switch sequentially between two (or more) base-tasks. Examples of possible base-tasks have included digit-parity tasks (i.e., a choice as to whether the digit presented was an odd number or an even number), colour-discrimination tasks (i.e., a choice as to whether the colour of the stimulus presented was red or blue), and semantic-categorisation tasks (i.e., a choice as to whether the stimulus presented was a fruit or a vegetable). More than one base-task may be used, for example, in the paradigm illustrated in Figure 3.1 (Vasta et al., 2018), participants were required to switch between a colour-discrimination base-task and a shape-discrimination base-task. Task-switching paradigms can also contain various stimulus features, such as the complexity of task-stimuli, the informativeness of task-cues, and the length of time between trials. It is unclear whether these modifications to task-switching paradigms capture task-switching performance in the same way as the original paradigm.

Adapting to changes is one of the important components underlying successful completion of the action of task-switching in both laboratory and real-life settings. In real-life

settings, a sudden change when faced with an unexpected situation (e.g., a dangerous car driving towards oneself) can happen at any point in time. Being able to switch from a routine task (e.g., talking to people) to a task that requires a reaction to the sudden change (e.g., avoiding a car) would be essential to ensure the individual's safety. The age-associated decline in task-switching abilities often found in later-life has been proposed to result in a reduction in the capacity of older adults to remain engaged in various tasks of daily living (Vaughan & Giovanello, 2010). As research on age-associated changes in task-switching performance is accumulating across the different variations of the task-switching paradigm, there is a need to aggregate evidence to allow for a more comprehensive understanding of ageing and task-switching. Reviews to date have either focussed on the underlying mechanisms of task-switching (e.g., as in Kiesel et al., 2010), or aggregated results across a variety of paradigm designs (e.g. as in Chen & Hsieh, 2023). We assert that it is important to understand how variability in the task-switching paradigm may impact task-switching performance, in order to unambiguously understand differences in task-switching performance attributable to age. Relevant considerations are the different measures of task-switching used in task-switching paradigms to test both young and older adults, the paradigm manipulations developed by previous researchers, sample size and effect size.

Figure 3.1

An Example of a Task-Switching Paradigm (Figure Modified Based on Vasta et al., 2018)



Note. Typical example of a task-switching paradigm. Maximum trial length is 3200ms, starting with fixation cross (200ms) in centre of screen, followed by cue (500ms) instructing participants to perform Task-A (cue: Colour) or Task-B (cue: Shape). Next, stimulus appears, and participants make forced-choice response within 2000ms. Trial ends with blank screen (500ms), and new trial begins that repeats previous sequence, until all trials are completed. In each trial, participants perform either Task-A, colour-discrimination task (i.e., colour of the stimulus is blue or red), or Task-B, shape-discrimination task (i.e., shape of the stimulus is circle or square). Panel (a) presents an example of two trials from Task-A pure-block, in which participants perform only Task-A (cue: Colour). (Task-B pure-block is not presented in this figure but in Task-B, participants would perform only Task-B (cue: Shape)). Two examples of trials from the mixed-block include: Panel (b) a no-switch trial, where the Task-B trial is followed by another Task-B trial, and Panel (c) a switch trial, where the Task A trial is followed by a Task-B trial.

3.1.1 Measuring Switch Costs in Task-Switching Paradigms

Task-switching paradigms make use of two kinds of blocks: pure-blocks and mixed-blocks. In pure-blocks, participants are required to complete only one task, such as a digit comparison task where they state if a given number is greater or smaller than five; or a digit-

parity task where they state if a given number is odd or even. In mixed-blocks, there is a requirement either not to switch between tasks, or to switch between tasks, such as a digit-comparison task followed by a digit-parity task, where the participant states if a given number is greater or smaller than five. Each block in a task-switching paradigm can contain from 20 trials to hundreds of trials.

Switch costs are quantifiable measures of the cognitive effort required to make a switch between trials. Switch costs are typically referred to as global-switch costs, sometimes referred to as mixing costs, or local-switch costs, sometimes referred to as switching costs. Global-switch costs are measures of the reaction time (RT) and accuracy differences between the pure-block trials and the no-switch trials within the mixed-block of trials, that is, trials within the mixed-block that require participants to perform the same task as in the previous trial. Typically, pure-block trials are performed faster and with higher accuracy compared to no-switch trials in the mixed-blocks. Local-switch costs are measured by the RT and accuracy differences within the mixed-blocks, comparing the no-switch trials and the switch trials. No-switch trials are trials within the mixed-block that require participants to perform the same task as in the previous trial, whereas switch trials are trials within the mixed-block that require participants to perform a different task from the previous trial. Typically, the no-switch trials of the mixed-block are performed faster and with higher accuracy compared to the switch trials of the mixed-block.

There are many other factors that go beyond the choice of base-tasks and switch-rules that can also influence performance, as measured by switch costs. When more complex stimulus-features are used in the base-tasks, they can affect the ease of identifying the features in the stimuli, resulting in slower RT and larger local-switch costs (Rey-Mermet & Meier, 2015). More complex and less informative task-environments are also associated with larger local-switch costs (Hahn et al., 2004). Longer preparation-times (i.e., a longer time

between cue and target within an experimental trial) are associated with lower local-switch costs (Meiran et al., 2001).

3.1.2 Young and Older Adults Task-Switching Performance

The extent to which different base-task combinations influence task-switching performance has not yet been explored. Divergence from Jersild's (1927) original task-switching paradigm has implications for interpreting the results as they relate to task-switching performance differences between young and older adults. The pattern of age-related cognitive decline varies across different executive functions (Deary et al., 2009; McCarrey et al., 2016). It follows that choice of base-task is important because different base-tasks will require different cognitive processes. For instance, Vonk et al. (2020) suggested that semantic processing abilities remain intact until the age of 70–75, whereas working memory and processing speed decline from the age of 55. This is unlikely to impact young versus older comparisons in task-switching paradigms that minimise working memory or semantic processing, such as requiring participants to switch between a digit-discrimination task and a digit-comparison task and either indicate if a digit was odd or even, or that it was smaller or greater than five (Chang et al., 2020). However, there is likely to be an asymmetry in older adults engaging with a paradigm requiring participants to switch between a semantic-categorisation task and a size-comparison task, in which they either categorised the meaning of a presented stimulus (e.g., fruit or vegetable) or compared the size of the presented stimulus to a reference, such as the computer screen (Simon & Bock, 2017). As such, the category of base-task needs to be separated from participants' task-switching performance to understand the function of task-switching independently of confounds, such as the choice of base-tasks. Consequently, the current review investigated whether any given combination of base-task was easier to switch between than others for older adults.

Another consideration is whether different switch-rules can exert an influence on task-switching performance. Switch-rules are used to instruct participants about what kind of task-switching will be required in a particular trial, with example categories of switch-rules including switching voluntarily (e.g., Butler & Weywadt, 2013), memorising switch-rules for the whole trial block (e.g., Hakun et al., 2015), and cueing before each trial of the task (e.g., West & Moore, 2005). Switching voluntarily means the choice to task-switch or not is made by the participant. This requires adequate planning and decision-making abilities. Memorising switch-rules for the whole trial block involves participants memorising in advance the switch-rules for the whole trial block. This requires intact memory abilities. A common memorising switch-rule is the alternate switch-rule, also known as alternate run or predicable task-switching (Kiesel et al., 2010), in which participants switch from the previous-task to the alternate-task between each trial for the whole trial block. The alternate-switch cost is the RT and accuracy differences between the pure-block trials and the alternate-block trials, typically pure-block trials are performed faster and with higher accuracy compared to alternate-block trials. Cueing before each trial of the task is where participants either repeat or switch tasks according to the cue provided before each of the trials. This requires adequate visual processing abilities.

While there is evidence that older adults are slower at task-switching than young adults (Wasylyshyn et al., 2011), a recent meta-analysis (Chen & Hsieh, 2023) suggested that the evidence is insufficient to confirm that local-switch costs are significantly larger in older adults. This may be because age-related decline in task-switching may be expressed differently with different switch-rule categories. For example, in voluntary switching, age-related decline could be compensated for by voluntarily choosing to minimise the amount of switching, and thus prioritising task-performance. When memorising switch-rules for the whole trial block, age-related decline in task-switching may be confounded by the influence

of age-related memory decline (Greene & Naveh-Benjamin, 2023), as noted by Kray et al. (2010) and Schapkin et al. (2014). One way to minimise the confounds of voluntary choice and memory is to cue before each trial of the task. Pre-task cues serve to prompt participants to prepare for task-switching, and thus may improve task-switching performance for both young and older adults. However, compared to young adults, older adults who demonstrate a tendency to prioritise accuracy over speed may be more likely to benefit from this opportunity to prepare in advance for task-switching. Overall, variations in how age-related decline in task-switching performance can be manifested necessitates an investigation into the effects of different switch-rules on task-switching performance in older adults.

3.1.3 Sample Sizes and Effect Sizes in Task-Switching Paradigms

The relationship between sample size and effect size can be considered crucial in shaping the robustness and generalizability of findings in the task-switching paradigm literature. Cognitive psychology studies often have small sample sizes, which can lead to biases from unreliable or inconsistent statistical outcomes (Cao et al., 2024). Therefore, in synthesising the evidence from the task-switching literature, it is important to assess whether statistically significant or non-significant effects are the result of a small or large sample size.

There are a number of narrative reviews and meta-analyses regarding task switching. Vandierendonck and colleagues (2010) investigated the underlying mechanisms of task-switching in their review. Around the same time, Wasylyshyn et al. (2011) conducted a meta-analysis focussing on task-switching in ageing. Recently, Chen and Hsieh (2023) published an updated and extended meta-analysis on the same topic. Yet, to our knowledge, no previous reviews or meta-analyses have focused on how the task-switching paradigm has been modified and manipulated over time in the study of healthy older adults. Therefore, the current systematic review aims to bolster our understanding of how task-switching

performance in healthy older adults is influenced by paradigm manipulations: the choice of base-task and switch-rule; the complexity of stimulus-features; the informativeness of task-environment; and preparation-time, including time interval between trials, and time interval between cue and stimulus. An understanding of how the task-switching paradigm has changed over time, and a consideration of the impact of these changes in studies comparing performance in young and older adults, is required to provide context to the exploration of age-associated changes in task-switching performance.

3.2 Methods

3.2.1 Search Protocol

This systematic review was conducted following the Preferred Reporting of Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). The search was performed in the three largest databases for psychology and medical science (Paperpile, 2025): Ovid, Web of Science (WoS), and Scopus. The original search was undertaken on 28/08/2021 and updated on 22/08/2023. The updated search was performed in Ovid, WoS, Scopus and PubMed. Search terms are presented in Table 1. Title screening was undertaken by XH. Abstracts were screened by XH and EIW, who each reviewed a different set of abstracts. All full texts were screened by XH and EIW independently, with discrepancies resolved by AAD. Data was extracted by EIW and XH, with independent verification by AAD.

Table 3.1

List of Search Terms

Categories	Search Terms
Task-Switching Keywords	(Task-Switching OR Task Switching OR Set-Shifting OR Set Shifting OR Task-shifting OR Task shifting OR Set-Switching OR Set Switching OR Cognitive-Switching OR Cognitive Switching OR Cognitive-Shifting OR Cognitive Shifting OR Cognitive-Flexibility OR Cognitive Flexibility)
Ageing Keywords	AND (Late* Life OR Aging OR Ageing OR Old* Adult* OR Old old OR Old-old)
Primary Exclusion Keywords	AND NOT (Medica* OR Intervent* OR Brain Damage OR Cognitive Impairment OR Child* OR Adoles* OR Teen* OR Young* adult* OR Middle Age)
Secondary Exclusion Keywords	AND NOT (Damage OR Impairment OR Disease OR Hospit* OR Disab* OR Drug OR Substance OR Physiolog* OR Syndrome OR Animal OR Mouse OR Mice OR Symptom OR Stroke OR Neglect OR Trum* OR Patient OR Brain Injury OR Schizophrenia OR Lesion OR Bipolar)

Note. The secondary exclusion keywords were searched in the title, abstract and keyword field to avoid over exclusion. All other search terms were searched in all fields to include all the relevant results. The plural forms of single word search terms were automatically included by search mechanisms of the databases; hence truncation was not used on those plural terms.

3.2.2 Inclusion and Exclusion Criteria

At the title-screening stage, articles were excluded if they:

(1) were written in a language other than English;

(2) did not include at least one group or sub-group of participants aged 60 or older (following

the cut-off definition of "older adults" used by WHO, 2025)[1];

(3) were review or commentary papers rather than first-hand data collection papers;

(4) were unrelated to the general topic of task-switching;

(5) did not include human participants;

(6) included participants with physical conditions known to damage the brain (e.g., stroke, epilepsy);

(7) focussed primarily on groups of participants with psychological conditions associated with acute executive dysfunction and damage to the brain (e.g., schizophrenia, substance abuse)[2];

(8) included experimental manipulation of natural cognitive performance, for example using medication or a cognitive training intervention.

At the abstract screening stage, the same criteria as for title screening were applied but additionally, articles were excluded if they:

(9) did not include task-switching related experimental paradigms or measures;

(10) were not available, either as an abstract or full-text.

At the full-text screening stage, the same criteria as for abstract screening were applied, with a final inclusion judgement based on whether the article:

(11) explicitly included the task-switching paradigm, or a variant of the task-switching paradigm. Journal articles that used other tests or paradigms that could be regarded as measures of cognitive switching ability (e.g., Wisconsin Card Sorting Test, Trail-Making Test, Stroop

[1] Where explicit age information was unavailable in the title and/or abstract, journal articles were retained for investigating as part of the full-text screening. Articles were included if the age group had substantial overlap with age <60 years (e.g., age range from 50–60 years), or used terms associated with this age group (e.g., old-old, elderly).

[2] Note that common risk factors that may potentially lead to physical brain damage, such as alcohol consumption and smoking, were not used as the basis for exclusion given their high prevalence in the broader population, and lower likelihood of being reported in studies focusing on general population samples.

Task, Go-No-Go Task) were excluded.

3.2.3 Data Extraction and Study Quality

Data was extracted in six main sections, explained in full in Appendix F Table F1. Briefly, these were: Basic Journal Article Information (e.g., year of publication); Experimental Paradigm Information (e.g., type of task-switching task); Additional Relevant Information (e.g., participant characteristics); Longitudinal Design Information (e.g., number of repeated measures); Task-Switching Definition Information (e.g., proposed theoretical source of switch costs); and Switch Cost Information (such as effect size of switch cost). For studies not reporting effect sizes, but including relevant information (e.g., *F*-statistics and degrees of freedom for ANOVA), an estimation of partial eta-squared was calculated using R (version 4.3.2; R Core Team, 2023), RStudio (version 2023.9.1.494; Posit Team, 2023), and function supplied by EIW (see Appendix A). Sample size evaluation technique developed by Garner et al. (2022) was used to assess potential bias in effect size relative to sample size. Study quality was assessed by the Meta Quality Appraisal Tool (MetaQAT, Rosella et al., 2016), chosen due to its applicability to multiple types of studies, including randomised control trials, cohort studies, cross sectional studies, mixed methods research, and qualitative research.

In the Results and Discussion sections of the systematic review, we adopted a numbering system (e.g., [Study 66]; see Appendix F Table F2) to reference reviewed studies. This was intended to enhance the clarity and transparency of reporting.

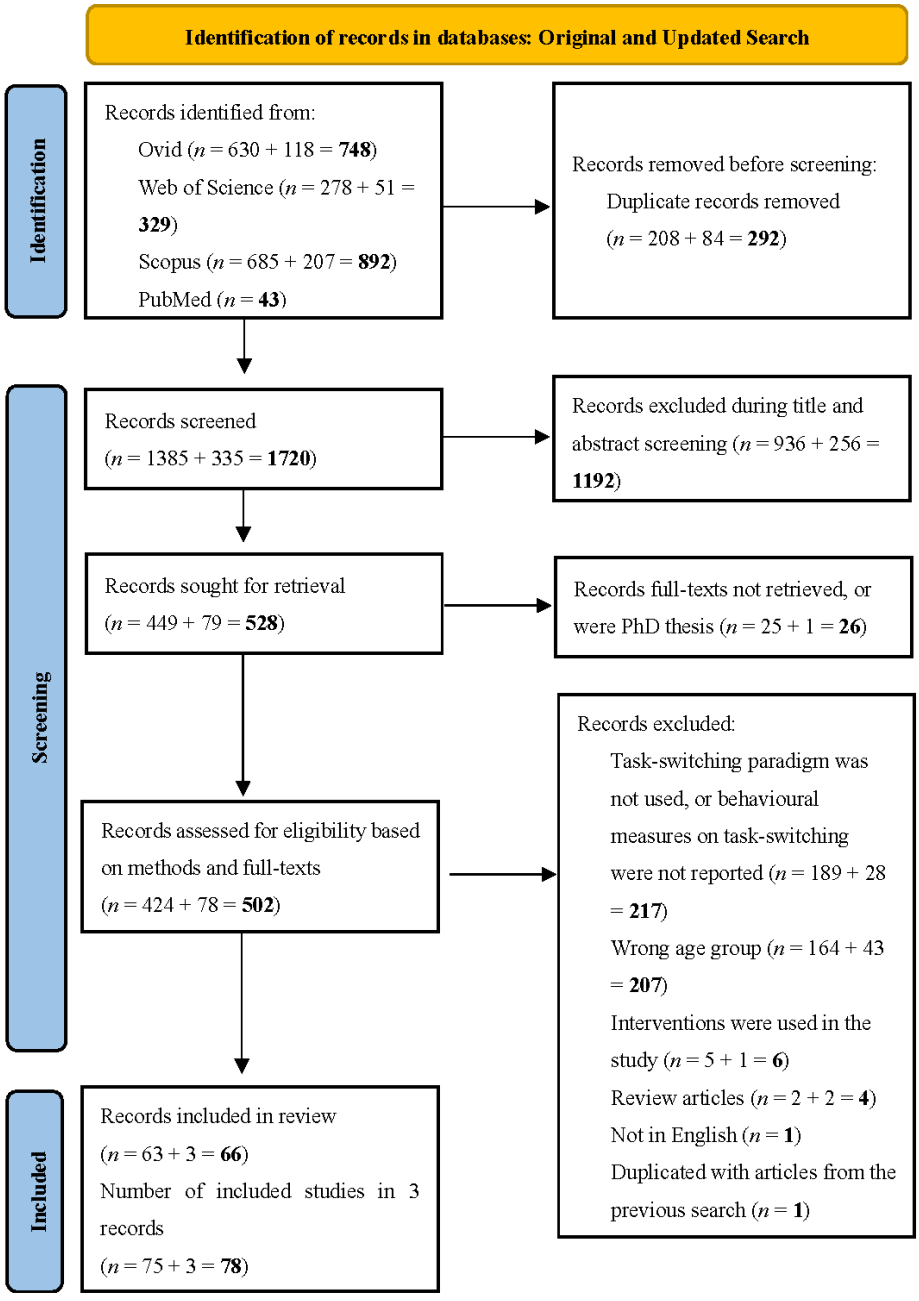
3.3 Results

As summarised in Figure 3.2, the original search returned a total of 1593 records, and the updated search returned a total of 419 records. After title, abstract, and full-text screening, a total of 66 publications were included in the current systematic review. As some

publications included multiple studies, there were 78 studies included. No study was excluded due to unacceptable level of poor study quality according to our evaluations based on guidelines provided by MetaQAT (Rosella et al., 2016).

Figure 3.2

PRISMA Diagram for the Process of Identification, Screening and Inclusion



Note. n is expressed as number of results identified by original search + unique new results identified in the refresh = total number of results included in screening.

3.3.1 Basic Study Information

Selected publications were published between 1997 and 2023, with a peak number of 9 publications published in 2015. The number of publications on task-switching in healthy older adults increased within the period of 2012 to 2016 (see Appendix F Figure F1). The average total participant sample size was $N = 63.86$ (range of $N = 16$ to $N = 369$). To investigate the age-related differences in task-switching function, a large proportion of the reviewed studies (66 out of 78) applied the design of comparing older adult groups with young adult groups. These sub-groups ranged from $n = 9$ to $n = 124$ (young) and $n = 8$ to $n = 245$ (older). The methods of reporting age characteristics varied. Of the 78 studies, 68 reported the mean age for older adults, which ranged from 62.9 to 80.3, and 52 of these studies also reported standard deviations (*SD*), which ranged from 1.30 to 9.38. Fifty-five out of the 78 studies also reported the age range for older adults, and the minimum age for older adults was 59, and the maximum age was 90. Studies that used young adults as a comparison group reported average ages ranging from 18.4 to 32.1 (*SD* range = 0.90–8.20, minimum age = 17, maximum age = 40).

Of the 78 studies, 61 reported the participant sample's gender characteristics. Studies disproportionately included women, irrespective of age group (i.e., young or older adult). One study (Gajewski & Falkenstein, 2015) included only men. Of the 60 studies including both genders, the average proportion of women was 57.71%, ranging from 35.94% to 82.05% (mean 57.94%, range 36.36% to 87.50% for older adult group; mean 56.76%, range: 29.41% to 95.00% for younger adult comparison group).

In the studies reviewed, the data pre-processing that was reported did not consistently state whether the results were based on correct responses or on all responses. During the process of data extraction, we have recorded whether RT was based only on correct responses. The articles reviewed included either: only correct responses, both correct and

incorrect responses, or did not indicate whether the included responses were correct or incorrect. Articles that only included correct responses were the majority among the studies reviewed.

3.3.2 Measurement of Switch Costs

Switch costs were not operationalised in the same way across studies. As shown in Table 3.2, the most common measures were local-switch costs (i.e., RT and accuracy differences between no-switch trials and switch trials) and global-switch costs (i.e., RT and accuracy differences between pure-block trials and no-switch trials in the mixed-blocks). No-switch trials were performed faster and with higher accuracy compared to switch trials, and pure-block trials were performed faster and with higher accuracy compared to no-switch trials in mixed-blocks.

Other switch costs reported included N-2-repetition costs and alternate-switch costs. In Lawo et al. (2012 [Study 1278]), N-2-switched trials (i.e., Task-Cs in task sequence ABC) were performed faster and with higher accuracy compared to N-2-repeated trials (i.e., Task-Cs in task sequence CBC). Some studies (e.g., Hirsch et al., 2016 [Study 128]) used the alternate switch-rule, in which participants switch from the previous-task (e.g., Task A) to the alternative-task (e.g., Task B) between each trial for the whole trial block. Here, the outcome was the alternate-switch cost, which was the reaction time and/or accuracy differences between their performance on the pure-block trials and their performance on the alternate-block trials where they switch between Task A and Task B. Pure-block trials were performed faster and with higher accuracy compared to alternate-block trials.

There was also one study that used a predictable-shift cost and an unpredictable-shift cost (Van Asselen & Ridderinkhof, 2000 [Study 1036]). The predictable-shift cost was the RT and accuracy differences between the cue-predicted-switch trials (i.e., the pre-task cue

provided correct information for the following trial) and no-switch trials. The unpredictable-shift cost was the RT and accuracy differences between the cue-unpredicted-switch trials (i.e., the pre-task cue provided wrong information for the following trial) and no-switch trials. No-switch trials were performed faster compared to both cue-predicted-switch trials and cue-unpredicted switch trials. Furthermore, cue-predicted-switch trials were performed faster compared to cue-unpredicted switch trials.

Nagy et al. (2023) [Study 1550] used a unique paradigm manipulation. In their design, both the task (colour-comparison or shape-comparison) and the focal stimuli (inner or outer of a shape) can be switched. In both young and older adults, RT was significantly shorter in no-switch trials compared to inner-outer-switch trials (i.e., the focal stimuli switched from the inner shape to the outer shape, or vice versa), and inner-outer-switch trials had shorter RTs than double-switch trials (i.e., both the focal stimuli and the task–colour-comparison or shape-comparison–were switched). Additionally, double-switch trials had significantly lower error rates and significantly larger switch costs, compared to the inner-outer-switch trials.

Table 3.2

Measurement of Switch Costs

Switch Cost Names	Definitions	Measurement Types	Publication Count	Reports of Testing Count	Significance Count (%)
Local-Switch Cost (Switching Cost, Specific Switch Cost)	The difference between the performance of switch trials and no-switch trials in mixed-blocks.	Reaction Time	26	33	**29** (87.88%)
		Accuracy / Error Rate	16	18	**18** (100%)
		Log Reaction Time	3	3	**3** (100%)
		Drift Rate[a]	1	1	**1** (100%)
		Non-Decision Time[a]	1	1	**1** (100%)
Global-Switch Costs (Mixing Cost, General Switch Cost)	The difference between the performance of mixed-block and single task block.	Reaction Time	19	19	**19** (100%)
		Accuracy / Error Rate	15	16	**13** (81.25%)
		Log Reaction Time	1	1	**1** (100%)
Alternate Cost	The difference between the performance of alternation block and single task block.	Reaction Time	3	4	**4** (100%)
		Accuracy / Error Rate	3	3	**3** (100%)

N-2-Repetition Cost	The difference between the performance of N-2 repetition trials and N-2 switch trials.	Reaction Time	1	1	**0** (0%)
		Accuracy / Error Rate	1	1	**0** (0%)
Predictable-Shift Cost	The difference between the performance of cue-predicted switch trials and non-switch trials.	Reaction Time	1	1	**1** (100%)
		Accuracy / Error Rate	1	1	**0** (0%)
Unpredictable-Shift Cost	The difference between the performance of cue-unpredicted switch trials and non-switch trials.	Reaction Time	1	1	**1** (100%)
		Accuracy / Error Rate	1	1	**0** (0%)

Note. Publication Count: Number of manuscripts using this type of switch cost measure. Reports of Testing Count: Number of reported statistical significance test results for this type of switch cost. These numbers did not add up to the total of 78 studies, as some studies implemented more than one switch costs measure. Significance Count (%): Out of the Reports of Testing Count, number of significant switch costs in this type of switch cost measure, and its percentage out of the total numbers of reports. [a]: Outcome of the Diffusion Decision model analysis, see Ging-Jehli and Ratcliff (2020) for more details.

3.3.3 Paradigm Characteristics

3.3.3.1 Base-Tasks

We organised base-tasks in identified studies into twelve categories: digit, colour and shape, colour and letter, digit and letter, spatial, semantic and non-semantic, digit and element number, letter, generate words, switch between three base-tasks, switch between multiple task-switching paradigms, and unusual base-task unique to a single study. As illustrated in Figure 3.3, the most common base-task was a switch between digit-parity and digit-comparison tasks. Of the 78 studies, 71 studies required participants to switch between two base-tasks, and the remaining 7 out of 78 studies required participants to switch between three base-tasks. There has been an increase in variation and complexity in the base-tasks of the task-switching paradigm over time; all four of the studies that used multiple task-switching paradigms were published after 2010, and all five studies with unique base-tasks were published after 2007 (continuous calculation tasks [Verhaeghen & Hoyer, 2007, Study 162], letter-discrimination or position-discrimination tasks [Gazes et al., 2012, Study 86] , shape-discrimination or size-discrimination tasks [Pettigrew & Martin, 2016, Study 1281], digit-discrimination or colour discrimination tasks [Idowu & Szameitat, 2023, Study 1519], and switch between either shape-discrimination or colour-discrimination tasks, inner-stimulus or outer-stimulus, or double-switch [Nagy et al., 2023, Study 1550]).

3.3.3.1.1 Comparisons of Switch Cost Related Findings Across Base-Task Categories

Switch costs across different base-tasks are summarised in Table 3.3. Analysis and reporting varied according to base-task categories. Seven of the base-task categories (digits, colour and shape, colour and letter, switch between three base-tasks, spatial, semantic and non-semantic, and multiple task-switching paradigms) focused more on reporting local-

switch costs, specifically on significant findings[3] for local-switch costs. No-switch trials were performed significantly faster and/or with significantly higher accuracy compared to switch trials. Some non-significant local-switch costs were reported in the colour and shape base-tasks (measured by RT and accuracy in Kunimi et al., 2016 [Study 732] and Zhu et al., 2015 [Study 963]), and the semantic and non-semantic base-tasks (operationalised by RT in in Madden et al., 2008 [Study 272]). Finally, statistical significance test results specific to switch costs were not reported for the word-generation base-tasks. The remaining four base-task categories (digit and letter, spatial, digit and element number, letter, generate words, and base-task unique to a single study) focused more on reporting global-switch costs (1 digit and letter base-task, 1 digit and element number base-task, 1 letter base-task, and 1 the base-task unique to a single study). Similar to local-switch costs, in studies reported global-switch costs, most of the studies found statistically significant global-switch costs, however, non-significant global-switch costs were found in the study switching between three base-tasks (Rey-Mermet & Meier, 2015 [Study 66]).

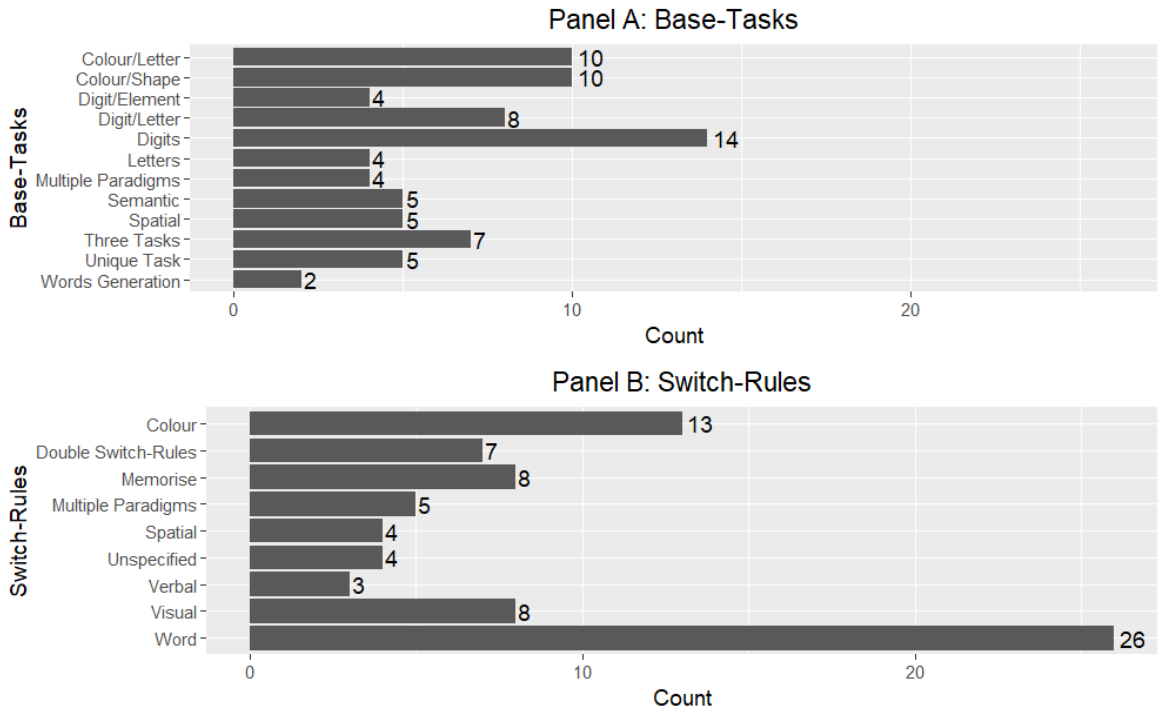
Other switch costs (defined in Table 3.2) were used with different base-tasks. Significant alternate-switch costs measured by RT was found in a study using the digit base-task (Hirsch et al., 2016 [Study 128-1]), and measured by both RT and accuracy in studies using the colour and shape base-task (Hakun et al., 2015 [Study 540]), the digit and letter base-task (Hirsch et al., 2016 [Study 128-2]), and the base-task unique to a single study (Verhaeghen & Hoyer, 2007 [Study 162]). Both a significant predictable-shift cost and unpredictable-shift cost were

[3] It is important to state that there was a notable under-reporting of detail for non-significant results. Where reported, non-significant switch costs were found in studies with the colour and shape task category, the colour and letter task category, the switch between three tasks category, and the semantic and non-semantic task category. (Further details for each base-task category can be found in Appendix F Table F3.) Non-significant switch costs were found across most of the switch cost types, with the exception of global-switch costs measured by reaction time (RT).

found by Van Asselen and Ridderinkhof (2000) [Study 1036] for the digit and letter base-task.

Figure 3.3

Graph of Base-Tasks and Switch-Rules for 78 Studies



Note. Count = The number of studies reviewed in each of the base-task/switch-rule categories. Three Tasks = Switch between three tasks, shortened for better visualisation. Unique Task = Task unique to a single study, shortened for better visualisation.

Table 3.3

Comparison of Switch Cost Related Findings Across Base-Tasks Categories

Base-Task Category (*N* = Number of studies)	**Local (RT)**	**Local (Accuracy)**	**Global (RT)**	**Global (Accuracy)**	**Other Related Findings**
Digit tasks (*N* = 14)	Sig = 7 Non-sig = 0	Sig = 4 Non-sig = 0	Sig = 4 Non-sig = 0	Sig = 2 Non-sig = 0	Significant alternate-switch costs measured by RT were identified (Hirsch et al., 2016 [Study 128]).
Colour and Shape tasks (*N* = 10)	Sig = 3 Non-sig = 2	Sig = 2 Non-sig = 2	Sig = 1 Non-sig = 0	Sig = 0 Non-sig = 0	Significant alternate-switch costs measured by RT and accuracy were identified (Hakun et al., 2015 [Study 540]).
Colour and Letter tasks (*N* = 10)	Sig = 6 Non-sig = 2	Sig = 3 Non-sig = 0	Sig = 3 Non-sig = 0	Sig = 1 Non-sig = 0	-
Digit and Letter tasks (*N* = 8)	Sig = 2 Non-sig = 0	Sig = 1 Non-sig = 0	Sig = 3 Non-sig = 0	Sig = 2 Non-sig = 0	Significant alternate-switch costs measured by RT and accuracy were identified (Hirsch et al., 2016 [Study 128]). Significant predictable-shift costs and unpredictable-shift costs measured by RT were identified (Van Asselen & Ridderinkhof, 2000 [Study 1036]).
Switch between three tasks (*N* =7)	Sig = 3 Non-sig = 0	Sig = 2 Non-sig = 0	Sig = 2 Non-sig = 0	Sig = 2 Non-sig = 2	Age-specific global-switch costs were identified in both young and older group (Rey-Mermet & Meier, 2015 [Study 66]). N-2-repetition costs measured by RT and accuracy were not significant (Lawo et al., 2012 [Study 1278]).
Spatial tasks (*N* = 5)	Sig = 2 Non-sig = 0	Sig = 3 Non-sig = 0	Sig = 0 Non-sig = 0	Sig = 1 Non-sig = 0	Significant global- and local-switch costs measured by RT latencies were identified (Bojko et al., 2004 [Study 88]).
Semantic and Non-Semantic tasks (*N* = 5)	Sig = 0 Non-sig = 1	Sig = 1 Non-sig = 0	Sig = 0 Non-sig = 0	Sig = 0 Non-sig = 0	Significant global- and local-switch costs measured by log RT latencies were identified (Kray & Eppinger, 2006 [Study 494]).
Digit and Element number tasks (*N* = 4)	Sig = 1 Non-sig = 0	Sig = 0 Non-sig = 0	Sig = 1 Non-sig = 0	Sig = 1 Non-sig = 0	-

Table 3.3

Comparison of Switch Cost Related Findings Across Base-Tasks Categories

Base-Task Category (*N* = Number of studies)	**Local (RT)**	**Local (Accuracy)**	**Global (RT)**	**Global (Accuracy)**	**Other Related Findings**
Letter tasks (*N* = 4)	Sig = 0 Non-sig = 0	Sig = 0 Non-sig = 0	Sig = 2 Non-sig = 0	Sig = 2 Non-sig = 0	-
Word Generation tasks (*N* = 2)	Sig = 0 Non-sig = 0	Sig = 0 Non-sig = 0	Sig = 0 Non-sig = 0	Sig = 0 Non-sig = 0	No test specific to switch costs was recorded. Studies suggested older adults have higher a rate of failure with switching word categories than young adults (Mayr & Kliegl, 2000 [Study 341]).
Task unique to a single study (*N* = 5)	Sig = 1 Non-sig = 0	Sig = 1 Non-sig = 0	Sig = 2 Non-sig = 0	Sig = 1 Non-sig = 1	Significant alternate-switch costs measured by RT and accuracy were identified (Verhaeghen & Hoyer, 2007 [Study 162]). Pettigrew and Martin (2016) [Study 1281] identified larger N-2-repetition costs in older adults, but this was not specific to switch costs. Double-switch trials had significantly larger switch costs, compared to the inner-outer-switch trials (Nagy et al., 2023 [Study 1550]).
Multiple Paradigms (*N* = 4)	Sig = 3 Non-sig =0	Sig = 0 Non-sig = 0	Sig = 0 Non-sig = 0	Sig = 0 Non-sig = 0	In Albinet et al. (2012) [Study 943], results were reported in the form of composite scores. This study found that older age was related to worse shifting composite scores (task-switching paradigm was one of the paradigms used to generate this score).

Note. More details on base-tasks can be found in the Appendix F Table F3 (Base-tasks summary). Details on the definitions of switch cost can be found in Table 3.2 (Switch cost summary). RT = Reaction Time. Local = local-switch costs. Global = global-switch costs. Sig = significant findings. Non-sig = non-significant findings. The level of reported information was inconsistent across base-task categories.

3.3.3.2 Switch-Rules

Switch-rules are the ways of instructing participants about the task switch required in a particular trial. We identified nine categories of switch-rules found in the selected 66 records (78 studies), presented in Figure 3.3. Switch-rules were mainly manipulated on two aspects: switch type (switching voluntarily, memorising the switch-rules for the whole trial block, or cueing on a trial-by-trial basis), and format (e.g., word, colour, visually, spatially, verbally).

Voluntary switch-rules (2 studies) are intended to mimic naturalistic switching performance, as in Butler and Weywadt (2013) and Terry and Sliwinski (2012) [Study 85 and 149]. Memorising switch-rules (8 studies) ask participants to alternate tasks after n^{th} trial, and explore the impact of memory ability on task-switching performance. Four out of the eight studies asked participants to alternate between two tasks (Hawkes et al., 2012; Hirsch et al., 2016; Verhaeghen & Hoyer, 2007 [Study 128, 1370, and 162]), two studies reported by Rey-Mermet and Meier (2015) [Study 66] presented tasks in triplets, and the remaining two studies asked participants to switch tasks every third trial (Gajewski & Falkenstein, 2015; Simon & Bock, 2017 [Study 763 and 1267]).

Cueing aims to remove the impact of memory on task-switching performance, by either cuing before trial onset (De Bruin et al., 2015a [Study 545]) or simultaneously with the trial stimulus (Ging-Jehli & Ratcliff, 2020 [Study 489]). Cues can take several forms (word, colour, visually, spatially, verbally). Word cues (26 studies), in which words or abbreviations of words were presented as cues for performing the corresponding task (e.g., “colour” for the colour-discrimination task), were the most common. Colour cues (13 studies), where the desired switch-rule was associated with a cue colour (e.g., blue background indicated response should be for odd rather than even numbers, as in Verstynen et al (2012) [Study 271]), was the second most common. Visual cues (8 studies), where the desired switch-rule was associated with a shape or gradient (e.g., border of box surrounding stimulus indicated

which task should be undertaken, as in Themanson et al. (2006) [Study 67]). Spatial cues (4 studies), where the location of the stimulus on the screen (typically upper or lower half) indicated the switch task (Erickson, 2008; Glisky et al., 2021; Kunimi et al., 2016; Mulligan et al., 2020 [Study 30, 401, 627, 732]). Verbal cues, where verbal instructions were presented as cues for performing the corresponding tasks, was found in three studies (two studies reported in Mayr & Kliegl, 2000 [Study 341], Mayr, 2001 [Study 82]). In one study, a simultaneous luminance and word cue was used (Ging-Jehli & Ratcliff, 2020 [Study 489]).

Some of the reviewed studies tested and compared multiple switch-rules. Seven studies contrasted two switch-rules. Comparisons of colour-cued versus word-cued switching (Chang et al., 2020 [Study 121]) and visually-cued versus word-cued switching (Tsai & Wang, 2015 [Study 570]) found that word-cued switching was associated with lower switch costs. Voluntary, rather than word cued (Gajewski et al., 2011; Hakun et al., 2015 [Study 540, 1230]) or visually cued (Dai et al. (2013) [Study 568]) switching was associated with lower switch costs. There was with further evidence that in voluntary cueing older adults chose to switch less often to maintain task performance (Butler & Weywadt, 2013; Terry & Sliwinski, 2012 [Study 85 & 149]). Gaál and Czigler (2015) [Study 136] compared informative cues (i.e., cues that provide task relevant information) with non-informative cues (i.e., cues that do not provide task relevant information), and reported that participants responded quicker when the cues were informative. This was also supported by the findings of Chang et al. (2020) [Study 121].

3.3.3.2.1 Comparison of Switch Cost Related Findings Across Switch-Rule Categories

Switch costs across different base-tasks are summarised in Table 3.4. As with base-tasks, analysis and reporting varied. Most studies did not report statistical significance-test (i.e., ANOVA) results for both global- and local-switch costs, with more studies focusing on local-

switch costs, and measuring switch costs in terms of RT rather than accuracy or both RT and accuracy. In four categories of switch costs (colour-cued, two switch-rules, multiple task-switching paradigms, and verbally-cued) only the significant switch costs were reported.

Studies of the memorise switch-rule also reported non-significant global-switch costs (Rey-Mermet & Meier, 2015 [Study 66]), which suggest that the accuracy differences between pure-block trials and the no-switch trials in the mixed-blocks were not significant (2 non-significant costs measured by accuracy). One study from the memorise switch-rule category also reported significant alternate-switch costs measured by RT and accuracy (Verhaeghen & Hoyer, 2007 [Study 162]).

Within the 9 switch-rule categories (word-cued, visually-cued, memorise, spatially-cued, colour-cued, two switch-rules, multiple task-switching paradigms, verbally-cued, and unspecified switch-rules), studies from 5 of the categories (word-cued, visually-cued, memorise, spatially-cued, and unspecified) reported non-significant switch costs. Studies that used spatially-cued switch-rule (Kunimi et al., 2016 [Study 732]) reported significant local-switch costs. Non-significant local-switch costs were also found in the studies that used word-cued switch-rules (Madden et al., 2008 [Study 272]; West & Moore, 2005 [Study 53]; Zhu et al., 2015 [Study 963]), and visually-cued switch-rules (West & Travers, 2008 [Study 409]). Significant global- and local-switch costs measured by RT latencies (Bojko et al., 2004 [Study 88]) and log RT latencies (Kray & Eppinger, 2006 [Study 494]) were also reported by studies that used word-cued switch-rules. Significant global-switch costs were reported in memorisation and colour-cued switch-rules (e.g., Gajewski and Falkenstein (2015) [Study 763] and Gazes et. al. (2015) [Study 612] respectively). For word cues, significant predictable and un-predictable shift cost measured by RT was found (Van Asselen & Ridderinkhof, 2000 [Study 1036]), but N-2-repetition cost was not (Lawo et al., 2012 [Study 1278]).

Table 3.4

Comparison of Switch Cost Related Findings Across Switch-Rule Categories

Switch-Rule Category (*N* = Number of studies)	**Local (RT)**	**Local (Accuracy)**	**Global (RT)**	**Global (Accuracy)**	**Other Related Findings**
Words (*N* = 26)	Sig = 8 Non-sig = 3	Sig = 6 Non-sig = 0	Sig = 5 Non-sig = 0	Sig = 3 Non-sig = 0	Significant predictable-shift costs and unpredictable-shift cost measured by RT were identified (Van Asselen & Ridderinkhof, 2000 [Study 1036]). Significant global- and local-switch costs measured by RT latencies were identified (Bojko et al., 2004 [Study 88]). Significant global- and local-switch costs measured by log RT latencies were identified (Kray & Eppinger, 2006 [Study 494]). N-2-repetition costs measured by RT and accuracy were not significant (Lawo et al., 2012 [Study 1278]). Double-switch trials had significantly larger switch costs, compared to the inner-outer-switch trials (Nagy et al., 2023 [Study 1550]).
Colour (*N* = 13)	Sig = 4 Non-sig = 0	Sig = 2 Non-sig = 0	Sig = 6 Non-sig = 0	Sig = 6 Non-sig = 0	-
Visual (*N* = 8)	Sig = 4 Non-sig = 1	Sig = 3 Non-sig = 0	Sig = 3 Non-sig = 0	Sig = 1 Non-sig = 0	-
Memorise (*N* = 8)	Sig = 1 Non-sig = 0	Sig = 1 Non-sig = 0	Sig = 1 Non-sig = 0	Sig = 1 Non-sig = 2	Significant alternate-switch costs measured by RT and accuracy were identified (Hirsch et al., 2016 [Study 128]; Verhaeghen & Hoyer, 2007 [Study 162]).

Table 3.4

Comparison of Switch Cost Related Findings Across Switch-Rule Categories

Switch-Rule Category (*N* = Number of studies)	**Local (RT)**	**Local (Accuracy)**	**Global (RT)**	**Global (Accuracy)**	**Other Related Findings**
					Significant alternate-switch costs measured by RT were identified (Hirsch et al., 2016 [Study 128]). Age-specific global-switch costs were identified in both young and older group (Rey-Mermet & Meier, 2015 [Study 66]).
Double Switch-Rules (*N* =7)	Sig = 6	Sig = 4	Sig = 2	Sig = 1	Significant alternate-switch costs measured by RT and accuracy were identified (Hakun et al., 2015 [Study 540]).
	Non-sig = 0	Non-sig = 0	Non-sig = 0	Non-sig = 0	
Multiple Paradigms (*N* = 4)	Sig = 3	Sig = 0	Sig = 0	Sig = 0	In Albinet et al. (2012) [Study 943], results were reported in form of composite score. This study found that older age was related to worse shifting composite score (task-switching paradigm was one of the paradigms used to generate this score).
	Non-sig = 0	Non-sig = 0	Non-sig = 0	Non-sig = 0	
Spatial (*N* = 4)	Sig = 0	Sig = 0	Sig = 0	Sig = 0	-
	Non-sig = 1	Non-sig = 1	Non-sig = 0	Non-sig = 0	
Verbal (*N* = 3)	Sig = 1	Sig = 0	Sig = 0	Sig = 0	-
	Non-sig = /	Non-sig = /	Non-sig = 0	Non-sig = 0	
Unspecified (*N* = 5)	Sig = 1	Sig = 1	Sig = 1	Sig = 0	-
	Non-sig = 0	Non-sig = 0	Non-sig = 0	Non-sig = 1	

Note. Details on definitions of switch costs could be found in Table 3. RT = Reaction Time. Local = Local-switch costs. Global = Global-switch costs. Sig = significant findings. Non-sig = non-significant findings.

3.3.4 Switch Cost Effect Sizes

Switch cost effect sizes are summarized in Appendix F (Table F4–F7, Figure F2–F5). Of the 69 incidences where effect sizes were reported or could be estimated via partial eta-squared, 40 analysed local-switch costs, and 29 analysed global-switch costs. Mean effect sizes were larger for RT (local-switch costs: 0.54, global-switch costs: 0.75) than accuracy (local-switch costs: 0.32, global-switch costs: 0.38).

3.3.4.1 Local-Switch Costs

3.3.4.1.1 Measured by Reaction Time (RT)

Effect sizes of local-switch costs measured by RT varied largely across studies, with a mean partial η^2 of 0.54 (range = 0.11 to 0.97). The digit base-task and spatial base-task had relatively larger effect sizes compared to other base-tasks (mean partial η^2 = 0.83 and 0.74 respectively). Conversely, colour and letter base-tasks had relatively smaller effect sizes (mean partial η^2 = 0.27).

Double switch-rules and visually-cued switch-rules had relatively larger effect sizes than other switch-rules (mean partial η^2 = 0.77 and 0.74 respectively), while word-cued switch-rules had smaller effect sizes than other switch-rules (mean partial η^2 = 0.43).

There was no clear linear association between effect size and study sample size (see Figure 3.4), indicating these differences in effect size across base-task and switch-rules were not an artefact of sample size. Studies with sample size range from 42 to 64 also had relatively high effect sizes (partial η^2 range = 0.61 to 0.96).

3.3.4.1.2 Measured by Accuracy

Compared to effect sizes of local-switch costs measured by RT, effect sizes of local-switch costs measured by response accuracy were smaller, and less variable, with an overall

mean partial η^2 of 0.32 (range = 0.13–0.57). Like effect sizes of local-switch costs measured by RT, the digit base-tasks had relatively larger effect sizes compared to other base-tasks (mean partial η^2 = 0.40), but one study using this base-task also had the smallest reported local-switch costs effect size measured by accuracy, partial η^2 = 0.13 (Tsai & Wang, 2015 [Study 570]). Colour and letter base-tasks had relatively smaller effect sizes (mean partial η^2 =0.22).

There were no clear associations between any given switch-rule and larger reported effect sizes (Figure 3.4), but on average word- and visually-cued switch-rules had slightly smaller effect sizes than other switch-rules (mean partial η^2 = 0.29 and 0.27 respectively).

There was no clear linear association between effect size and study sample size (see Figure 3.4), indicating these differences in effect size across base-task and switch-rules were not an artefact of sample size.

3.3.4.2 Global-Switch Costs

3.3.4.2.1 Measured by Reaction Time (RT)

Effect sizes of global-switch costs measured by RT varied largely across studies, with a mean partial η^2 of 0.75 (range = 0.29 to 0.93). The digit base-tasks and letter base-tasks had relatively larger effect sizes compared to other base-tasks (mean partial η^2 = 0.85 and 0.86 respectively). Conversely, digit and letter base-tasks had relatively smaller effect sizes (mean partial η^2 = 0.31). However, when compared to local-switch costs measured by RT, global-switch costs measured by RT had relatively larger effect sizes, and were less variable.

Double switch-rules had relatively larger effect sizes than other switch-rules (mean partial η^2 = 0.87), while word-cued switch-rules had smaller effect sizes than other switch-rules (mean partial η^2 = 0.72), which had the same pattern as the effect sizes of local-switch costs measured by RT.

There was no clear linear association between effect size and study sample size (see Figure 3.4), indicating that the effect of global-switch cost measured by RT was also not an artefact of large sample sizes. The peak effect size ($\eta^2 = 0.93$) was reported in the study with a total sample size of 51. However, this peak was not directly reflected in Figure 3.4, as this effect size was averaged with another study with the same total sample size of 51.

3.3.4.2.2 Measured by Accuracy

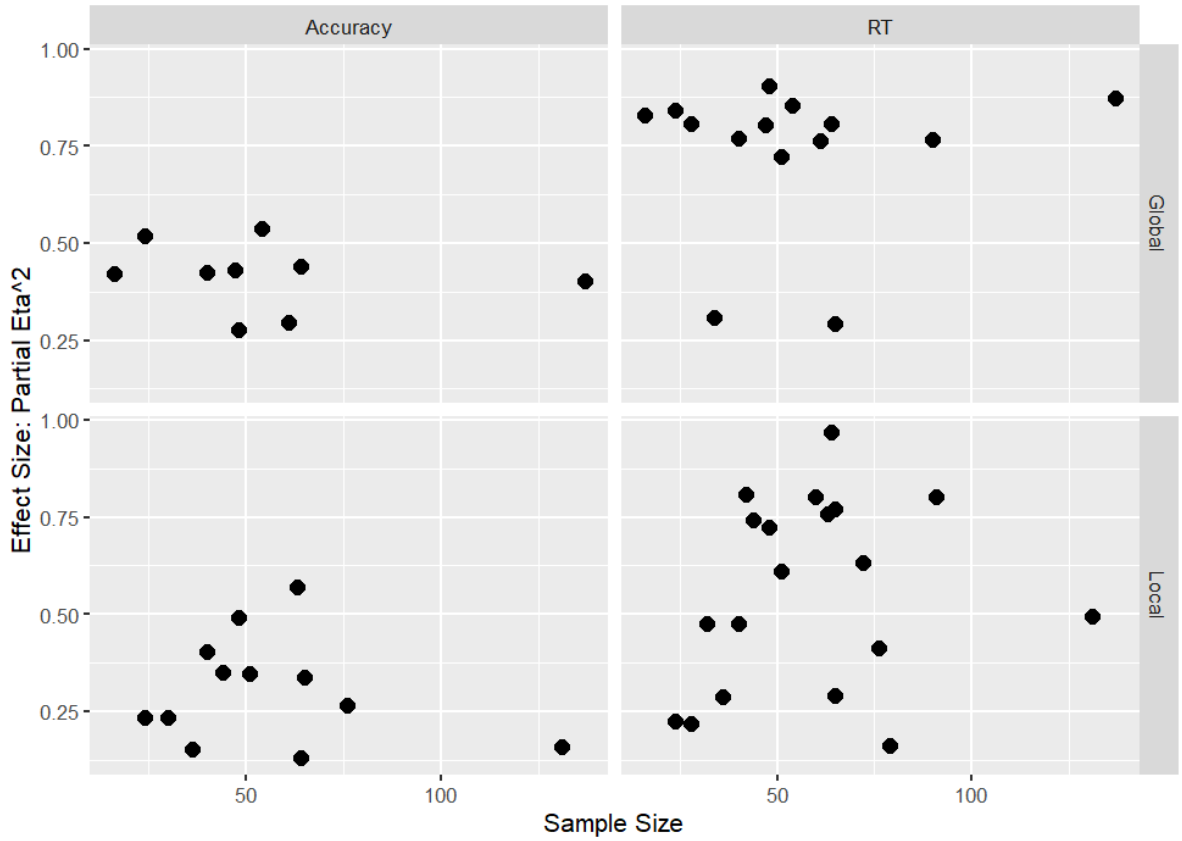
Compared to effect sizes of local-switch costs measured by accuracy, effect sizes of global-switch costs measured by accuracy had a larger range (i.e., more variation). Compared to effect sizes of global-switch costs measured by RT, effect sizes of global-switch costs measured by accuracy were smaller. Effect sizes of global-switch costs measured by accuracy also varied largely across studies, with a mean partial η^2 of 0.38 (range = 0.17 to 0.54). The letter base-tasks had relatively larger effect sizes compared to other base-tasks (mean partial η^2 = 0.47). However, among the 8 base-tasks categories, 5 categories (colour and letter, colour and shape, digit and element number, digit and letter, letter and position) included only one study, the other 3 categories (digit, letters, three base-tasks) included two studies. Hence, a summary on the relationship between base-tasks and effect sizes of global-switch costs measured by accuracy could not be constructed.

Visually-cued switch-rule (mean partial $\eta^2 = 0.52$) and memorise switch-rule (mean partial η^2 = 0.46) had relatively larger effect sizes than other switch-rules. However, both of these switch-rule categories included only one study. Among switch-rule categories with multiple studies, colour-cued switch-rules had relatively larger effect sizes than other switch-rules (mean partial $\eta^2 = 0.43$). Conversely, word-cued switch-rules had smaller effect sizes than other switch-rules (mean partial η^2 = 0.33), which had a consistent pattern among all reported test results, regardless of local-/global-switch costs measured by RT/accuracy.

There was no clear linear association between effect size and study sample size (see Figure 3.4), indicating these differences in effect size across base-tasks and switch-rules were not an artefact of sample size.

Figure 3.4

The Relationship Between Effect Sizes and Sample Sizes



Note. This figure depicts the relationship between effect sizes and study sample sizes. The pattern indicates a lack of bias in effect size related to sample size in reviewed studies, per Garner et al. (2022). Accuracy = switch costs measured by accuracy. RT = switch costs measured by reaction time. Global = global-switch costs. Local = local-switch costs.

3.3.5 Other Paradigm Manipulations

Other paradigm related manipulations included stimulus-features (e.g., univalent stimulus versus bivalent stimulus). Bivalent stimuli can be used to perform two tasks (e.g., the stimulus "A8", can be used to perform both a letter-discrimination task and a digit-discrimination task). Conversely, univalent stimulus can only be used to perform a single task (e.g., the stimulus "A" can be used to perform a letter-discrimination task, and the stimulus "8" can be used to perform a digit-discrimination task). Bivalent stimuli were associated with slower reaction times, and larger local-switch costs than univalent stimuli (Ging-Jehli & Ratcliff, 2020; Hirsch et al., 2016; Lien et al., 2008; Rey-Mermet & Meier, 2015 [Study 489, 127, 128, 66]). Smaller stimulus set size was associated with larger practice improvement (Kray & Eppinger, 2006 [Study 494]).

Other paradigm manipulations also included task-environment (e.g., informative cues, changed stimulus versus unchanged stimulus). Providing more informative cues in task-switching can result in better task-switching performance (Gaál & Czigler, 2015 [Study 136]). Cue repetition was associated with larger global-switch costs in accuracy (West & Travers, 2008 [Study 409]). The cost of an unexpected-switch was larger than an expected-switch. The unexpected trials cost more when there was task-repetition, compared to task-switching (Lien et al., 2008; Van Asselen & Ridderinkhof, 2000 [Study 127, 1036]). Overlap in response set (i.e., the keys that were used to provide responses) was associated with larger global- and local-switch costs (Mayr, 2001 [Study 82]). Additionally, when the response set as well as the task switched, similar effects of switch cost as found in task-switching was observed. There was an additive effect between response-switching and task-switching, where switching in both resulted in additional larger switch costs compared to a switch only in the response set or the task (Hahn et al., 2004 [Study 89]).

The last domain of other paradigm manipulations is preparation-time (longer versus

shorter time intervals between the response and the next trial). Multiple measures of preparation-time were used. Longer Cue-stimulus interval (CSI) was associated with smaller global-switch costs, and lower N-2-repetition costs in accuracy (Lawo et al., 2012; Meiran et al., 2001 [Study 882, 1278]). Longer Inter-stimulus interval (ISI) was associated with smaller local-switch costs (Kunimi et al., 2016 [Study 732]). Longer Response-cue interval (RCI) was associated with smaller local-switch cost (Meiran et al., 2001 [Study 882]). Longer Response-stimulus interval (RSI) was associated with smaller local-switch costs and smaller alternate-switch costs (Hirsch et al., 2016; Kramer et al., 1999 [Study 128, 1100]).

3.3.6 Findings in Relation to Local-Switch Costs and Global-Switch Costs

Table 3.5 presents the relationship between paradigm manipulations and task-switching performance measured by local-switch costs and global-switch costs. However, these results need to be considered with caution, due to variation in the reporting of non-significant statistical significance-test results across studies when compared with the more consistent reporting of significant results.

In studies reporting local-switch costs, less statistical evidence (e.g., results of ANOVA) were gathered for studies that used task-switching paradigms that switched between colour and shape base-tasks, colour and letter base-tasks, semantic and non-semantic base-tasks, compared to other base-task categories. Regarding switch-rules, less statistical evidence (e.g., results of ANOVA) were gathered for studies that used word-cued, visually-cued and spatially-cued switch-rules, compared to other switch-rule categories. In addition, non-significant local-switch costs were reported within the studies that used the base-task and switch-rule listed above.

In studies reported global-switch costs, less statistical evidence (e.g., results of ANOVA) were gathered for studies that used task-switching paradigm that switched between three

base-tasks, compared to other base-task categories. Regarding switch-rules, less statistical evidence (e.g., results of ANOVA) were gathered for studies that used memorise switch-rules, compared to other switch-rules categories. In addition, non-significant global-switch costs were reported within the studies that used the base-task and switch-rule listed above.

Table 3.5

Overview of Relationship Between Paradigm Manipulation Categories and Switch Costs

	Local (RT)		Local (Accuracy)		Global (RT)		Global (Accuracy)	
	Sig	Non-sig	Sig	Non-sig	Sig	Non-sig	Sig	Non-sig
Base-Tasks								
Colour/Letter	X	X	X		X		X	
Colour/Shape	X	X	X	X	X		X	
Digit/Element	X				X		X	
Digit/Letter	X		X		X		X	
Digits	X		X		X		X	
Letters					X		X	
Multiple Paradigms	X							
Sematic and Non-Semantic		X	X					
Spatial	X		X				X	
Tasks Used by One Study	X		X		X		X	X
Three Tasks	X		X		X		X	X
Switch-Rules								
Colour	X		X		X		X	
Double Switch-Rules	X		X		X		X	
Memorise	X		X		X		X	X
Multiple Paradigms	X							

Table 3.5

Overview of Relationship Between Paradigm Manipulation Categories and Switch Costs

	Local (RT)		**Local (Accuracy)**		**Global (RT)**		**Global (Accuracy)**	
	Sig	Non-sig	Sig	Non-sig	Sig	Non-sig	Sig	Non-sig
Spatial		X		X				
Unspecified	X		X		X			X
Verbal	X							
Visual	X	X	X		X		X	
Words	X	X	X	X	X		X	

Note. This table presents an overview of evidence of the relationship between paradigm manipulations (i.e., base-task and switch-rule) and task-switching performance measured by local- and global-switch costs. An "X" in the corresponding column indicates there is information reported in the reviewed studies. Accuracy = switch costs measured by accuracy. RT = switch costs measured by reaction time. Global = global-switch costs. Local = local-switch costs.

3.4. Discussion

To the best of our knowledge, this systematic review has provided the first summary of task-switching performance in a healthy ageing population with an emphasis on paradigm manipulations. In the 78 studies across 66 publications in this systematic review, we found substantial variability in how task-switching is currently measured in terms of task-switching paradigm selection, how switch costs were operationalised, and how results were reported. The switch cost was measured in six different ways (local-switch, global-switch, alternate-switch, N-2-repetition, predictable-shift, and unpredictable-shift). There were 12 base-tasks which were (from most to least common): digit; colour and shape; colour and letter; digit and letter; switches between three base-tasks; spatial; semantic and non-semantic; digit and element number; letter generating words; and other base-tasks. There were three categories of switch-rules (from least to most common): switching voluntarily; memorising switch-rules for the whole trial block; and cueing before each trial of the task. When present, there were six forms of cues (from most to least common): word; colour; visual; spatial; verbal; and simultaneous cue-response presentation. There were also studies that used multiple switch-rules. Other within-paradigm manipulations included: stimulus-features (e.g., stimulus set-size); task-environment (e.g., informativeness of cue); and preparation time (e.g., cue-stimulus interval). This mirrors findings elsewhere that laboratory tests of cognitive constructs can substantially vary, such as experimental paradigms of short-term memory noted in Richardson (2007), inattentional blindness noted in Redlich et al. (2021), and executive function noted in Faria et al. (2015).

There was substantial variability in how results were reported, including in the precision

of demographic information, and the presence versus absence of reporting of non-significant results. Nonetheless, findings for switch costs were somewhat consistent across studies and age groups. Local-switch costs as measured by RT was both the most common measure, and had the strongest support in terms of achieving statistical significance. This has mixed implications when examining switch costs in ageing. Global-switch costs focus on the differences between the pure-block trials and the no-switch trials within mixed-blocks, which involves a switch cost alongside the higher working memory load introduced by the need to activate two tasks in a mixed-block (Kiesel et al., 2010). Working memory is another aspect of executive function that is found to decline with age (McCarrey et al., 2016), which means global-switch costs may be confounded by these age-related differences. Thus, local-switch costs are arguably a more appropriate focus when comparing age groups. Conversely, when cognitive resources are not sufficient, older adults have the tendency to sacrifice RT to maintain accuracy (Van Asselen & Ridderinkhof, 2000). Due to this trade-off, measures merely focussing on RT will not be sufficient to obtain a holistic picture of task-switching performance. Accuracy measures and measures incorporating RT and accuracy characteristics (e.g., Diffusion Decision Model; Ging-Jehli & Ratcliff, 2020) are thus more appropriate for use with older adult samples.

3.4.1 Switch Costs—Grouped by Base-Tasks and Switch-Rules

Substantial variability in base-tasks identified in this review may have implications for whether or not statistically significant switch costs are identified, and whether differences are found between young and older cohorts.

3.4.1.1 Findings for Switch Costs Grouped by Base-Tasks

In the 78 reviewed studies, base-tasks varied in frequency of use. Digit base-tasks were most common (e.g., Dai et al., 2013 [Study 568]), and were associated with the frequent reporting of both significant local-switch and global-switch costs. In comparison to other base-tasks, digit base-tasks had the highest mean effect sizes for local-switch costs (as measured by both RT and accuracy) and global-switch costs (as measured by RT). This may be because the first task-switching paradigm study by Jersild (1927) was a digit base-task. Digit base-tasks have the desirable property of using only simple digit stimuli, which is less likely to be influenced than other stimuli such as letter, word, or colour. However, the current evidence is not sufficient to inform us of whether the dominance of digit base-tasks is due to its widely accepted optimality in task-switching paradigm design, the need to replicate prior research, or a reflection of methodological inertia. This consideration echoes Bush et al. (2018)'s discussion of the issue between new and revised tests under the context of psychological and neuropsychological instruments.

The joint-second most frequently used base-task category were the colour and shape base-tasks (e.g. as in Zhu et al., 2014 [Study 134]) and the colour and letter base-tasks (as in West & Travers, 2008 [Study 409]). Colour and shape base-tasks (as in Zhu et al., 2014 [Study 134]) are similar to the Wisconsin Card Sorting test (WCST, Berg, 1948)[4], but the

[4] The WCST is also a common measure of task-switching ability that incorporates the tasks of colour-discrimination and shape-discrimination. However, the WCST requires participants to categorise the stimulus, and the rules of categorisation and the rules of task-switching are not directly presented to the participants. This makes performance on the WCST depend not only on the task-switching function, but also on other functions such as decision-making.

task-switching paradigm is a more direct measure of task-switching functioning in comparison with the WCST. Colour and letter base-tasks (as in West & Travers, 2008 [Study 409]) are similar to the Stroop task (Stroop, 1992)[5], as both apply the tasks of word-reading and colour-naming. When the Stroop task was introduced into the task-switching setting as one of the base-tasks, the effort required for inhibition of the old task and activation of the new task was found to be asymmetrical: switching from the colour-naming task to the word-reading task was more effortful than switching from the word-reading task to the colour-naming task because the dominant word-reading task took more effort to be inhibited (Allport et al., 1994). This asymmetry may be why we found that studies using colour and letter base-tasks had the lowest mean effect sizes on local-switch costs (as measured by RT and accuracy) and global-switch costs (as measured by RT). The different inhibition requirements between colour and letter tasks might play a role in the notably lower effectiveness of colour and letter base-tasks in the task-switching paradigm. Under the context of the current systematic review, "effectiveness" refers to the appropriateness of using the colour and letter base-tasks in the task-switching paradigm to measure task-switching performance, a term which will be reused in the subsequent content.

[5] For the Stroop task, the colour words (e.g., Blue, Green) are printed in various font colours (e.g., Yellow, Green). The "colour words" and the "font colours" could be either consistent or inconsistent. The participants' task was either a word-reading task (i.e., read the colour word; stimulus: GREEN, answer: Green), or a colour-naming task (i.e, name the font colour; stimulus: GREEN, answer: Blue). When these two tasks conflict with each other, inhibiting the intention to perform the word-reading task was harder than inhibiting the intention to perform the colour-naming task.

3.4.1.2 Findings for Switch Costs Grouped by Switch-Rules

The most frequently utilised switch-rule was cueing before each trial of the task with word cues (e.g., as in Zhu et al., 2014 [Study 134]). Studies utilising word-cued switch-rules had relatively lower effect sizes for local-switch costs (as measured by RT and accuracy) and for global-switch costs (as measured by RT and accuracy). Consequently, using the task-switching paradigm with word-cued switch-rules might result in obtaining smaller but clearer switch costs, compared to task-switching paradigms utilising other switch-rules. This might be because the pre-acquired semantic meaning of word cues is more informative, and thus required less learning compared with other cues. This comports with Gaál and Czigler (2015 [Study 136]) who compared the magnitude of switch costs between task-switching paradigms using informative cues (blue cues indicate digit-parity task, and yellow cues indicate letter-classification task) and non-informative cues (grey cues with no task information), and found more informative cues facilitated easier switching between the tasks. This interpretation on cue informativeness was consistent with the findings of Nessler et al. (2012a), where an informative cue led to decreased switch costs, compared to a non-informative cue. Beyond the context of task-switching, Fujawa and Strybel (1997)'s finding also align with the effect of cue informativeness, a more informative auditory cue facilitates visual search, compared to a less informative auditory cue.

The next most frequently utilised of the switch-rules was cueing before each trial of the task with colour cues (e.g., as in Gazes et al., 2015 [Study 612]), followed by other visual cues (as in West & Travers, 2008 [Study 409]). Compared to other switch-rules, studies utilising colour-cued switch-rules had relatively larger variations in effect sizes on local- and

global-switch costs measured by RT. The effect sizes on global-switch costs measured by accuracy were relatively more consistent. Applying the same logic as above, this larger variation in effect sizes obtained by task-switching paradigms utilising colour-cued switch-rules could result from the effect of lack of informativeness in the cue rather than purely from the results of task-switching. Referring to the findings from Gaál and Czigler (2015 [Study 136]), more informative cues (i.e., word cues) reduced switch costs more than less informative cues (i.e., visual cues). The association between tasks and colour cues or the association between tasks and visual cues is more arbitrary than the association between tasks and word cues. This interpretation shows similarities with Jiménez et al. (2021)'s discussion on the effectiveness of cues, based on their findings of Stroop-based tasks. When there was an arbitrary association between the stimuli and the responses, the cue was less effective due to higher cognitive load created by the task design. In task-switching paradigms, higher cognitive load can be created by utilising arbitrary associations between the task and the cue, which introduces greater variability in the effectiveness of colour-cued switch-rules in measuring task-switching performance.

Studies utilising visually-cued switch-rules had larger effect size on local-switch costs measured by RT compared with those studies using other switch-rules. In contrast, there was a relatively smaller effect size on local-switch costs, as measured by accuracy when comparing between studies utilising visually-cued switch-rules and studies utilising other switch-rules. One possible explanation that can account for this discrepancy between switch costs measured by RT and accuracy also draw upon the findings in regard to the informativeness of cues (Gaál & Czigler, 2015 [Study 136]; Nessler et al., 2012). Due to the

arbitrariness within the association between visual cues and base-tasks, visually-cued switch-rules fall into the category of less informative cues, compared with other switch-rules such as word-cued switch-rules. When the visual cue instructed a switch of the task, longer processing and interpreting time is required for participants to decode the instruction and perform the instructed task-switching action, hence larger effect sizes of task-switching measured by RT were obtained. This longer processing time might be beneficial in terms of maintaining task accuracy, hence smaller effect sizes of task-switching measured by accuracy were obtained.

3.4.2 Switch Costs—Other Paradigm Manipulations

Complexity of the stimulus-features, such as bivalent stimulus versus univalent stimulus, was related to slower reaction times (RT) and greater local-switch costs (e.g., as in Ging-Jehli & Ratcliff, 2020; Hirsch et al., 2016; Lien et al., 2008; Rey-Mermet & Meier, 2015 [Study 489, 128, 127, 66]). Ging-Jehli and Ratcliff (2020) found complex stimulus-features were not only related to increased RT, but also to larger RT and accuracy differences between no-switch trials and switch trials, where the switch trials were subsequently slower and less accurate.

Complexity of the task-environment was also explored in the selected studies, with more complex and less informative task-environments being associated with larger switch costs (Gaál & Czigler, 2015; Hahn et al., 2004; Lien et al., 2008; Mayr, 2001; Van Asselen & Ridderinkhof, 2000; West & Travers, 2008 [Study 136, 89, 127, 82, 1036, 409]). This aligns with cognitive load theory, which states that higher cognitive load created by complexity of

the material can lead to worse performance (Paas & Van Merriënboer, 2020; Sweller et al., 2019).

Finally, longer preparation-time (of all kinds) were associated with lower switch costs (Hirsch et al., 2016; Kramer et al., 1999; Kunimi et al., 2016; Lawo et al., 2012; Meiran et al., 2001) [Study 128, 1100, 732, 1278, 882]). One interpretation is that there was an enhancement in performance introduced by having more time in advance to prepare for the task-switching. This could be related to a potential explanation underlying the RT-accuracy trade-off found in older adults when responding to task-switching tasks (Van Asselen & Ridderinkhof, 2000), where longer time was actively taken to prepare for responding to the task accurately. This advance preparation effect was well-established in task-switching performance, that is not restricted to only older populations (Altmann, 2004; Karayanidis et al., 2010). This advance preparation effect can also apply to other aspects of executive functioning, such as working memory (e.g., Manelis & Reder, 2015).

During the task-switching process, the old task needs to be inhibited, and the new task needs to be activated (Kiesel et al., 2010) for efficient task-switching to occur. Digit base-tasks were found to be the most used base-task with the largest reported effect size, among all variations of task-switching paradigms. This is partly due to using the same set of stimuli (i.e., digits 1, 2, 3, 4, 6, 7, 8, 9) across the two distinct base-tasks (i.e., digit-parity task and digit-comparison task). These stimuli had bivalent characteristics, which increased the difficulty to switch between tasks due to the greater level of interference between two base-tasks (Ging-Jehli & Ratcliff, 2020). This effect of bivalent stimuli aligned with “bivalency cost” discussed in Woodward et al. (2003) and “bivalency effect” discussed in Grundy et al.

(2013). Meier et al. (2015) also found the bivalency effect by testing task-switching performance in grapheme-colour synesthetes. The bivalent feature was created on univalent stimuli by introducing synesthetic colour experiences, which was associated with longer RTs in responding to tasks in the task-switching paradigm (Meier et al., 2015).

3.4.3 Study Demographics: Publication Year, Age, Gender

There is a constant debate in the field of experimental psychology in regards to under-powered studies due to smaller than required sample sizes (e.g., Lakens, 2022; Marszalek et al., 2011). In the 78 studies, the average total sample size of participants was 64, with 16 being the smallest number of participants and 369 being the largest. Using the sample size evaluation technique developed by Garner et al. (2022), we found evidence that statistically significant switch costs were not simple artefacts of large sample sizes. The findings of the current systematic review provide evidence that contributes to the consideration of appropriate sample sizes for experimental studies in cognitive psychology, where small sample sizes around 40–60 participants, can be sufficient to detect hypothesised effects, such as in task-switching.

Within the reviewed studies, publications peaked around 2012 to 2015, with the number of publications post-2015 showing a marked decrease in number. One explanation for this trend could be that informative reviews and meta-analysis of task-switching were published around the year 2010 (e.g., Kiesel et al., 2010; Vandierendonck et al., 2010; Wasylyshyn et al., 2011). In a study of citation rates, Cho et al. (2012) also indicated that there was evidence of an increase trend in publications within the field of experimental psychology. In relating

this to the manipulation of the task-switching paradigm, more variations in paradigm manipulations were introduced before 2005 and after 2015. When comparing results across studies, the literature published between 2008–2016 presented larger variability in reported statistical significance, compared to literature published before 2008 and after 2016. Non-significant task-switching results were published during this period of time (e.g., West & Travers, 2008; Zhu et al., 2015 [Study 409, 963]). This is especially important when a meta-analysis or review of studies is conducted. Although there are methods that have been developed to deal with heterogeneity in the reviewed studies (Böhning et al., 2021; Crippa et al., 2016), identifying the potential heterogeneity conceptually is still an important first step for selecting appropriate analysis.

There were large inconsistencies in how age was reported. Some studies did not report age range, while others reported age range but did not report means standard deviations or age means. Precise age characteristics are an important basis for interpreting age-related performance, and thus reporting age and relevant measures of central tendency (e.g., mean and median) and variability (e.g., standard deviation) are critical for improving understanding of ageing trajectories. Cognitive function in ageing generally follows a pattern of gradual decline, then a change point followed by more rapid decline. Estimates from longitudinal research on cognitive functions suggests significant age-related declines occurred across multiple cognitive functions such as memory, attention and executive functions, and including task-switching, between 64.1 to 69.7 years (McCarrey et al., 2016). Longitudinal research suggests change points typically take place between 55-65, and varies on the basis of the specific test, with an estimated 58 years of age for-switching measured by Trail Making,

and 62 years of age when measured by the Wisconsin Cart Sorting test (Caselli et al., 2020). Future studies could consider precisely reporting the participants age range, mean and standard deviation to permit better comparison and generalisation across studies, and to capture the change point specific to the task-switching function.

Seventy-eight percent of the reviewed studies (61 out of 78) reported gender characteristics, and of those, there was a bias toward including more women than men. This may be important as different ageing trajectories have been found in cognitive functioning between men and women. Compared to men in the same age group, women commonly have better performance and greater resilience in multiple cognitive functions including perceptuomotor speed, visuospatial abilities (McCarrey et al., 2016), and episodic memory (Wahlin et al., 2006). Conversely, men typically outperform women on visuospatial abilities (McCarrey et al., 2016) and semantic memory (Wahlin et al., 2006). However, evidence supports no gender-related differences in task-switching performance (as measured by Trail Making (Caselli et al., 2020; McCarrey et al., 2016)). These findings suggested that this is likely not a concern in terms of generalisation to both women and men.

The level of detail in reporting results varied across studies, with notable under-reporting of non-statistically significant results. It is common that the published studies have found at least one statistically significant result, yet the reporting of other non-significant results is often overlooked. This suggests that studies that had no significant results failed to reach publication. Though we do not have sufficient evidence to comment on this directly, this aligns with publication and reporting bias that is an ongoing discussion in cognitive science (Ioannidis et al., 2014). A recent meta-meta-analysis suggested that the publication

bias is still prevalent in industrial/organisational psychology, with bias assessment methods being underused, and allowing for publication bias to be largely undetected (Siegel et al., 2022). The phenomenon of publication bias was also noted in the research on cognitive advantage introduced by bilingual experiences (de Bruin et al., 2015b), where authors stated that regardless of sample sizes and analysis methods, studies supporting bilingual advantage were more likely to be published, compared to studies against. In the studies reported in the current systematic review, non-significant results were either not reported, or reported with minimal details consistently, with many only reporting "F<1" for non-significant ANOVA tests. Accordingly, in future studies, statistics relating to non-significant test results could be reported with the same level of details as significant tests to avoid the potential impacts of bias. The necessity of reporting non-significant results was also discussed and embraced by the *Neurology* Null Hypothesis Special Edition (Petty & Gross, 2019), to encourage researchers to share non-significant results. Open Science Framework (Foster & Deardorff, 2017) has also emerged to support the scientific significance of non-significant results by encouraging pre-registration and open access of study methods.

3.4.4 Strengths, Limitations and Future Directions

The current review used a systematic approach to provide a comprehensive overview of task-switching performance in healthy older adults. This review built on previous findings (Kiesel et al., 2010; Wasylyshyn et al., 2011), aiming to capture how the task-switching paradigm has evolved over time, and explore the consequences this may have for research comparing task-switching performance across younger and older adults. This required

reviewing the details of paradigm manipulations, with findings related to task-switching performance being compared across different manipulations to understand the differential influences of these manipulations. The current review also paid attention to the use of different switch costs, with the outcomes of different switch costs being summarised and compared. As a result of the comprehensive review of manipulations to the task-switching paradigm and choice of different switch costs, the findings can be used to inform future studies about how design and selection of switch costs has changed over time and influences task-switching performance.

The chosen databases for this review were carefully selected, but they were still not perfectly comprehensive. The four databases selected provide among the most comprehensive collections of psychological literature available (Paperpile, 2025), but may not have captured all of the relevant literature. In addition, this review was limited to English language only, meaning that that the findings cannot be generalised to the findings of task-switching studies reported in languages other than English. As a result, paradigm manipulations and task-switching performance used in other cultures were not reviewed in the current work, potentially biasing the literature search results of the systematic review, and restricting its applicability. For instance, based on a quick search in Baidu Scholar (Chinese equivalent to Google Scholar, searched in 2025) using the combined search terms “任务转换范式” (i.e., task-switching paradigm) and “老” (i.e., old, which is a character used in phrases such as older adult, older age, and later-life), 110 relevant results were found that were not considered in the current search due to the language inclusion criteria.

Studies in languages other than English might provide a different view from the current

group of reviewed studies due to the influence of culture differences (e.g., language, education, mode of thinking) on cognitive functioning. As an example, Gul and Humphreys (2014) found that when participants were asked to switch between identifying the gender or the emotion of a face, participants from Britain were faster at identifying gender, whereas participants from Pakistan were faster at identifying emotions. The authors suggested that this is because different culture groups were focused on different characteristics of a face. Another finding of the study was that participants from Pakistan performed task-switching with smaller switch costs than participants from Britain, possibly due to the effect of bilingualism (Gul & Humphreys, 2014). Experiments conducted by Prior and Gollan (2011) suggested that the language-switching behaviour that was commonly experienced by bilinguals was associated with better task-switching performance. The age-related decline in task-switching was also reduced in lifelong bilinguals, compared to monolinguals (Houtzager et al., 2017). Therefore, it is likely that paradigm manipulations could have diverse effects across different culture groups with different language backgrounds. The cross-culture comparison can be a topic of future reviews in the investigation of task-switching function.

The current systematic review focused only on task-switching in the context of comparing young and healthy older adults. Although the variety of paradigms aligns with evidence that cognitive tests in general have evolved and become more varied over time (McCarrey et al., 2016), it is unclear if findings here are applicable to task-switching performance across all ages, health conditions, and task-switching paradigms that are not included in the current review. Future reviews could examine paradigm manipulations and their effect on task-switching performance across all ages, or in samples such as older adults

with cognitive impairments. This would facilitate greater understanding of the specificity and generalisability of the findings of the current review to further the understanding of task-switching idiosyncrasies.

3.4.5 Conclusion

The current systematic review provides an overview of the effects on task-switching performance of the different manipulations that have been introduced to the task-switching paradigm. The most common base-task was the digit base-task, and the most common switch-rule was word-cued switch-rule. The most common measure of switch costs was the local-switch cost measured by RT.

Overall, switch costs were consistently found across multiple base-task and switch-rule categories, and across young and older participants. Substantial variability was observed in how task-switching was measured, and how both demographic and substantive results were reported. This makes it difficult to disentangle if the consistencies found across paradigms is genuine, or whether it reflects an under-reporting of null results.

Taken together, the findings indicate that digit base-tasks, word-cued switch-rules and local-switch costs best captured reliable task-switching performance across age groups. However, due to the variability in reporting and lack of direct comparisons between different base-tasks and switch-rules, these conclusions should be interpreted with caution.

Future research with better consistency in reporting could confirm and build on the current findings, informing the comparisons between different manipulations of task-switching paradigms, and clarifying whether paradigm manipulations can impact the

fundamental target of accurately capturing task-switching function with task-switching paradigms in healthy young and older adults.

Chapter Four

The Association Between Current Life Complexity and Task-Switching in Young and Older Adults

The Association Between Current Life Complexity and Task-Switching in Young and Older Adults

4.1 Introduction

Task-switching, sometimes also called set-shifting or cognitive-flexibility, refers to the ability to alternate between multiple tasks sequentially (Ging-Jehli & Ratcliff, 2020). Task switching is crucial for performing multiple real-world daily activities (Lee & Schumacher, 2024). As individuals age, their ability to switch between tasks declines (Wasylyshyn et al., 2011) and switching between different tasks becomes slower and more effortful (Chen & Hsieh, 2023). Compensatory mechanisms are active or passive processes that are employed to counteract decline when aiming to achieve the goal of maintaining performance (APA, 2018b). Compensatory mechanisms could mask decline until the mechanisms start to fail, which can lead to a sudden decline in functioning (Gavett & Stern, 2012). This period of apparently preserved functioning reduces the likelihood of detecting the decline, and thus of introducing interventions to treat or delay the underlying cognitive problems.

In task-switching, older adults have a tendency to sacrifice speed to maintain performance accuracy (Van Asselen & Ridderinkhof, 2000). When the decline is managed with compensatory mechanisms, the cost in reaction time (RT) is likely to be larger (i.e., slowing down to maintain accuracy), or fewer switches will be attempted if switching is voluntary (i.e., minimising effort to maintain performance). When the decline exceeds the limit of compensation, both RT and accuracy are measurably impaired, reflecting a change point in cognitive functioning during ageing (see Chapter One). Accordingly, task-switching performance measured by reaction time (RT) and accuracy in controlled experimental

settings is a potential tool for early detection of possible decline in functioning in real world settings outside the laboratory.

Compensatory mechanisms underlying real-world activity selection are complex, making the decline masked by compensation difficult to detect (Volpi et al., 2017). The concept of selective optimisation with compensation suggests that individuals select the domains in which they will invest energy, time, and cognitive resources to obtain knowledge and experience (Baltes & Baltes, 1993). Individuals need to be selective in the process of investing resources. More investment, as seen in the range of activities in which individuals participate, and the time and attention invested, could be related to having more available resources, or to the better use of compensatory strategies in real-life. Therefore, a more complex cognitive lifestyle, as seen in the number of daily activities in which a person engages, and the amount of time and attention used for the engagement, can be a result of better maintenance of later-life functional ability, or better application of cognitive compensatory mechanisms. Both the diversity of activities and the amount of investment into each of the activities are important parameters in the consideration of lifestyle complexity, disregarding either parameter can make the assessment of complexity simplistic and incomplete. Given the current body of evidence, it cannot be said that any given pattern of breadth or depth of involvement in activities should be considered healthier or "better" than any other. Still, it is likely that greater breadth of engagement across activities is beneficial in some way. For instance, Carlson et al. (2012) concluded that the greater the variety of activities the lower the risk of cognitive decline in later-life. However, for the purposes of this study, low current life complexity arising from low breadth or depth of involvement is

sufficient for the potential detection of compensation under cognitive decline.

Understanding the difference between these two kinds of compensation is an important prerequisite to early detection of a decline in functional ability, even though the decline is masked by compensation. One possible approach to this problem is to examine the relationship between a laboratory task where compensation is evident and quantifiable, such as task-switching, and potential compensation in the real-world selection and performance of daily activities. At the real-life level, Jarosz (2023) found that reduced complexity of daily life was associated with increased age. Reducing complexity increased people's ability to complete the remaining activities, by being able to attribute sufficient cognitive resources to these selected activities. This can be interpreted as a compensatory strategy in response to an age-related decrease in cognitive resources, which leads to a lesser need to adapt to changes in daily life. In the laboratory, when participants can voluntarily choose to switch or not switch tasks, older participants have a tendency to switch less frequently (Butler & Weywadt, 2013). Similarly, this tendency leads to a lesser need to adapt to changes in experimental settings. When task-switching was required, Van Asselen and Ridderinkhof (2000) found that in older adults, reaction times were longer so as to maintain performance accuracy, and accuracy and quality were preferred over speed and quantity. When cognitive resources are limited due to age-related changes, reduced complexity was selected to maintain the quality of the remaining tasks/activities. When the need to adapt to changes was unavoidable, older adults had a tendency to invest more cognitive resources to adapt to changes accurately. Compensatory strategies, used in both real-life and laboratory situations, can be the potential theoretical basis of linking real-life investment of cognitive resources exemplified by current

life complexity with the experimental in-laboratory performance of task-switching.

"Current life complexity" is defined as the level of engagement in everyday activities during daily life that require individuals to invest cognitive resources. The dimensions of the concept are represented by the breadth and depth of involvement, with greater breadth and depth of involvement in daily activities indicating a higher current life complexity (see Chapter Two). Compensation for a potential reduction in current life complexity, because of a reduction in cognitive resources, may be expressed in two ways. First, individuals may choose to reduce the number of activity categories they are involved in, to preserve the levels of performance in other categories. Second, individuals may reduce the depth of involvement in each activity category they are involved in, to preserve the number of categories.

Understanding the relationship between current life complexity and task-switching performance in young and older adults in the context of selective optimisation with compensation has practical implications for designing interventions that maintain cognitive functions, and promote healthy lifestyles in later-life. Accordingly, the aims of the present studies were:

1. To identify which of two task-switching paradigms, digit-comparison/digit-parity, or letter-categorisation/luminance-discrimination, could provide the best measure of task-switching performance in young and older adults.
2. To identify which of two levels of stimulus difficulty could provide the best measure of task-switching performance in young and older adults.
3. To investigate the degree to which older adults maintain accuracy by sacrificing reaction time speed during task-switching.

4. To investigate the relationship between current life complexity and task-switching performance.
5. To investigate a potential age-related effect on the relationship between task-switching performance and cognitive lifestyle complexity.

4.2 Study 1: The Digit Versus Letter Paradigm

The purpose of Study 1 was to explore which of the task-switching paradigms was the most suitable and effective instrument for measuring task-switching performance in both young and older adults. Task-switching function has been explored primarily in laboratory settings, through a task-switching paradigm first developed by Jersild (1927). This paradigm requires participants to alternate sequentially between two (or more) tasks. For example, switching between a digit parity task (i.e., a digit is an odd or an even number) and a digit comparison task (i.e., a digit is larger or smaller than five; Dai et al., 2013). Task-switching paradigms use pure blocks (where only one task is undertaken) and mixed blocks (where the participant needs to switch between multiple tasks). In mixed blocks, switch task trials require participants to perform a different task from the previous trial. In contrast, no-switch trials require participants to perform the same task as the previous trial. Switch cost is a commonly used concept that is used to quantify the effort needed to switch between tasks (see Chen & Hsieh, 2023 for a meta-analysis). Task switching performance is assessed in terms of local-switch costs (also known as switching costs), which are the accuracy and reaction time differences between no-switch trials and switch trials, and global-switch costs

(also known as mixing costs), which are the accuracy and reaction time differences between pure block trials and no-switch trials in the mixed block. The current study used local-switch costs with both reaction time and accuracy measures to assess the performance of task-switching.

There is a range of different modifications of the task-switching paradigm used to measure task-switching function in older populations (Chapter Three). Based on the systematic review (Chapter Three), two task-switching paradigms with slightly different designs were selected as the most suitable candidates for exploring the association between task-switching and current life complexity. The first was a combination of the digit-comparison task and the digit-parity task, which were modified but based on the paradigm used by Dai et al. (2013). The other was a combination of the letter-categorisation task and the luminance-discrimination task, which were modified but based on the paradigm used by Ging-Jehli and Ratcliff (2020).

The digit-comparison and digit-parity task-switching paradigm (henceforth digit paradigm) is the most frequently used task-switching paradigm (Chapter Three), and has been used to associate in-lab task-switching performance with real-world lifestyle factors, such as physical activity (Dai et al., 2013). However, many studies report high accuracy, which is close to ceiling in young and older groups (Chapter Three), and thus limits investigation into the influence of task-switching on performance accuracy, a key potential marker of decline under compensatory mechanisms.

The letter-categorisation and luminance-discrimination task-switching paradigm (henceforth letter paradigm) is more difficult (Ging-Jehli & Ratcliff, 2020), and thus is more

suited to detecting variation in accuracy. It also has clear ecological validity, being closer to tasks that we might experience in daily life, for instance, reading a sign while walking. However, this means that the letter paradigm may be more susceptible to potential noise introduced by the complexity of the task (Kiesel et al., 2010). To our knowledge, there is no direct comparison of these two task-switching paradigms in young and older adults in the current literature at the time of writing.

In Study 1, the exploration of differences between task-switching performance, as measured by the digit paradigm and the letter paradigm, was carried out in two steps:

1. To confirm the effect of task-switching, for which switch trials would take longer and be less accurate than no-switch trials in a local sample of participants.
2. To compare the effectiveness of the digit paradigm and the letter paradigm in young and older adults.

We predicted that:

1. Reaction times (RT) would be significantly longer in young and older adults for both task-switching paradigms.
2. Accuracy would be significantly lower in young and older adults in the letter and luminance paradigm compared to the digit paradigm.

Also, we intended to compare and explore which of the two paradigms, digit or letter, would more effectively capture the cost of switching in both young and older adults. The comparison and exploration used was a within-subject design.

4.3 Study 1: Methods

The study was conducted in accordance with the ethical standards outlined in the National Statement on Ethical Conduct in Human Research (2018) and approved by the ANU Human Research Ethics Committee (Protocol Number 2023/555). Participants were informed about the experiment, provided with an information sheet, and asked for their consent before the experiment started. After completion of the experiment, participants were debriefed and provided with reimbursement (15 dollars for each hour of their time). University students were provided with the option of course credits (1 credit point for each hour of their time).

4.3.1 Participants

A total of 49 participants was recruited from the Canberra region community. There were 25 young participants, and 24 older participants. According to the findings of my previous systematic review (Chapter Three), the maximum effect sizes in task-switching were found with a sample size of 20–30 participants per condition.

Older participants went through a screening process. The Montreal Cognitive Assessment (MoCA; Julayanont et al., 2015) was used to exclude participants with cognitive impairment, and the Visual Object and Space Perception battery (VOSP; Warrington & James, 1991) was used to exclude participants with visual processing issues. The Edinburgh Handedness Inventory (EHI; Oldfield, 1971) was used to assess participants' hand preferences. Subsequently, 5 participants were excluded from the study. Of the young participants: 1 was left-handed; of the older participants: 1 was left-handed, 2 did not pass the MoCA screening, and 1 did not complete the whole study. For the remaining 44 participants,

there were 24 young participants (Age mean = 24.29, age *SD* = 5.30, age range = 18–40; 17 women, 6 men, 1 prefer not to say), and 20 older participants (Age mean = 72.75, age *SD* = 7.93, age range = 63–87; 10 women, 10 men; all of whom had passed the screening with the MoCA and VOSP).

4.3.2 Self-Report Instruments

4.3.2.1 Demographics

The Demographic and Language History Questionnaire (DLHQ, adapted from Gullifer et al., 2021) was used to measure participants' demographic information and language history. The DLHQ included questions asked about participants' age, gender, history of neurological impairment, if they had normal or corrected-to-normal vision (e.g., wearing contacts lens or glasses), highest level of education, cultural and ethnic group, and language experience (e.g., speaking more than one language or not).

4.3.2.2 Current Life Complexity and Covariates

Details of the following three questionnaires are provided in Study 3, where their outcomes are reported and analysed. The Current Life Complexity Questionnaire (CLCQ) was used to measure participants' current life complexity. In brief, participants reported their activity engagement, frequency, and estimated durations using visual scales, with randomisation applied to both activity categories and items within each of the activity categories. The Cognitive Reserve Index questionnaire (CRIq, Nucci et al., 2012; assessing

cognitive reserve), and the short form of the International Physical Activity Questionnaire (IPAQ, questionnaire and computation method provided by Craig et al., 2003; assessing current physical activity level) were used to assess covariates.

4.3.3 Computerised Task-Switching Paradigms

4.3.3.1 Stimulus

Two task-switching paradigms were used to determine which of the two was better, both in capturing the switch-cost and as related to the cognitive life complexity measure (i.e., CLCQ). The first paradigm used a combination of the digit-comparison task (i.e., the stimulus was greater or smaller than 5) and the digit-parity task (i.e., the stimulus was an odd number or an even number) as used by Dai et al (2013). The second used a combination of the letter-discrimination task and the luminance-discrimination task, as used by Ging-Jehli and Ratcliff (2020). To be comparable with the digit paradigm, the latter tasks were modified. Instead of discriminating the identity of each letter presented (Ging-Jehli & Ratcliff, 2020), a letter-categorisation task (i.e., was the stimulus a consonant or a vowel) and a luminance-discrimination task (i.e., was the stimulus a dark letter or a bright letter) were used. At the fixation stage (200ms), a fixation cross (Colour = White; Font = “Arial”; Font size = 40) was presented against a grey background. Next, in the cue stage (500ms), the fixation cross disappeared, and the cue (e.g., “Odd/Even”; Colour = White; Font = “Arial”; Font size = 20) was presented against the same grey background, slightly above the place of the fixation cross. Then, in the target stage, the cue consistently stayed on the screen, and a stimulus appeared in the middle of the screen. A reminder about using the response-key was also

presented below the stimulus (e.g., “Odd” at the right side, “Even” at the left side; Colour = White; Font = “Arial”; Font size = 20). The stimuli used in each of the two paradigms will be described below.

4.3.3.1.1 Digit-Comparison Task and Digit-Parity Task

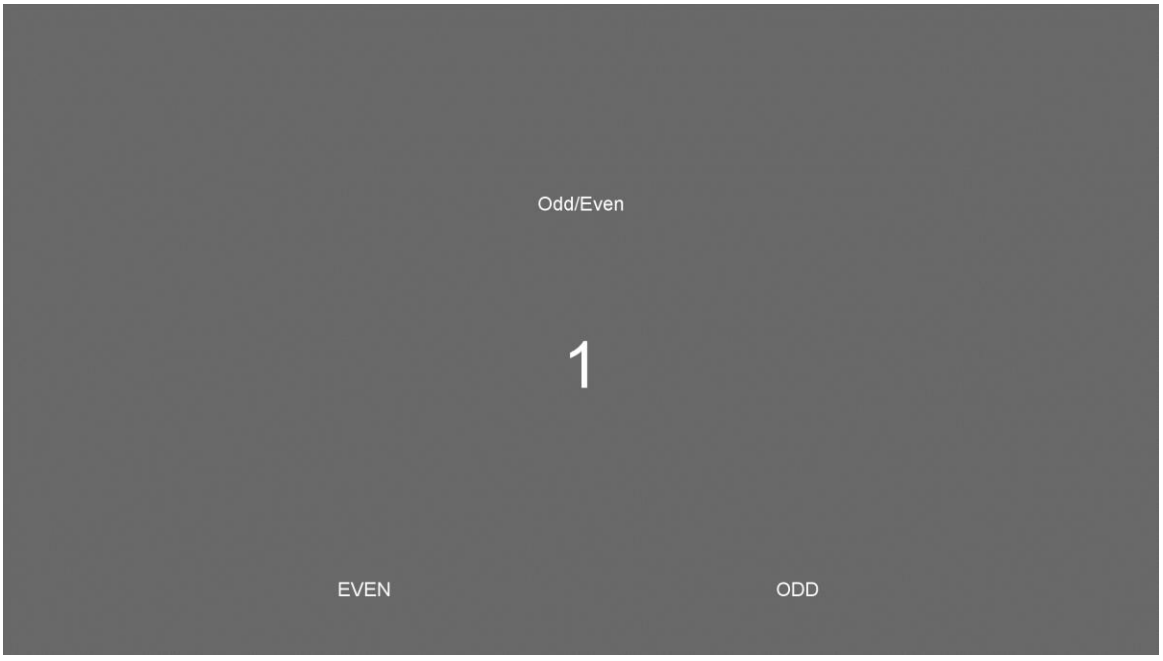
Stimuli in the digit-comparison tasks (i.e., was the stimulus greater or smaller than 5; see Figure 4.1 Panel A) and digit-parity tasks (i.e., the stimulus was an odd number or an even number; see Figure 4.1 Panel B) were based on the design used by Dai et al (2013). All stimuli in the digit-parity tasks and digits-comparison tasks were single-digit numbers (i.e., 1, 2, 3, 4, 6, 7, 8, 9; Colour = White; Font = “Arial”; Font size = 40) against a grey background. The digit was presented in the centre of the screen for a maximum of 2000ms, or until the participant gave a response.

Figure 4.1

Example Stimuli of the Digit-Comparison Task and Digit-Parity Task

Panel A: Digit-Comparison Task

Panel B: Digit-Parity Task



Note. Panel A presents an example of the target stage of a digit-comparison task (expected response: Greater). Panel B presents an example of the target stage of a digit-parity task (expected response: Odd).

4.3.3.1.2 Letter-Categorisation Task and Luminance-Discrimination Task

The stimuli in the letter-categorisation tasks (i.e., was the stimulus a consonant or a vowel) and luminance-discrimination tasks (i.e., was the stimulus a dark letter or a bright letter) were based on the design used by Ging-Jehli and Ratcliff (2020). For both the letter-categorisation and letter luminance discrimination tasks, the stimuli were constructed on a 64*64 pixel array, where 50% of the random pixels were in black and the other 50% were in white.

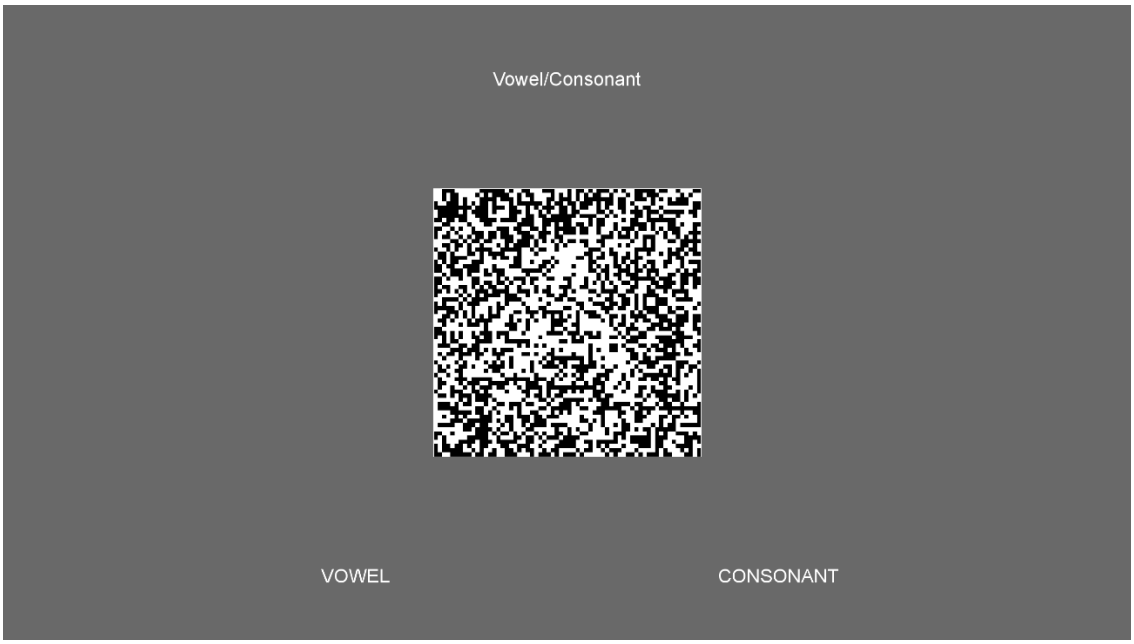
To generate stimuli for the letter-categorisation tasks (see Figure 4.2 Panel A), a black or white letter (A, E, O, U, H, N, T, X; Font = “Arial”; Font size = 40) replaced the pixels of the 64*64 pixel array, and 30% of the pixels were flipped to the opposite luminance (i.e., 30% of the pixels in a black letter were flipped to white). Each of the letters was selected to be distinct from each other as suggested by Ging-Jehli and Ratcliff (2020).

The letter stimuli were also used for the luminance-discrimination task (see Figure 4.2 Panel B). Stimuli with black letters were expected to be identified as dark letters, whereas stimuli with white letters were expected to be identified as bright letters. These stimuli were designed so that participants were working with bivalent stimuli in both tasks (i.e., the same stimuli were used in both the letter-categorisation task and luminance-discrimination task). However, Ging-Jehli and Ratcliff (2020) suggested that the luminance task might be too easy for participants so that a ceiling effect would occur in response accuracy. This was also tested in the first study.

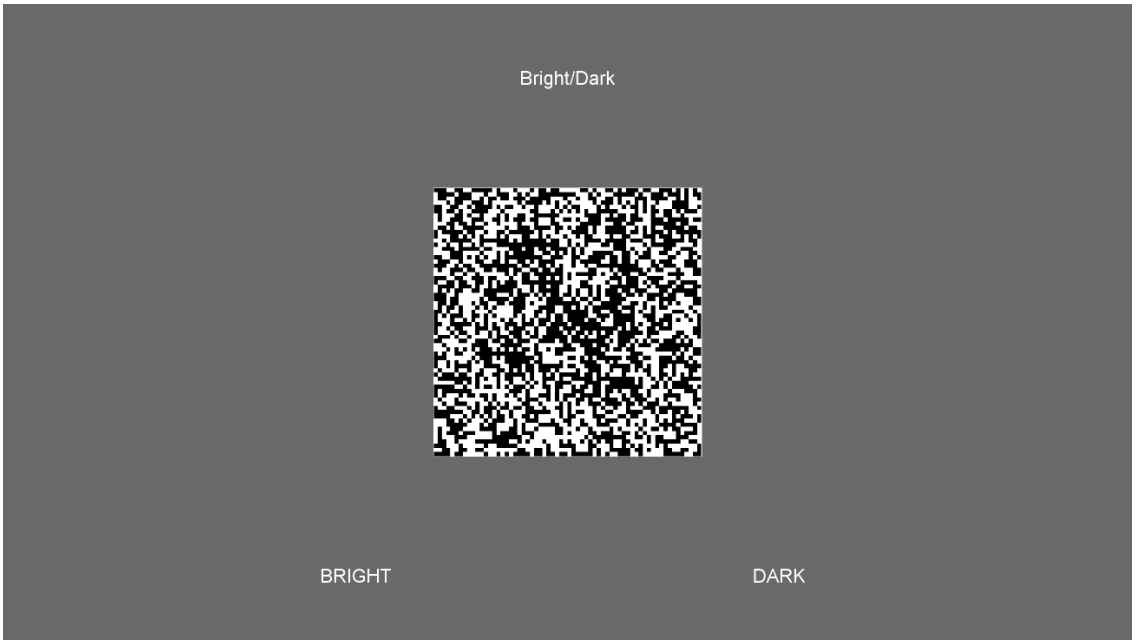
Figure 4.2

Example Stimuli of the Letter-Categorisation Task and Luminance-Discrimination Task

Panel A: Letter-Categorisation Task



Panel B: Luminance-Discrimination Task



Note. Panel A presents an example of the target stage of a letter-categorisation task (expected response: Vowel). Panel B presents an example of the target stage of a luminance-discrimination task (expected response: Dark).

4.3.3.2 Apparatus

The computer-based task-switching paradigms were programmed and run using Inquisit (Version 6.6.1; Millisecond Software, 2022). The programming script of the Inquisit task-switching paradigm program "category switch task: random task switches (Friedman et al., 2008)" was modified. A fixation phase was added at the beginning of each trial. The original visual shape cues (i.e., heart and cross) were changed to word cues (e.g., "Odd/Even" for the digit-parity tasks). A 500ms time interval was added between the cue-presentation phase and the stimulus-presentation phase for every trial. Also, the instructions and the stimulus were updated for switching between the digit-comparison task and the digit-parity task, or for switching between the letter-categorisation task and the luminance-discrimination task. The experiment was presented on a 27-Inch Dell LED-lit liquid crystal monitor (Dell S2719DGF), with a setting of 2560*1440 resolution and a 60.011 Hz refresh rate. A chin-and-head rest was used to keep the viewing distance at 70cm from the computer screen to match the setting used by Dai et al. (2013). A Cedrus Response Pad (Model RB-844, https://cedrus.com/rb_series/) was used to measure reaction times precisely.

4.3.3.3 Procedures

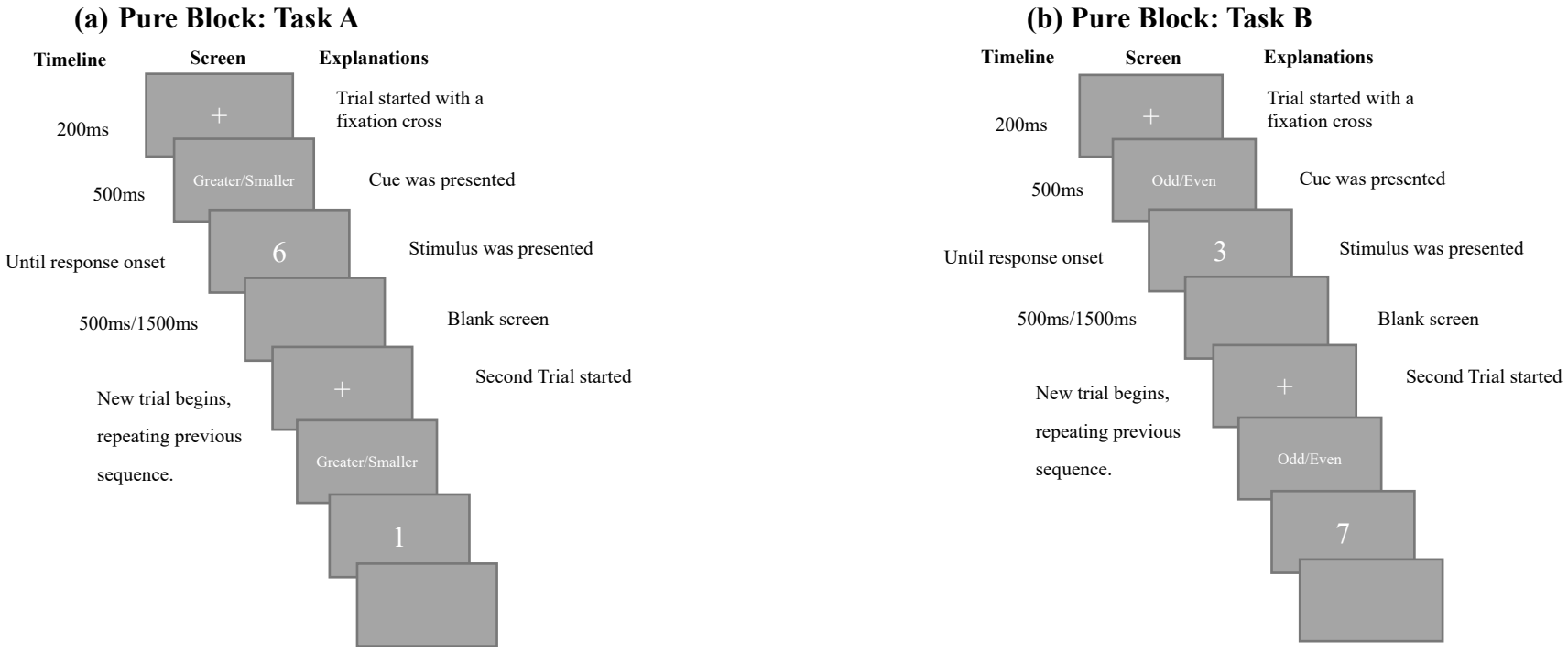
First, participants were taken to the laboratory room. After giving their consent to participate in the study by signing a consent form, older participants started the session by completing two screening tests (MoCA and VOSP), followed by completing the first task-switching experiment. Young participants started the session by completing the first task-switching experiment. All of the young and older participants started with the digit paradigm

as their first experiment, then completed the letter paradigm as their second experiment. The following procedures describe the digit-comparison task and the digit-parity task. The letter-categorisation task and the luminance-discrimination task followed the same procedures, and only the instructions and stimuli were different for those tasks.

All groups of participants were asked to complete a series of trials presented by a modified version of the task-switching paradigm (Rogers & Monsell, 1995). The experiment consisted of 6 blocks, of 32 trials. In the six blocks, there were two pure blocks (see Figure 4.3 and Table 4.1). One of these required participants to perform a digit-comparison task (indicated whether a digit was greater or smaller than 5, Task A, typical task sequence: AAAAAA). The second pure block required participants to perform a digit-parity task (indicating whether a digit was Odd or Even, Task B, typical task sequence: BBBBBB). For each trial in the digit-comparison pure block and the digit-parity pure block, participants were expected to give a forced-choice response by pressing keys in the response pad with the index and middle fingers of their dominant hand. The order of completing the digit-comparison task and digit-parity task blocks was randomised.

Figure 4.3

Digit Task-Switching Paradigm: Pure Blocks



Note. Participants performed either Task-A or Task-B in each trial. Task-A was a digit-comparison task (i.e., the digit was greater or smaller than 5). Task-B was a digit-parity task (i.e., the digit was odd or even). Panel (a) presents an example of two trials from the Task-A pure block, in which participants performed only Task-A. Panel (b) presents an example of two trials from the Task-B pure block, in which participants performed only Task-B. Each trial started with a fixation cross (200ms) in the centre of the screen and was followed by a cue (500ms) instructing participants to perform Task-A (cue: Odd/Even) or Task-B (cue: Greater/Smaller). Next, a digit stimulus appeared, and participants were required to give a forced-choice response. The trial ended with a blank screen (500ms after a correct response; 1500ms after a response with an error), and a new trial started, repeating the previous sequence until all 32 trials were completed.

Table 4.1

Timing and Screen Presentations of Task-Switching Paradigms

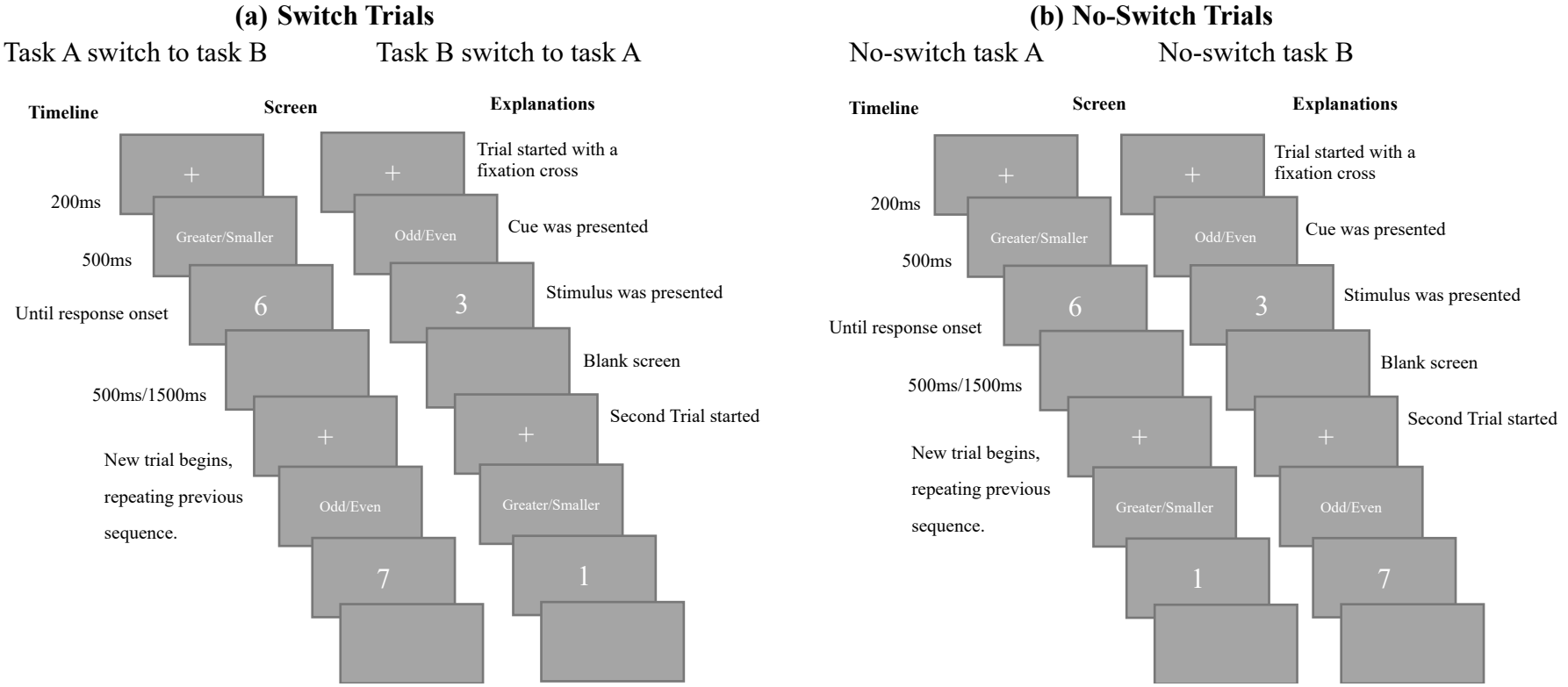
Stage	Duration	Screen Presentations
Fixation	200ms	Fixation cross at the centre of the screen
Cue	500ms	**Digit-Comparison Task:** Greater/Smaller **Digit-Parity Task:** Odd/Even **Letter-Categorisation Task:** Vowel/Consonant **Luminance-Discrimination Task:** Bright/Dark
Target	Until a response is given	**Digit Paradigm:** 1, 2, 3, 4, 6, 7, 8, 9 presented until participants gave a response **Letter Paradigm:** A, E, O, U, H, N, T, X presented until participants gave a response
Blank	500ms/1500ms	A blank screen presented between two trials ◆ After a correct response: 500ms ◆ After a response with an error: 1500ms

Note. This table presents all stages and the duration involved in the procedures of a trial from the task-switching paradigm. ms = millisecond.

The other four experimental blocks were mixed blocks (see Figure 4.4 and Table 4.1), where each block contained 32 trials. The sequence of the trials was pseudorandom. In a total of 128 trials, there were 64 switch trials (i.e., Task-A switch to Task-B, or Task-B switch to Task-A). The other 64 tasks were no-switch trials (i.e., Task-A followed by another Task-A, or Task-B followed by another Task-B). All participants started with two pure blocks, followed by four mixed blocks. Half of the participants started with Task-A pure block, and the other half with Task-B pure block. The number of trials in each category is presented in Appendix G.

Figure 4.4

Digit Task-Switching Paradigm: Mixed Blocks



Note. Participants performed either Task-A or Task-B in each trial. Task-A was a digit-comparison task (i.e., the digit was greater or smaller than 5). Task-B was a digit-parity task (i.e., the digit was odd or even). Panel (a) presents two examples of switch trials (i.e., Task A switched to a Task B or Task B switched to Task A) from the mixed block, in which participants performed both Task-A and Task-B. Panel (b) presents two examples of no-switch trials (i.e., no-switch Task A or no-switch Task B) from the mixed block. Each trial started with a fixation cross (200ms) in the centre of the screen followed by a cue (500ms) instructing participants to perform Task-A (cue: Odd/Even) or Task-B (cue: Greater/Smaller). Next, a digit stimulus appeared, and participants were required to give a forced-choice response. The trial ended with a blank screen (500ms/1500ms), and a new trial started, repeating the previous sequence until all trials were completed.

As illustrated in Figure 4.4, in the mixed blocks, each of the trials started with a fixation cross in the centre of the screen, presented for 200ms. Following the fixation cross, a cue was presented for 500ms. Then, a digit stimulus was presented, and participants were asked to give their response. Their response time (RT) and response accuracy were recorded for further analyses.

After the first task-switching experiment was completed, a five-minute break was provided. After the break, participants were provided with questionnaires, including the DLHQ, the CRIq (Nucci et al., 2012) and the short form of the IPAQ (Craig et al., 2003). After the questionnaires were completed by the participants, the second task-switching experiment was administered. The second task-switching paradigm followed the same procedures as the first task-switching paradigm, with two different tasks. Following the second task-switching paradigm, participants were provided with the CLCQ to assess their current life complexity. In between the experiments and the questionnaire session, participants were offered breaks and cookies.

Before each of the different block types started, the experimenter familiarised participants with the procedures of the task-switching paradigm. All the participants received the same information (see Appendix H). The instructions were provided both verbally and on the screen. At the beginning of each of the different blocks, practice trials were provided, to ensure that participants had understood the task procedures. There were break times between every block.

4.3.4 Analysis

All the statistical analyses were conducted using R (version 4.3.2; R Core Team, 2023) and RStudio (version 2023.9.1.494; Posit Team, 2023). Bonferroni corrections were used for multiple hypotheses testing, as both RT and accuracy data were used in two planned hypothesis tests. Due to our within-subject design, non-independence within RT and accuracy of performance across two paradigms was also expected, but as convention in the area, this is not included in the alpha level adjustments. Accordingly, alpha was set at 0.025.

4.3.4.1 Task-Switching Performance

The original experiment (Friedman et al., 2008) excluded RT that was faster than 100ms. Trials were also excluded if was no response was recorded. The current study did not modify this setting for exclusion. The current study did not modify this setting for exclusion. In the current study, local-switch costs measured by both RT and accuracy were used for the analyses. The local-switch costs were the mean differences (in RT and accuracy) between switch trials and no-switch trials.

4.3.4.2 Intra-Class Correlation Coefficient (ICC)

Performance was expected to vary both within paradigms (due to different trial types) and between paradigms (due to varying difficulty levels between digit and letter tasks). Performance was also expected to vary both within participants across trial and paradigm types, and between participants reflecting variations in individual functional ability. Therefore, prior to model fitting, ICCs were calculated to assess variance components both

within and between participants, as well as within and between paradigms (digit versus letter). This analysis was conducted to determine whether a linear mixed-effects model approach was necessary for appropriate data analysis.

4.3.4.3 Cost of Switching

Linear mixed-effect models were used to test the significance of the effect of trial types (i.e., switch versus no-switch) on task-switching performance, where trial type was the fixed effect, and the participant was the random effect (i.e., nested by participants). The model was fit using restricted maximum likelihood (REML).

4.3.4.4 Comparison Between Two Task-Switching Paradigms

Linear mixed-effect models were used to test the significance of the effect of paradigm types (i.e., digit versus letter) on task-switching performance, where paradigm type was the fixed effect, and the participant was the random effect (i.e., nested by participants). The model was fit using REML.

4.4 Study 1: Results

4.4.1 Basic Descriptive Information and Demographics

4.4.1.1 Demographics

Of the young participants (N = 24), most held an undergraduate degree (n = 11), a masters degree (n = 7), or a senior high school degree (n = 6). Half of the young participants (n = 12) were monolingual, and the other half were bilingual or multilingual. The mean EHI

handedness score was 58.46 (*SD* = 34.63, range = -30–100).

In older participants (*N* = 20), most held an undergraduate degree (*n* = 8), a masters degree (*n* = 5), other qualifications (*n* = 3; e.g., diploma), doctoral degree (*n* = 2), or a senior high school degree (*n* = 2). Most of the older participants (*n* = 18) were monolingual, and the remaining 2 participants were bilingual or multilingual. The mean EHI handedness score was 81.82 (*SD* = 18.64, range = 41.18–100).

Due to differences in the proportion of bilinguals/multilinguals in the young and older participants, independent t-test comparisons on task-switching performance were made between young bilingual/multilingual participants and young monolingual participants. The results suggested that there were no significant differences in task-switching performance measured by the digit paradigm and the letter paradigm (see Appendix I.1).

4.4.1.2 Task-Switching Performance

The task-switching performance of young and older participants for both the digit paradigm and letter paradigm are presented in Table 4.2.

Table 4.2

Summary of Task-Switching Performance for both the Digit Paradigm and Letter Paradigm in Young (N = 24) and Older (N = 20) Participants

Age Groups	Paradigm	Measure	Trial	*Mean*	*SD*
Young					
	Digit	RT	No Switch	829.53	220.77
			Switch	972.16	288.16
			Cost	142.63	155.33
		Acc	No Switch	0.97	0.03
			Switch	0.95	0.05
			Cost	0.02	0.04
	Letter	RT	No Switch	1164.16	487.94
			Switch	1348.33	558.33
			Cost	184.17	172.04
		Acc	No Switch	0.88	0.07
			Switch	0.85	0.07
			Cost	0.03	0.06
Older					
	Digit	RT	No Switch	1151.90	376.61
			Switch	1309.24	376.96
			Cost	157.35	143.45
		Acc	No Switch	0.98	0.02
			Switch	0.96	0.03
			Cost	0.01	0.03
	Letter	RT	No Switch	1981.19	750.42
			Switch	2208.42	960.35
			Cost	227.23	275.98
		Acc	No Switch	0.89	0.06
			Switch	0.85	0.08
			Cost	0.03	0.06

Note. RT = Reaction time (ms). Acc = Accuracy as a proportion of correct responses out of the total number. No Switch = No-switch trials. Switch = Switch trials. Cost = Local-switch costs.

4.4.2 Intra-Class Correlation Coefficient (ICC)

For young participants, ICC values between and within paradigms were 0.26 for RT and 0.59 for accuracy. The between and within subjects ICC was 0.52 for RT, while the ICC for accuracy was too small to be calculated (NA). In older participants, ICC values between and within paradigms were 0.45 for RT and 0.65 for accuracy. The between and within subjects ICC was 0.35 for RT and 0.001 for accuracy.

These results indicated that variance components existed both within and between paradigms for both age groups. When performance was measured by RT, within-paradigm variance was greater; when measured by accuracy, between-paradigm variance was greater. However, between- and within-subject variance patterns showed age-related differences. For RT, young participants exhibited more between-subjects variance, while older participants exhibited more within-subjects variance. For accuracy, most of the variance was within-subjects for both age groups. Based on these ICC values, a linear mixed-effects modelling approach was necessary for appropriate data analysis.

4.4.3 Cost of Switching

4.4.3.1 ***Performance of Young Participants***

For the digit paradigm, a linear mixed-effects model was constructed to examine the effect of trial types on digit paradigm performance measured by RT (Figure 4.5, Panel A), with a random intercept for participants. The model revealed a significant main effect of trial type, $b = 142.63$, $SE = 31.71$, $t(23) = 4.50$, $p < 0.001$, 97.5% CI [63.22, 222.04]. Participants responded significantly more slowly on switch trials compared to no-switch trials, indicating

a significant local-switch cost in the digit paradigm. The same model was constructed to examine the digit paradigm performance measured by accuracy (Figure 4.5, Panel B). The model revealed a significant effect of trial type, b = -0.021, SE = 0.007, $t(23)$ = -2.88, p = 0.008, 97.5% CI [-0.0395, -0.0025]. Participants were significantly less accurate on switch trials compared to no-switch trials, indicating a significant local-switch cost in the digit paradigm.

For the letter paradigm, a linear mixed-effects model was constructed to examine the effect of trial type on performance measured by RT (Figure 4.5, Panel A) with a random intercept for participants. The model revealed a significant effect of trial type, b = 184.17, SE = 35.12, $t(23)$ = 5.24, $p < 0.001$, 97.5% CI [96.20, 272.14]. Consistent with the results found with the digit paradigm, participants responded significantly more slowly on switch trials compared to no-switch trials, indicating a significant local-switch cost in the letter task. The same model was constructed to examine the letter paradigm performance measured by accuracy (Figure 4.5, Panel B). The model revealed a significant effect of trial type, b = -0.029, SE = 0.012, $t(23)$ = -2.42, p = 0.024, 97.5% CI [-0.059, 0.0011]. Consistent with the results found with the digit paradigm, participants were significantly less accurate on switch trials compared to no-switch trials, indicating a marginal significant local-switch cost in the letter task.

4.4.3.2 Performance of Older Participants

For older participants, a linear mixed-effects model was constructed to examine the effect of trial type on digit paradigm performance measured by RT (Figure 4.5, Panel A), with

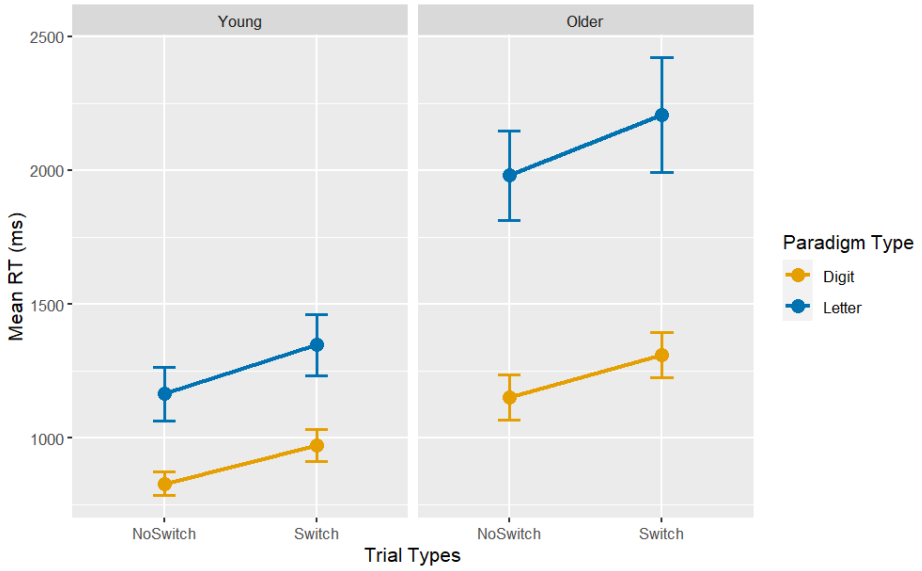
a random intercept for participants. The model revealed a significant main effect of trial type, $b = 157.35$, $SE = 32.08$, $t(19) = 4.91$, $p < 0.001$, 97.5% CI [75.92, 238.78]. This indicated that participants responded significantly slower on switch trials compared to no-switch trials, suggesting a significant local-switch cost in the digit paradigm. The same model was constructed to examine the digit paradigm performance measured by accuracy (Figure 4.5, Panel B). The model revealed that the effect of trial type was not significant, $b = -0.013$, $SE = 0.006$, $t(19) = –2.20$, $p = 0.040$, 97.5% CI [-0.028, 0.0022]. The data indicated that accuracy was lower on switch trials compared to no-switch trials, although the effect was not significant after correction for multiple comparisons.

For the letter paradigm, a linear mixed-effects model was constructed to examine the effect of trial type on performance measured by RT (Figure 4.5, Panel A), with a random intercept for participants. The model revealed a significant main effect of trial type, $b = 227.23$, $SE = 61.71$, $t(19) = 3.68$, $p = 0.002$, 97.5% CI [70.55, 383.91]. Consistent with the results found with the digit paradigm, participants responded significantly slower on switch trials compared to no-switch trials, indicating a significant local-switch cost in the letter paradigm. The same model was constructed to examine the letter paradigm performance measured by accuracy (Figure 4.5, Panel B). The model revealed a marginal but non-significant effect of trial type, $b = -0.034$, $SE = 0.014$, $t(19) = –2.42$, $p = 0.026$, 97.5% CI [-0.070, 0.0015]. The data indicated that accuracy was lower on switch trials compared to no-switch trials, but again, the effect was not significant after correction for multiple comparisons.

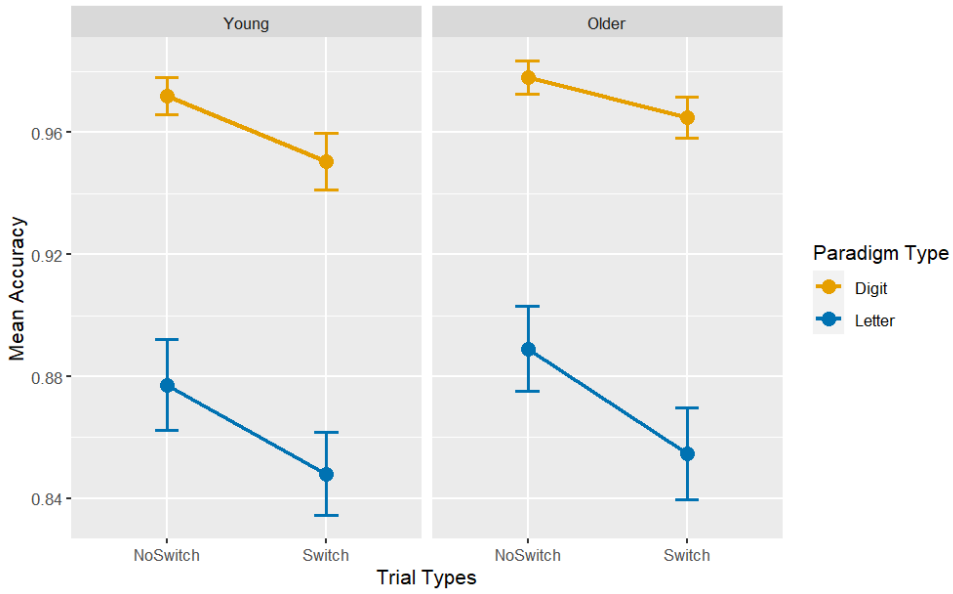
Figure 4.5

Task-Switching Performance in the Digit Paradigm and Letter Paradigm for Young (N = 24) and Older (N = 20) Participants

Panel A: RT



Panel B: Accuracy



Note. Error bars are indications of standard errors. RT = Reaction time (ms). NoSwitch = No-switch trials. Switch = Switch trials. The performance difference between the no-switch and switch trials are local-switch costs. Compared to young participants, older participants' responses were slower but more accurate.

4.4.4 Comparison Between Two Task-Switching Paradigms

To compare the effectiveness of digit paradigm and letter paradigm in measuring the costs of task-switching, direct comparisons were made between local-switch costs. For young participants, a linear mixed-effects model was constructed to examine whether there was a significant difference between the digit and letter paradigms on RT (Figure 4.5, Panel A), with a random intercept for participants. The model revealed that the main effect of paradigm type was not significant, $b = 41.54$, $SE = 47.31$, $t(23) = 0.88$, $p = 0.39$, 97.5% CI [-76.74, 159.82]. This suggested that there was no significant difference in local-switch costs (RT) between the digit and letter paradigms in young adults. The same model was constructed to examine the difference between the digit and letter paradigms with regard to accuracy (Figure 4.5, Panel B). The model revealed that the main effect of paradigm type was not significant, $b = -0.0077$, $SE = 0.012$, $t(23) = -0.67$, $p = 0.51$, 97.5% CI [-0.0331, 0.0177]. This suggests that there was no significant difference in local-switch costs (accuracy) between the digit and letter paradigms in young adults.

For older participants, a linear mixed-effects model was constructed to examine whether there was a significant difference between the digit and letter paradigms on RT (Figure 4.5, Panel A), with a random intercept for participants. The model revealed that the main effect of paradigm type was not significant, $b = 69.88$, $SE = 65.47$, $t(19) = 1.07$, $p = 0.30$, 97.5% CI [-67.23, 206.99]. This suggested that there was no significant difference in local-switch costs (RT) between the digit and letter paradigms in older adults. The same model was constructed to examine the difference between the digit and letter paradigms on accuracy (Figure 4.5, Panel B). The model revealed that the main effect of paradigm type was not significant, $b =$ -

0.021, *SE* = 0.015, *t*(19) = -1.37, *p* = 0.19, 97.5% CI [-0.052, 0.010]. This suggests that there was no significant difference in local-switch costs (accuracy) between the digit and letter paradigms in older adults.

4.5 Study 1: Discussion

The aim of Study 1 was to explore which of the task-switching paradigms (i.e., digit paradigm or letter paradigm) was the most suitable instrument to measure task-switching performance in young and older adults. This exploration was conducted following two steps.

4.5.1 Step 1: Confirming the Significance of the Cost of Switching

In the young participants, the switch trials were performed significantly more slowly and less accurately than no-switch trials regardless of paradigm type—digit or letter paradigm. This indicates that there were significant local-switch costs, which is consistent with our predictions, and consistent with previous task-switching studies using similar tasks (e.g., Dai et al., 2013; Ging-Jehli & Ratcliff, 2020), which also found significant switch costs in young participants, whether measured by RT or accuracy.

In the older participants, the switch trials were performed significantly more slowly than no-switching trials in both the digit and letter paradigms. However, the accuracy in older participants were not significantly different between the switch and no-switch trials. This is consistent with previous task-switching studies (e.g., Van Asselen & Ridderinkhof, 2000), which indicated that there was a tendency of sacrificing reaction time speed in order to maintain accuracy in older adults. Comparing the mean RT and accuracy of older participants

with young participants, older adults took longer to switch tasks, but the accuracy maintained was slightly better, suggesting that our older participants were a group of high-performing individuals.

4.5.2 Step 2: Exploring and Comparing the Digit Versus Letter Paradigms

In both young and older participants, responses to the letter paradigm were performed more slowly and less accurately. However, none of the differences between the digit paradigm and the letter paradigm were significant. This finding could be explained by the fact that both the digit paradigm and letter paradigm used the same design, and were intended to measure the same cognitive construct—task-switching. Although there are studies that used multiple task-switching paradigms in their study designs (e.g., Arrington et al., 2003), to the best of our knowledge, there was no previous study that directly compared the performance of two task-switching paradigms with different base-tasks (e.g., digit tasks and letter tasks). However, it is well-established that different types of task-switching paradigms have convergent results, which reflect significant costs of switching as measured by both RT and accuracy (e.g., Kiesel et al., 2010; and the systematic review study reported in Chapter Three). Our within-subject design also limited the potential effects of individual differences in task-switching performance. The findings of Study 1 can be perceived as evidence confirming that the effect of base-tasks (i.e., digit tasks or letter tasks) in a task-switching paradigm did not significantly impact task-switching performance as measured by RT and accuracy.

However, another explanation of this pattern of results may be tied to the verbal feedback we received while administering the letter paradigm, but not during the digit paradigm. Participants from both age groups, but more so from the older group, suggested that the incomplete letter stimuli in the letter paradigm were difficult to identify during the experiment. Given all the older participants had passed the VOSP screening, we ruled out the possibility that this was the result of impairments in object recognition (Warrington & James, 1991). Although participants' performance accuracy on the letter paradigm was not unacceptably low, when visualising the association between RTs of the digit paradigm and RTs of the letter paradigm, heterogenous patterns were found (See Appendix I.2). These heterogenous patterns could be interpreted to mean that there were other factors that influenced the task-switching performance as measured by the letter paradigm. Therefore, combining information from the quantitative data and qualitative feedback, the potential effect of task difficulties on task-switching performance needs to be taken into consideration when exploring the results.

The reported difficulties with the letter stimuli may have contributed and influenced the outcome performance of the task-switching paradigm. This is not a new concern shown by the current study. Ravizza and Carter (2008) discussed the influence of task complexity (i.e., difficulty) on task-switching performance. They found that increased task complexity led to increased cognitive load, which resulted in participants demonstrating greater switch costs as measured by both RT and accuracy. Similar results were also summarised in a review of voluntary task-switching (Dreisbach & Mendl, 2024), which suggested that participants were less willing to switch to more difficult tasks, although the difficulty of the task was a

subjective judgement.

To conclude, based on the results of Study 1, the digit paradigm was a more reliable and direct measure of task-switching. However, further investigation into the influence of letter stimulus difficulty on task-switching performance might be necessary and is explored below in Study 2.

4.6 Study 2: Difficult Versus Easy Letter Stimuli

In Study 2, we compared the task-switching performance of participants completing the letter and luminance task-switching paradigm with the difficult version and with the easy version of the letter stimuli. The difficult version of the letter stimuli was used in Study 1. The easy version of the letter stimuli was generated specifically to be used in Study 2. This comparison could indicate whether the difficulty of the letter stimuli influenced task-switching performance, and test whether a letter and luminance paradigm with easier letter stimuli could be a better option for investigating task-switching in young and older adults.

4.7 Study 2: Methods

4.7.1 Participants

Data from 44 participants who participated in Study 1, and data from 46 new participants (recruited from the Canberra region community) were combined to conduct the analyses for Study 2. Of the 46 new recruited participants, 4 participants were excluded. Of the young participants: 1 did not complete the whole study; of the older participants: 1 did not pass the MoCA screening, and 2 did not complete the whole study. Of the total of 86

participants, there were 46 young participants (Age mean = 23.54, age *SD* = 5.00, age range = 18–40; 33 women, 11 men, 2 prefer not to say), and 40 older participants (Age mean = 71.35, age *SD* = 6.61, age range = 61–87; 23 women, 17 men).

In the Difficult Condition, the letter and luminance paradigm used the more difficult version of the letter stimuli (30% noise, as used in Study 1). In the Easy Condition, the letter and luminance paradigm used an easier version of the letter stimuli (25% noise). A pilot study with 7 participants was conducted to identify the appropriate level of noise in the easy version of the letter stimuli, among a series of letter stimuli with a descending level of noise. The appropriate level of noise (25%) was taken as the average level of noise required for the participants to become certain of the identity of the letter stimuli. Of the total of 86 participants, 24 young and 20 older participants were in the Difficult Condition, 22 young and 20 older participants were in the Easy Condition.

4.7.2 Procedure

The experiment in Study 2 used the same procedures as the experiment in Study 1 to ensure that the task-switching performance in the easier version of the letter paradigm was comparable with the task-switching performance in the difficult version (i.e., the version used in Study 1) of the letter paradigm.

4.7.3 Letter Stimuli

The stimuli in the letter-categorisation tasks (i.e., the stimulus was a consonant or a vowel) and luminance-discrimination tasks (i.e., the stimulus was a dark letter or a bright letter) were

based on the design used by Ging-Jehli and Ratcliff (2020). For both letter-categorisation and letter luminance discrimination tasks, the stimuli were constructed on a 64*64 pixel array, where 50% of random pixels were in black and the other 50% of pixels were in white.

Based on the feedback from the participants, we decided to run an easy version of the letter paradigm with less noise in the letter stimuli. However, to maintain the effect of task-switching on accuracy we did not want to reduce the difficulty of the letter stimuli extensively. A pilot test was conducted with 7 participants aged from 25 to 67. They looked at four different letters (A, N, O, H), where the noise level decreased progressively, and they were asked to report the point at which they were certain about the letter in the stimuli. The results suggested an average of 25% noise. Therefore, the easy version of the stimuli had 25% noise.

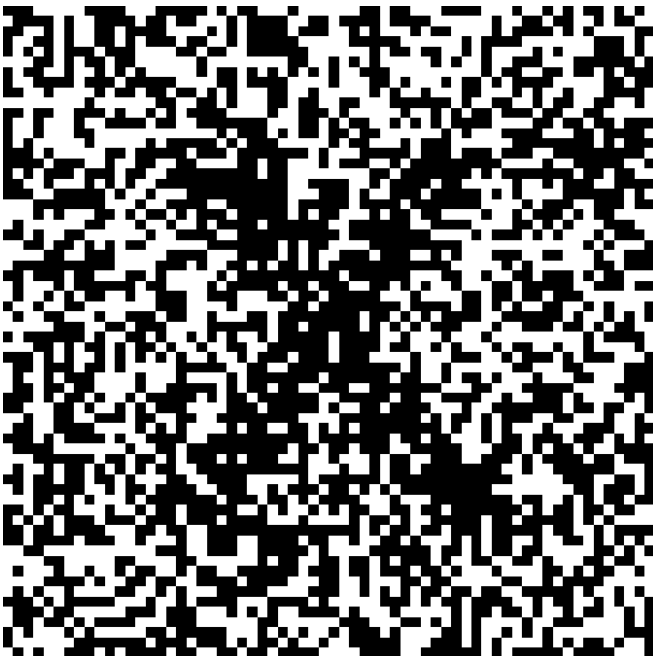
To generate the easy version of the letter stimuli for the letter-categorisation tasks (see Figure 4.1 Panel A), a black or white letter (i.e., A, E, O, U, H, N, T, X; Font size = 40) replaced the pixels of the 64*64 pixel array, and 25% of the pixels were flipped to the opposite luminance (i.e., 25% of the pixels in a black letter were flipped to white). Each of the letters was selected to be distinct from each other as suggested by Ging-Jehli and Ratcliff (2020). An example of both difficult and easy version of the letter stimuli can be found in Figure 4.6.

Figure 4.6

Examples of Letter Stimuli Used in the Letter Paradigm

Panel A: Difficult Version (30% noise)

Panel B: Easy Version (25% noise)



Note. Both panels present examples of a Black Letter X.

4.7.4 Analysis

The statistical analysis followed similar steps as the statistical analysis in Study 1. All the statistical analyses were conducted using R (version 4.3.2; R Core Team, 2023) and RStudio (version 2023.9.1.494; Posit Team, 2023). Bonferroni corrections were used for multiple hypotheses testing. Conservative Bonferroni correction, given previous use of some variables in Study 1, would set alpha to 0.017.

4.7.4.1 Task-Switching Performance

Consistent with Study 1, in Study 2, local-switch costs measured by both RT and accuracy were used for the analyses. The local-switch costs were the mean differences (in RT and accuracy) between switch trials and no-switch trials.

4.7.4.2 Comparison Between Difficult and Easy Letter Stimuli

Linear regression models were used to examine whether there were differences in RT and accuracy between the difficult and easy letter stimuli in the letter paradigm for both young and older participants. The model included difficulty of letter stimuli as a between-subjects predictor, with two levels (Difficult, Easy).

4.8 Study 2: Results

4.8.1 Basic Descriptive Information and Demographics

4.8.1.1 Demographics

Of the young participants ($N = 46$), most held an undergraduate degree ($n = 20$), a senior

high school degree (*n* = 16), masters degree (*n* = 9), or doctoral degree (*n* = 1). Half of the young participants (*n* = 23) were monolingual, and the other half were bilingual or multilingual. The mean EHI handedness score was 65.20 (*SD* = 28.88, range = -30−100).

Of the older participants (*N* = 40), most held an undergraduate degree (*n* = 14), a masters degree (*n* = 10), other qualifications (*n* = 6; e.g., diploma), a senior high school degree (*n* = 5), a doctoral degree (*n* = 4), or a junior high school degree (*n* = 1). Most of the older participants (*n* = 37) were monolingual, and the remaining 3 participants were bilingual or multilingual. The mean EHI handedness score was 77.43 (*SD* = 20.86, range = 30−100).

In both young and older participants, between-condition comparisons of age and task-switching performance in the digit paradigm (presented in Table 4.3), which were not significant. Due to differences in the proportion of bilinguals/multilinguals between young and older participants, independent t-test comparisons on task-switching performance were made between young bilingual/multilingual participants and young monolingual participants. The results suggested that there were no significant differences in task-switching performance, as measured by both Difficult and Easy versions of the letter paradigm (see Appendix I.1).

Table 4.3

Group Characteristics (Mean (SD)): Comparisons Between the Difficult Condition and the Easy Condition for Young (N = 46) and Older (N = 40) Participants

	Young (*N* = 46)			**Older (*N* = 40)**		
	Difficult	**Easy**	***t (df), p***	**Difficult**	**Easy**	***t (df), p***
Age	**24.29** (5.30)	**22.73** (4.65)	1.07 (43.92), 0.29	**72.75** (7.93)	**69.95** (4.76)	1.35 (31.14), 0.19
Digit RT	**142.63** (155.33)	**146.34** (209.86)	-0.07 (38.52), 0.95	**157.35** (143.45)	**146.58** (107.66)	0.27 (35.25), 0.79
Digit Acc	**0.02** (0.04)	**0.02** (0.04)	-0.51 (41.85), 0.61	**0.01** (0.03)	**0.01** (0.03)	-0.50 (36.69), 0.62
Diff RT	**184.17** (172.04)		*NA*	**227.23** (275.98)		*NA*
Diff Acc	**0.03** (0.06)		*NA*	**0.03** (0.06)		*NA*
Easy RT		**119.45** (127.23)	*NA*		**161.68** (110.97)	*NA*
Easy Acc		**0.02** (0.04)	*NA*		**0.02** (0.06)	*NA*

Note. Data is presented in *Mean (SD)* format in the current table for indicated groups. Difficult/Diff = Difficult Letter Stimuli Condition, or difficult letter paradigm. Easy = Easy Letter Stimuli Condition, or easy letter paradigm. *t (df), p* = Independent *t*-value (degree of freedom), *p*-value. Digit = Digit paradigm. RT = Local-switch costs measured by RT, in milliseconds. Acc = Local-switch costs measured by accuracy. For both young and older participants, no significant differences found between the Difficult condition and the Easy condition.

4.8.1.2 Task-Switching Performance

The task-switching performance of young and older participants for the letter paradigms in the difficult condition and the easy condition are presented in Table 4.3. A record of the raw RT and accuracy measures of task performance for switch and no-switch trials separately can be found in Appendix I.3.

4.8.2 Comparison Between Difficult Letter and Easy Letter

For young participants, the linear model revealed that the mean RT (Figure 4.7 Panel A) for the difficult letter condition was not significantly different from the easy letter condition, b = -64.72, SE = 44.96, $t(44)$ = -1.44, p = 0.157, 98.3% CI [-174.66, 45.22]. The model explained a small portion of the variance in reaction time (R^2 = 0.04), with an F-statistic of 2.07, p = 0.157, indicating that the letter paradigm (easy vs. difficult) did not significantly impact the mean local-switch costs measured by RT in the young participants. The same model was constructed to examine the difference between the digit and letter paradigms on accuracy (Figure 4.7 Panel B). The model revealed that the accuracy for the easy letter condition was not significantly different from the difficult letter condition, b = 0.012, SE = 0.015, $t(44)$ = 0.75, p = 0.46, 98.3% CI [-0.025, 0.049]. The model explained a small portion of the variance in accuracy (R^2 = 0.01), with an F-statistic of 0.57, p = 0.46, indicating that the different difficulties of letter paradigm (easy vs. difficult) did not significantly impact local-switch costs, as measured by accuracy in the young participants.

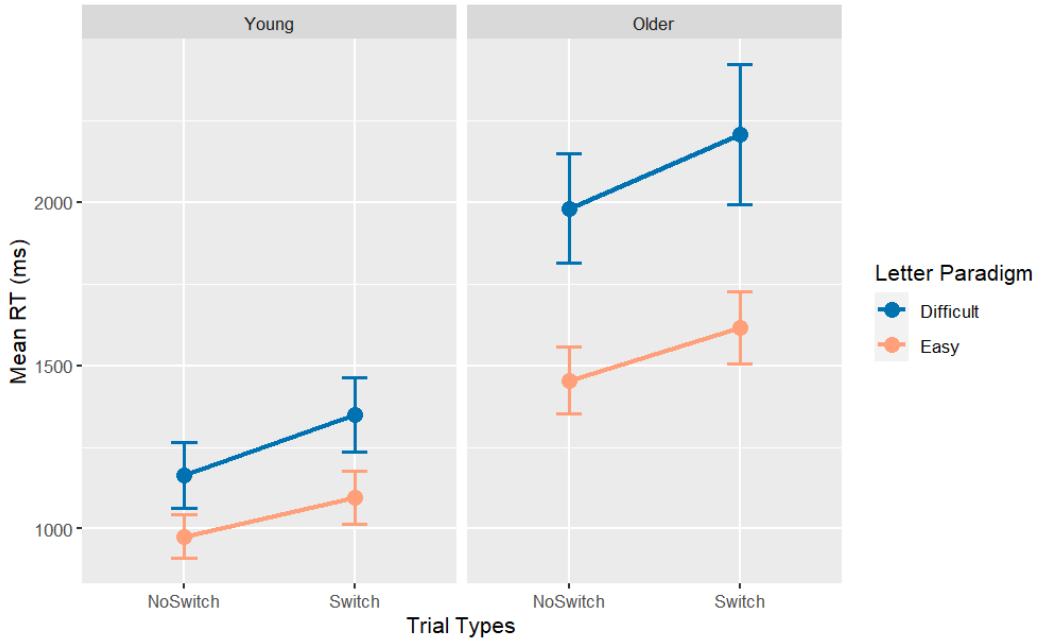
For older participants, the linear model revealed that the mean RT (Figure 4.7 Panel A) for the difficult letter condition was not significantly different from the easy letter condition,

b = -65.55, *SE* = 66.51, *t*(38) = -0.99, *p* = 0.331, 98.3% CI [-229.30, 98.20]. The model explained a very small portion of the variance in RT (R^2 = 0.02), with a *F*-statistic of 0.97, *p* = 0.331, indicating that the letter paradigm (easy vs. difficult) did not significantly impact the mean local-switch costs measured by RT in older participants. The same model was constructed to examine the difference between the digit and letter paradigms on accuracy (Figure 4.7 Panel B). The model revealed that the accuracy for the easy letter condition was not significantly different from the difficult letter condition, *b* = 0.019, *SE* = 0.019, *t*(38) = 0.99, *p* = 0.33, 98.3% CI [-0.028, 0.066]. Consistent with the model constructed for RT, the model explained a very small portion of the variance in accuracy (R^2 = 0.03), with an *F*-statistic of 0.98, *p* = 0.328, indicating that the difficulty of letter paradigm (easy vs. difficult) did not significantly affect local-switch costs, as measured by accuracy in older participants.

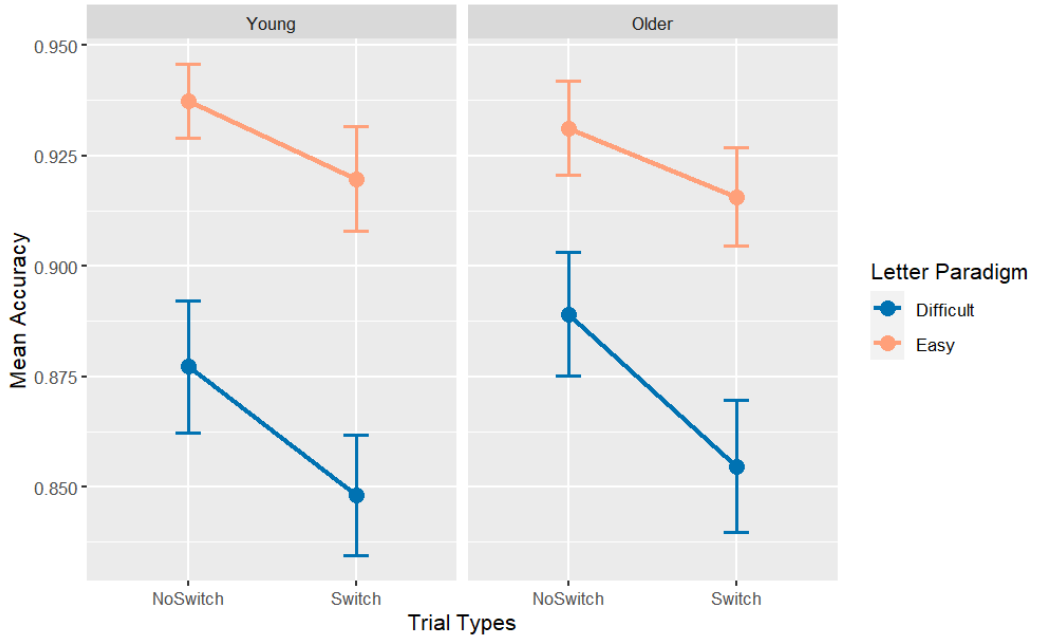
Figure 4.7

Task-Switching Performance in Difficult Letter and Easy Letter Conditions in Young (N = 46) and Older (N = 40) Participants

Panel A: RT



Panel B: Accuracy



Note. Error bars are indications of standard errors. RT = Reaction time (ms). NoSwitch = No-switch trials. Switch = Switch trials. The performance difference between the no-switch and switch trials are local-switch costs.

4.9 Study 2: Discussion

The aim of Study 2 was to explore that whether the easy version of the letter paradigm would more effectively capture task-switching performance in both young and older participants, compared to the difficult version of the letter paradigm. The results suggest that although participants respond to the easy letter stimuli faster and more accurately, the differences between performance with difficult letter stimuli and performance with easy letter stimuli were not significant, neither for RT nor accuracy. These results could imply that the difficulty of the letter stimuli did not introduce a significant effect on task-switching performance, which is in contrast to findings by Ravizza and Carter (2008). This might be because the manipulation of task difficulty in Study 2 was more subtle (i.e., the noise level of the letter stimuli), than the manipulation of the task difficulty in Ravizza and Carter (2008; i.e., the stimulus complexity).

However, alternative explanations could also be generated by considering the underlying characteristics of the tasks in the letter paradigm design. The letter-categorisation task and the luminance-discrimination task were two base-tasks used in the letter paradigm design. According to Ging-Jehli and Ratcliff (2020; see also Küper et al., 2017), the luminance-discrimination task was easier compared to the letter-categorisation task. There was an asymmetry in their baseline task difficulty. Previous research (first described by Allport et al., 1994; explained by Yeung & Monsell, 2003; and further discussed by Schneider & Anderson, 2010) found that the asymmetry in task difficulty could have an impact on task-switching performance. Combining these previous findings with the experimental setting of Study 2, the 5% change of noise level in the letter stimuli (i.e., 30% in the difficult condition, 25% in the

easy condition) might result in asymmetrical effects on the two tasks due to the differences in their baseline difficulty. To investigate the effect of stimulus difficulty further, future studies could compare the effects of changing the degree of difficulty of the tasks. Tasks with symmetrical baseline difficulty, where a similar level of information processing is required, can be compared to tasks with asymmetrical baseline difficulty, where different levels of information processing is required.

Another limitation of Study 2 was that the comparisons were between-subjects, instead of within-subjects. Individual differences in task-switching performance could be a factor that affected the outcome. However, our participants were randomly assigned into the two difficulty conditions. Within each age group, comparisons between Difficult and Easy Conditions on the task-switching performance in the digit paradigm were conducted. The results suggested that the difference between the two conditions was not significant for either the young or older participants. Additionally, due to the difficulty of the task, minimising participant burden where possible is necessary for obtaining optimal performance (López-Rodriguez et al., 2025). A between-subject design could also effectively reduce the participant burden and fatigue by reducing task repetition (Charness et al., 2012). Lorist et al. (2000) and Plukaard et al. (2015) found that fatigue had a negative effect on task-switching performance. Taken together, the reduction in repetition of similar tasks could lead to collecting performance data with better quality and consistency (Gunawan et al., 2022).

4.9.1 Conclusions in Combination with Study 1

Both the letter and digit paradigms can capture switch costs measured by RT and

accuracy. However, cleaner results representing the cost of switching were found using the digit paradigm, as there were fewer confounding factors that are identified to influence the outcome measures of task-switching performance (e.g., stimuli difficulty).

As well, although the accuracy measure of the digit task was close to 100%, the mean accuracy for both age groups did not completely reach the ceiling of 100%, regardless of trial type (i.e., switch or no-switch trials). Hence, the digit task-switching paradigm was selected as the most appropriate measure for assessing in-laboratory task-switching performance. In Study 3, task-switching performance measured by the digit paradigm was used to answer the main research question of the study: Is there an association between current life complexity and task-switching performance?

4.10 Study 3: The Association Between Current Life Complexity and Task-Switching

In later-life, compensatory strategies have been found both in real life, and in laboratory studies. At the real-life level, Jarosz (2023) found that a reduced complexity of daily life was associated with increased age. At the in-lab level, Van Asselen and Ridderinkhof (2000) found that response speed was reduced to maintain performance accuracy in older adults, but not in young adults. To examine the potential use of compensatory strategies at the real-life level, investigating the potential reduction in life complexity becomes necessary. The Current Life Complexity Questionniare (CLCQ; See Chapter Two) was developed and initially validated, for the purpose of assessing current life complexity.

The aim of Study 3 was to investigate the relationship between current life complexity

and task-switching performance in young and older adults, and the potential age-related effects on the relationship between current life complexity and task-switching. In Study 3, we hypothesised that current life complexity is negatively related to the cost of switching (i.e., local-switch costs) as measured by RT and accuracy. Greater current life complexity would be related to smaller local-switch costs in RT and accuracy. More specifically, in older adults, the local-switch costs measured by both reaction time and accuracy will be significantly smaller in people with greater life complexity. The analysis was also exploratory, and intended to investigate potential compensation between reaction time and accuracy in task-switching performance, and between breadth and depth in current life complexity.

The potential covariates for the relationship between current life complexity and task-switching needs to be taken into consideration. Cognitive reserve, one of the factors that has an impact on the pattern of cognitive ageing, is also associated with task-switching performance (Moretti et al., 2018). The level of current physical activity has a well-established relationship with cognitive functioning including task-switching (Dai et al., 2013). Hence, cognitive reserve and current physical activity level are considered covariates in the current study when examining the relationship between current life complexity and task-switching performance.

To examine the potential use of compensatory strategies in the laboratory, the potential trade-off between RT and accuracy needs to be investigated. The Diffusion Decision Model (DDM; Ratcliff, 2014; Ratcliff & McKoon, 2008) is an analysis tool that translates the RT and accuracy performance of two-choice decisional responses into cognitively meaningful parameters. This model has been applied to analyse task-switching performances: more

specifically, the process of inhibiting interference from the old task, and updating information in preparation for the new task (e.g., Ging-Jehli & Ratcliff, 2020; Schmitz & Voss, 2014). This model separates task-switching performance into three components: drift rate, boundary separation, and non-decision time; taking into account RT and accuracy. Schmitz and Voss (2012, 2014) decomposed the underlying mechanisms of task-switching with parameters computed by the DDM. The drift rate is a representation of efficiency of information processing in task-switching, where the control mechanism is involved in resolving interference from the old task. The boundary separation is a representation of participants' cautiousness in giving responses. Larger boundary separation results in slower but more accurate responses. The non-decision time is a representation of task preparation in task-switching, in which the information related to task rules and required responses was updated for the new task. A typical cost of switching was represented by a decreased drift rate, and an increased non-decision time (Schmitz & Voss, 2014). Investigating the relationships between current life complexity and each of the DDM components enables the understanding of the potential associations between current life complexity and control mechanisms that underlie task-switching.

However, given the results obtained in Study 1 and Study 2, we may conclude that our participants had a relatively high accuracy when responding to the digit paradigm, with higher than 94% correct responses in young participants, and higher than 96% correct responses in older participants. This violated the pre-requisites of running the full DDM, which requires correct responses to be lower than 90% (Wagenmakers et al., 2007). The EZ-Diffusion Model (EZ-DM) approach developed by Wagenmakers et al. (2007) is capable of

handling data with high accuracy (see also Wagenmakers et al., 2008). Therefore, the EZ-DM instead of the full DDM was implemented in the current study.

4.11 Study 3: Methods

4.11.1 Participants

Study 3 used a sub-set of participants' data collected in Study 1 and 2, but focused on analysing the association between current life complexity and task-switching performance. Participants who did not complete the most updated version of the Current Life Complexity Questionnaire (CLCQ; $N = 10$) were excluded from the analysis. Within the total of 76 participants, there were 36 young participants (Age mean = 23.08, age *SD* = 5.44, age range = 18–40; 25 women, 9 men, 2 prefer not to say), and 40 older participants (Age mean = 71.35, age *SD* = 6.61, age range = 61–87; 23 women, 17 men).

4.11.2 Self-Report Instruments

4.11.2.1 Current Life Complexity

The Current Life Complexity Questionnaire (CLCQ) was used to measure participants' current life complexity. As described in Chapter Two, the CLCQ is comprised of 10 activity categories. Participants selected activities they were involved in over the past year, reported on involvement frequency, and estimated typical, minimum, and maximum daily durations using a visual analogue scale. The order of items was randomised to control for order effects. Current life complexity variables were calculated based on these results (see Appendix D for the scoring manual).

4.11.2.2 Cognitive Reserve and Physical Activities

The Cognitive Reserve Index questionnaire (CRIq; Nucci et al., 2012) was used to measure participants' cognitive reserve. The questionnaire was administered, and the scores were computed following the instructions provided on the questionnaire's website (Nucci et al., 2012, https://www.cognitivereserveindex.org/). A higher score is an indication of a higher level of cognitive reserve.

The short form of the International Physical Activity Questionnaire (IPAQ; questionnaire and the computation method provided by Craig et al., 2003) was used to measure participants' current physical activity level. Participants' responses were used to calculate the metabolic equivalent of the task (MET) following the weighting assigned by Craig et al. (2003). A higher score of MET is an indication of a higher level of current physical activity. Participants' scores on these two questionnaires were recorded and used as covariates in further analysis, to eliminate the influence of cognitive reserve and current physical activity level.

4.11.3 Analysis

The statistical analysis of task-switching followed similar steps as the statistical analysis in Study 1. All statistical analyses were conducted using R (version 4.3.2; R Core Team, 2023) and RStudio (version 2023.9.1.494; Posit Team, 2023). Bonferroni corrections were used for multiple hypotheses testing. Consistent with Study 1, non-independence within task-switching performance measures (RT, accuracy, drift rate, boundary separation, non-decision time) was also expected, but by convention this is not included in the alpha level adjustments.

Conservative Bonferroni correction, given previous use of some variables in Study 1 (but not Study 2), would set alpha to 0.017.

4.11.3.1 Scoring of the Current Life Complexity Questionnaire (CLCQ)

The scoring of the CLCQ resulted in six life complexity variables:

1. The composite complexity score (range between 0 and 136) is the sum of the number of activities selected in each category, plus the sum of the number of other activities reported in each category.
2. The breadth of involvement (range between 0 and 10) is the count of the number of categories with more than one activity selected and/or reported.
3. The depth of involvement (range between 0 and 365) is a direct report of the number of days/year a participant was involved in each activity category.
4. The variability of time of involvement (a positive continuous number) is the standard deviation of the number of days involved in the activities across 10 activity categories.
5. The concentration of activities (Gini Index, range between 0 and 1, Gastwirth, 1972) reflects how concentrated each participant's selections of activities are, across 10 activity categories.
6. The inclusiveness of the activities (range between 0 and 10) is based on 10 depth of involvement measures, adding them up and dividing them by 365.

More details of the scoring process can be found in the scoring manual presented in Appendix D.

4.11.3.2 Task-Switching Performance

In the current study, task-switching performance measured by the digit paradigm was selected, based on the results of Study 1 and Study 2. Local-switch costs measured by both RT and accuracy were used for the analyses. The local-switch costs were the mean differences (in RT and accuracy) between switch trials and no-switch trials.

EZ-DM was applied to the trial-based task-switching performance data. For each of the participants, three parameters (drift rate, boundary separation, and non-decision time) was computed based on R-codes provided in Wagenmaker et al. (2007) for no-switch trials and switch trials separately. Switch costs were calculated by subtracting the parameters of no-switch trials from the corresponding parameters from switch trials. In accordance with Study 1, linear mixed-effect models were used to test the significance of the effects of trial type (i.e., switch versus no-switch) on EZ-DM parameters, where trial type was the fixed effect, and the participant was the random effect (i.e., nested by participants). The model was fit using restricted maximum likelihood (REML).

4.11.3.3 Current Life Complexity and Task-Switching

Linear regression models were used to test the significance of the association between current life complexity and task-switching performance. Current life complexity was represented by the composite complexity score generated based on responses to the CLCQ. Task-switching performance was represented by the local-switch costs measured by RT, accuracy, drift rate, boundary separation, and non-decision time separately. Current physical activities and cognitive reserve scores were used as covariates.

4.12 Study 3: Results

4.12.1 Basic Demographics and Descriptives

4.12.1.1 Demographics

Of the young participants (N = 36), most held a senior high school degree (n = 16), an undergraduate degree (n = 14), a masters degree (n = 5), or a doctoral degree (n = 1). Twenty-two were monolingual, and the remaining 14 were bilingual or multilingual. The mean EHI handedness score was 67.61 (SD = 27.40, range = -30–100).

Of the older participants (N = 40), most held an undergraduate degree (n = 14), a masters degree (n = 10), other qualifications (n = 6; e.g., diploma), a senior high school degree (n = 5), a doctoral degree (n = 4), or a junior high school degree (n = 1). Most participants (n = 37) were monolingual, and the remaining 3 participants were bilingual or multilingual. The mean EHI handedness score was 77.43 (SD = 20.86, range = 30–100).

4.12.1.2 Task-Switching Performance

The task-switching performance of young and older participants for the digit paradigm are presented in Table 4.4, and Figure 4.8 Panel B and C. The mean local-switch costs measured by RT was smaller in young participants compared to older participants, although the difference was not significant (independent t-test results: $t(58.38) = 0.14$, $p = 0.89$). The range and variability were larger in young participants compared to older participants. In contrast with the RT measures, the mean local-switch costs measured by accuracy was larger in young participants compared to older participants, although the difference was not significant (independent t-test results: $t(63.94) = -1.15$, $p = 0.25$). The range and variability of

accuracy were also larger in young participants, compared to older participants.

4.12.1.3 CLCQ Scores

The composite complexity score was used as a representative measure of current life complexity. The descriptives of the composite complexity score are presented in Table 4.4. The mean composite complexity score was lower in young participants compared to older participants, although the difference was not significant (independent t-test results: $t(69.67) = 0.90$, $p = 0.370$). The range was smaller in young participants compared to older participants, where older participants had a lower minimum score than young participants. According to Figure 4.8 Panel A, the composite complexity score was normally distributed for young and older participants. Given the characteristics of the composite complexity score, linear regression models were used in consequent association analyses.

In addition, the breadth of involvement was close to ceiling for both young and older participants: 72.22% of young participants and 67.50% of older participants were involved in all 10 categories of activity.

Table 4.4

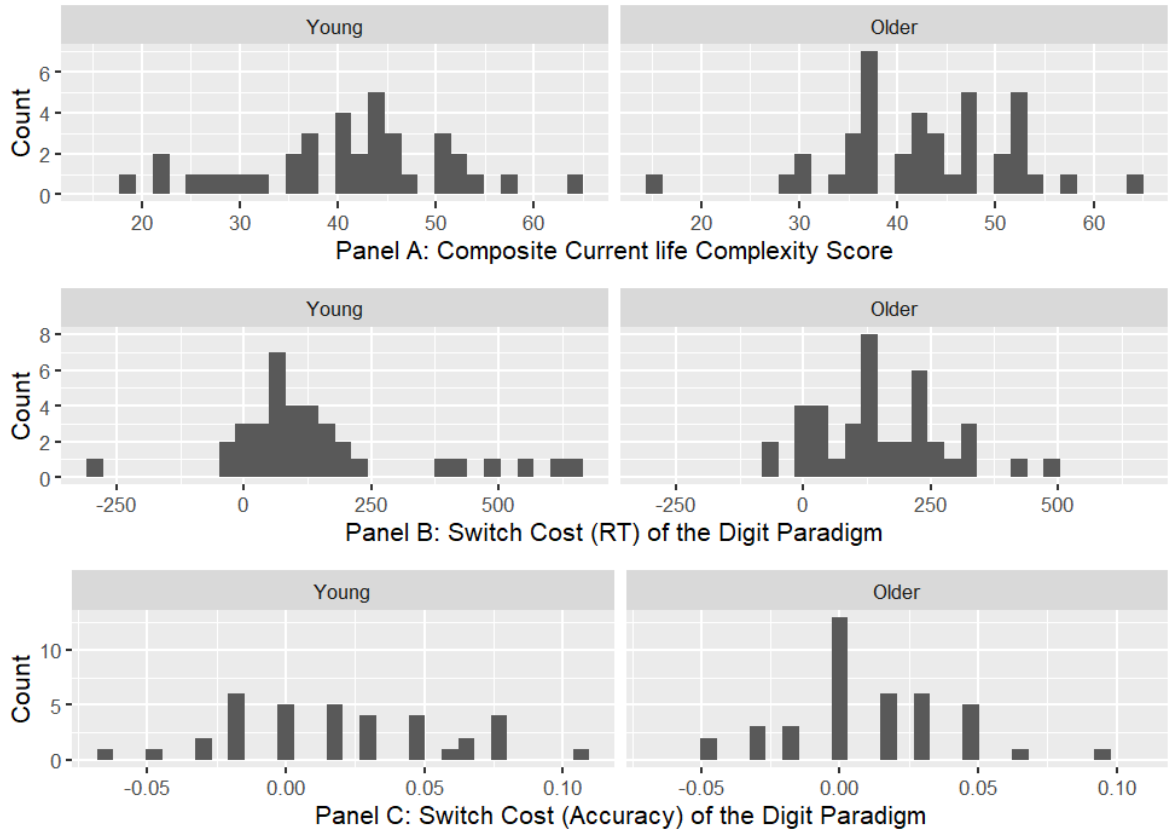
Descriptives of Current Life Complexity and Task-Switching Variables for Young (N = 36) and Older (N = 40) Participants

Age Group	Variable	*Mean (SD)*	*Range*
Young			
	Complexity	**40.81** (10.37)	[18, 65]
	Cost RT	**146.76** (196.07)	[-298.43, 645.80]
	Cost Accuracy	**0.02** (0.04)	[-0.06, 0.11]
Older			
	Complexity	**42.83** (8.98)	[16, 65]
	Cost RT	**151.96** (125.31)	[-74.47, 472.35]
	Cost Accuracy	**0.01** (0.03)	[-0.05, 0.09]

Note. Complexity = Composite Complexity Score. Cost RT = Local-Switch Costs measured by RT in the digit paradigm. Cost Accuracy = Local-Switch Costs measured by RT in the digit paradigm.

Figure 4.8

Distribution of Current Life Complexity and Task-Switching Variables for Young (N = 36) and Older (N = 40) Participants



Note. The local-switch costs were measured in the digit paradigm. The presented variables are normally, or close to normally distributed.

4.12.2 EZ-DM Parameters

Local-switch costs measured by EZ-DM parameters, including drift rate, boundary separation, and non-decision time, are presented in Table 4.5. The descriptives and distributions of these parameters are presented in Appendix I.4. In the process of implementing EZ-DM, the trial-based data of 1 young participant was missing, and 4 young participants were identified having theoretically impossible negative values for the non-

decision time parameter. Further investigation into the raw data and parameters suggested that high accuracy and large variance in RT was the potential cause of these invalid parameter estimations. These 5 young participants were then excluded from further analysis using the EZ-DM parameters.

4.12.2.1 Cost of Switching

Linear mixed-effects models were constructed to examine the effect of trial type on drift rate, boundary separation, and non-decision time separately. The main effects from the models are presented in Table 4.5. Both young and older participants had significantly larger non-decision time values for switch trials, compared to no-switch trials. Only older participants had significantly larger drift rate values for switch trials, compared to no-switch trials. The values of boundary separation were not significantly different between switch and no-switch trials, regardless of age groups.

Table 4.5

Descriptives of EZ-DM Parameters and Corresponding Task-Switching Performance for Young (N = 31) and Older (N = 40) Participants

Age Group	Variable	*Mean (SD) [Range]*	*Results of Analysis*
Young			
	Cost Drift	**-0.01** (0.03)	b = -0.01, SE = 0.01,
		[-0.08, 0.05]	$t(30)$ = -2.18, p = 0.038
	Cost Boundary	**-0.01** (0.05)	b = -0.01, SE = 0.01,
		[-0.14, 0.12]	$t(30)$ = -0.73, p = 0.47
	Cost Non-Decision	**0.11** (0.14)	b = 0.11, SE = 0.02,
		[-0.22, 0.42]	$t(30)$ = 4.56, p < 0.001*
Older			
	Cost Drift	**-0.02** (0.04)	b =-0.02, SE = 0.01,
		[-0.15, 0.09]	$t(39)$ = -2.61, p = 0.013*
	Cost Boundary	**-0.01** (0.07)	b = -0.01, SE = 0.01,
		[-0.14, 0.19]	$t(39)$ = -0.57, p = 0.57
	Cost Non-Decision	**0.13** (0.20)	b = 0.13, SE = 0.03,
		[-0.54, 0.61]	$t(39)$ = 4.16, p < 0.001*

Note. Results of Analysis = The main effect of trial type (no-switch versus switch) in corresponding linear mixed-effects models. Cost Drift = Local-Switch Costs measured by drift rate in the digit paradigm. Cost Boundary = Local-Switch Costs measured by boundary separation in the digit paradigm. Cost Non-Decision = Local-Switch Costs measured by non-decision time in the digit paradigm. * = significant under the alpha value corrected for multiple comparisons (<0.017).

4.12.3 Association Between Current Life Complexity and Task-Switching

4.12.3.1 Task-Switching Measured by RT and Accuracy

For young participants, the linear regression model revealed that there was no significant association between current life complexity (as measured by the composite complexity score) and task-switching performance (as measured by local-switch costs in RT, Figure 4.9 Panel A), b = -3.73, SE = 3.18, $t(34)$ = -1.18, p = 0.25, 98.3% CI [–11.45, 3.99]. The model accounted for a small proportion of variance in task-switching performance measured by RT (R^2 = 0.04), $F(1, 34)$ = 1.38, p = 0.25, indicating there was not sufficient evidence for a relationship between current life complexity and task-switching performance as measured by RT in our young participants.

The same model was constructed for local-switch costs measured by accuracy (Figure 4.9 Panel B). There was no significant association between current life complexity and task-switching performance, b = 0.00063, SE = 0.00065, $t(34)$ = 0.97, p = 0.34, 98.3% CI [-0.00095, 0.0022]. The model accounted for a small proportion of variance in task-switching performance measured by accuracy (R^2 = 0.03), $F(1, 34)$ = 0.93, p = 0.34, indicating there was not sufficient evidence for a relationship between current life complexity and task-switching performance as measured by accuracy in young participants.

For older participants, the linear model revealed that there was no significant association between current life complexity (as measured by the composite complexity score) and task-switching performance (as measured by local-switch costs in RT, Figure 4.9 Panel A), b = -0.34, SE = 2.26, $t(38)$ = -0.15, p = 0.88, 98.3% CI [-6.01, 5.33]. The model accounted for a very small proportion of variance in task-switching performance measured by RT ($R^2 < 0.01$),

$F(1, 38) = 0.02$, $p = 0.88$, indicating there was not sufficient evidence for a relationship between current life complexity and task-switching performance measured by RT in older participants.

The same model was constructed for local-switch costs measured by accuracy (Figure 4.9 Panel B). There was no significant association between current life complexity and task-switching performance, $b = 0.0010$, $SE = 0.00051$, $t(38) = -1.93$, $p = 0.061$, 98.3% CI [-0.00028, 0.0023]. The model accounted for a small proportion of variance in task-switching performance measured by accuracy ($R^2 = 0.09$), $F(1, 38) = 3.74$, $p = 0.061$, indicating there was only a trend-level relationship between current life complexity and task-switching performance measured by accuracy in older participants.

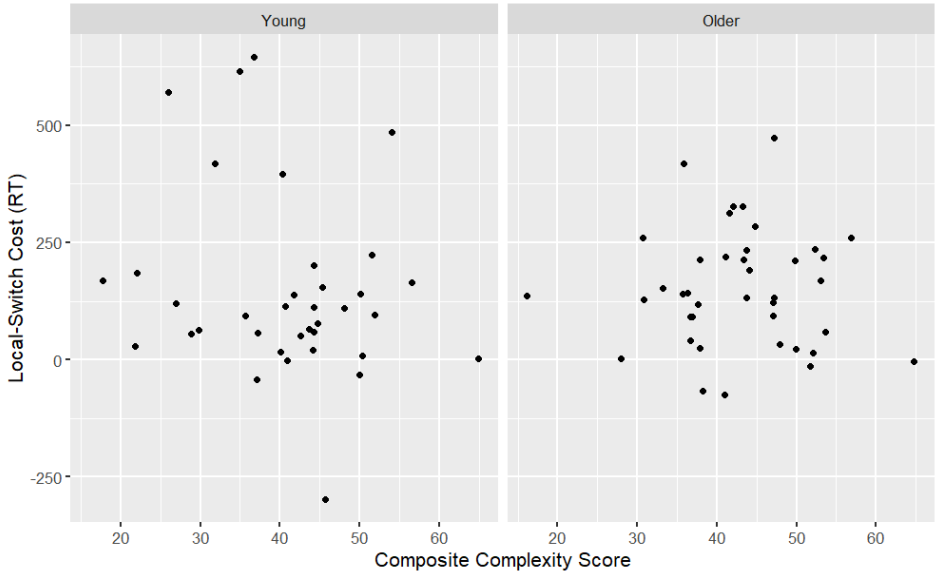
In summary, the composite complexity scores consistently explained less than 10% of the variance in switch costs, regardless of how they were measured. The composite complexity scores explained less than 1% variability in local switch costs measured by RT in older adults. However, given that the statistical model's assumptions were satisfied, it may be more likely that these results reflect that the composite complexity score was an ineffective predictor of switch costs in our sample of participants. Based on the results, only the simplest model was constructed for the analysis, further analysis did not proceed.

To confirm the role of covariates, the correlation between the current life complexity composite score and the cognitive reserve score was 0.15, and the correlation between the current life complexity composite score and the standardised physical activity score was 0.07. This finding of low magnitude associations was consistent with the lack of significant results found by the main analyses.

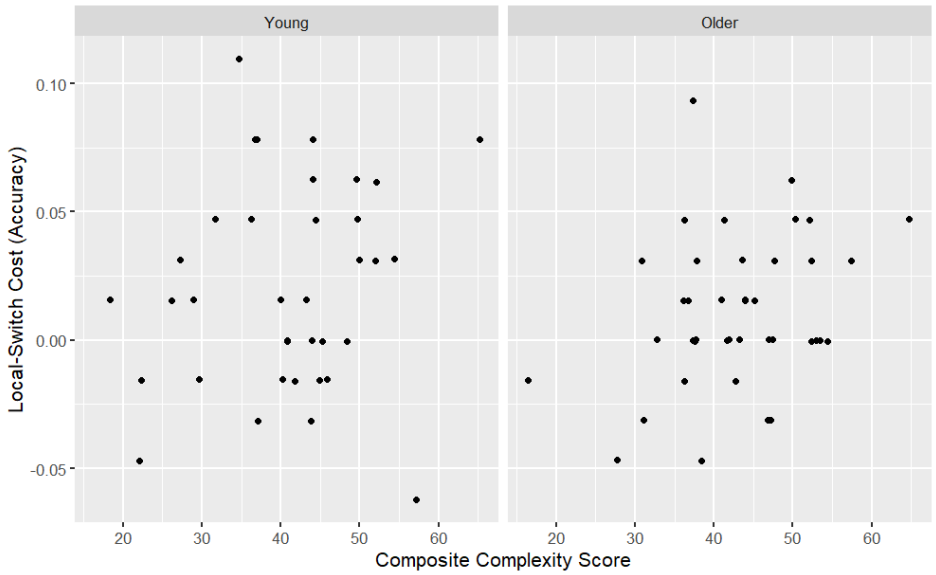
Figure 4.9

Association Between Current Life Complexity and Task-Switching Performance (Measured by RT and Accuracy) for Young (N = 36) and Older (N = 40) Participants

Panel A: RT



Panel B: Accuracy



Note. RT = Reaction time (ms). The switch costs were local-switch costs measures from the digit paradigm. No clear associations between the composite complexity score and local-switch costs measured by RT and accuracy can be observed in the present figure.

4.12.4 Task-Switching Measured by EZ-DM Parameters

The same linear regression models were constructed with EZ-DM parameters. For young participants, the linear regression model was constructed to examine the association between current life complexity and local-switch costs measured by drift rate. The results indicated that current life complexity was not significantly associated with drift rate, b = -0.00055, SE = 0.00052, $t(29)$ = -1.06, p = 0.30, 98.3% CI [-0.0019, 0.00075]. The model accounted for a small proportion of the variance in drift rate differences (R^2 = 0.037), $F(1, 29)$ = 1.12, p = 0.30.

The same model was constructed to examine the association between current life complexity and local-switch costs measured by boundary separation. The results indicated that current life complexity was not significantly associated with boundary separation, b = -0.0014, SE = 0.00091, $t(29)$ = -1.52, p = 0.14, 98.3% CI [-0.0037, 0.00089]. The model accounted for a small proportion of variance in boundary separation differences (R^2 = 0.074), $F(1, 29)$ = 2.31, p = 0.14.

The same model was also constructed to examine the association between current life complexity and local-switch costs measured by non-decision time. The results indicated that current life complexity was not significantly associated with non-decision time, b = 0.0014, SE = 0.0024, $t(29)$ = 0.58, p = 0.56, 98.3% CI [-0.0046, 0.0074]. The model accounted for a small proportion of the variance in non-decision time differences (R^2 = 0.012), $F(1, 29)$ = 0.34, p = 0.56.

For older participants, the linear regression model was constructed to examine the relationship between current life complexity and local-switch costs measured by drift rate.

The results revealed that current life complexity was not significantly associated with drift rate, b = -0.00059, SE = 0.00078, $t(38)$ = -0.76, p = 0.45, 98.3% CI [-0.0025, 0.0013]. The model accounted for a small proportion of the variance in local-switch costs measured by drift rate (R^2 = 0.015), $F(1, 38)$ = 0.58, p = 0.45.

The same model was constructed to examine the association between current life complexity and local-switch costs measured by boundary separation. The results revealed that current life complexity was also not significantly associated with boundary separation, b = -0.0016, SE = 0.0012, $t(38)$ = -1.29, p = 0.21, 98.3% CI [-0.0046, 0.0014]. The model accounted for a small proportion of the variance in local-switch costs measured by boundary separation (R^2 = 0.042), $F(1, 38)$ = 1.66, p = 0.21.

The same model was constructed to examine the association between current life complexity and local-switch costs measured by non-decision time. The results revealed that current life complexity was also not significantly associated with non-decision time, b = 0.0024, SE = 0.0037, $t(38)$ = 0.65, p = 0.52, 98.3% CI [-0.0067, 0.012]. The model accounted for a small proportion of the variance in local-switch costs measured by non-decision time (R^2 = 0.011), $F(1, 38)$ = 0.43, p = 0.52.

In summary, the results of the associations between current life complexity and task-switching performance, when performance was measured by EZ-DM parameters, were consistent with results of the associations when performance was measured by RT and accuracy. The correlations between other current life complexity variables and task-switching performance are presented in Appendix I.5. Based on the results, only the simplest model was

constructed for the analysis. No further analyses were conducted due to the lack of significant associations between current life complexity and task-switching performance.

4.13 Study 3: Discussion

The aim of Study 3 was to investigate the relationship between task-switching performance and cognitive lifestyle complexity in young and older adults. Contrary to our predictions, the results indicated that the association between current life complexity and task-switching performance were not significant in either young or older participants. Both the conventional RT and accuracy measures of performance, and the EZ-DM parameters confirmed these findings of non-significance. This is consistent with findings of a relationship between engagement within individual activity categories and the general level of cognition in older adults (Weaver & Jaeggi, 2021). However, it contrasts with the findings of Mueller et al. (2013), which suggest there is a significant association between activity engagement and executive functioning. Following are several interpretations that may explain the pattern of results we obtained.

4.13.1 Small Effect of the Lifestyle Factor

One interpretation is that less than 10% of the variances can be explained by the model, which suggests that if the association between current life complexity and task-switching exists, this would likely be a small effect. The effect size was consistent with Mueller et al. (2013)'s study on activity engagement and executive functioning, and Weaver and Jaeggi (2021)'s study on activity engagement and general cognitive function in older adults, with

around 10% to 20% of the variance explained by their final analysis model. Hence, a larger sample size would be ideal (Linden et al., 2024). However, the current study was a first attempt to associate the real-life measure of current life complexity with the in-laboratory measure of task-switching performance, and thus started with a relatively small sample of participants.

4.13.2 No Association at the Current Stage

Another interpretation could be that there is no association between current life complexity and task-switching in young and older participants. However, this would contradict previous research that has supported an association between a more cognitively-demanding lifestyle and better performance in cognitive functions in older adults (e.g., Hultsch et al., 1999). Conflicting results suggesting a dominant effect of age and education were also found in studies investigating the association between activity engagement and cognitive functions in older adults (Weaver & Jaeggi, 2021). To investigate this further, a longitudinal study could be conducted to obtain information of age-related changes in the measure of current life complexity, and how these changes could relate to task-switching performance in later-life.

4.13.3 Well-Performing Participants

Another interpretation is that because our older participants were highly educated and well-performing, the association cannot be observed at the current stage, due to the highly-educated and active nature of our sample of older Canberrans (e.g., cohort profile reported by

Anstey et al., 2012). This was supported by the fact that our older participants had a mean composite complexity score approximately 10 points higher than the norms obtained from a larger Australian population (See Chapter Three). Due to compensatory mechanisms, it is reasonable to expect that before the onset of severe cognitive decline, individuals can maintain effective daily functioning (such as current life complexity) regardless of their cognitive performance (such as task-switching performance). Further investigations could be conducted by measuring current life complexity in less well-performing and/or pathology-affected samples. The obtained results could be compared with the results of the current study to develop further understanding of the relationship between current life complexity and task-switching.

4.13.4 Insights Provided by EZ-DM Parameters

Additional insights can be obtained by investigating the results based on EZ-DM parameters. In older participants, the cost of task-switching resulted in significantly decreased drift rate and significantly increased non-decision time. This is consistent with findings reported by Schmitz and Voss (2014) and Ging-Jehli and Ratcliff (2020). Based on the theoretical interpretation of the parameters (Schmitz & Voss, 2012, 2014), this result can be explained as the cost of task-switching originating both from inhibiting the old task and activating the new task in our older participants. In young participants, the cost of switching mainly came from activating the new task. No significant changes in the trade-off between RT and accuracy (i.e., boundary separation) were found for both groups of participants. These insights provided by EZ-DM parameters were consistent with a lack of real-life based

compensation as reflected by current life complexity variables extracted from the CLCQ, where the breadth of involvement was close to ceiling for both young and older participants.

4.14 General Discussion

Understanding the relationship between cognitive lifestyle and task-switching performance in young and older adults—particularly in relation to the model of selective optimisation with compensation—has meaningful implications for early detection of decline in cognitive functional ability in later-life and to promote healthy ageing. Study 1 aimed to identify the most suitable task-switching paradigm for reliably measuring performance across young and older adults. The findings indicated that the digit paradigm offered a more consistent and direct assessment of task-switching function across age groups. Although the overall accuracy level was high, switch cost measured by accuracy did not reflect a ceiling effect. However, given the reported difficulty associated with the letter paradigm, further investigation was conducted to clarify the influence of stimulus difficulty on performance. Study 2 examined whether an easier version of the letter paradigm could better capture task-switching abilities in both young and older adults, compared to the difficult version of the letter paradigm. Although participants performed faster and more accurately with the easier version, the difference between easy and difficult conditions was not statistically significant for either RT or accuracy. Consequently, Study 3 explored the relationship between current life complexity and task-switching performance using the digit paradigm. No significant associations were found between current life complexity and task-switching outcomes in either age group.

We did not find a significant difference in task switching performance between digit or letter base-tasks. This is partly consistent with the body of research showing similar conclusions on task-switching performance across task-switching paradigms with different base-tasks (See the systematic review reported in Chapter Three). Although the use of different variations of base-tasks in the task-switching paradigm reflect a consistent group-level pattern distinction in reported effect-sizes, most variations of task-switching paradigms result in convergent findings, which suggest that the costs of switching were significant (Chapter Three). The results of Study 1 provided additional evidence that supported the successful assessment of the common construct (i.e., task-switching function) underlying varieties of task-switching paradigms, by directly comparing two task-switching paradigms with different base-tasks.

Similarly, we did not find a significant difference between task-switching paradigms with different levels of difficulty in letter stimuli (i.e., difficult letter stimuli and easy letter stimuli). This is inconsistent with the body of research suggesting that task difficulty would increase the cost of switching (e.g., Ravizza & Carter, 2008). Combining these results with findings from our systematic review that investigated the effect of paradigm manipulations (Chapter Three), we posit two possible explanations. The systematic review identified a great level of variability in task-switching paradigms. The first explanation may be related to this variability in the paradigm. The effect of task difficulty found in task-switching studies consisting of letter-selection and shape-selection tasks (Ravizza & Carter, 2008), might not be generalisable to the task-switching paradigm consisting of letter-categorisation and luminance-discrimination tasks, which were used in the current study. The variations between

task-switching studies could disproportionately impact older participants, compared with young participants, and/or obscure findings due to ceiling effects, introduced by low difficulty in base-tasks (Ging-Jehli & Ratcliff, 2020). However, this explanation alone is less likely to provide a comprehensive account of the non-significant outcome in light of the findings from Study 1.

As the second explanation, the inconsistency between current findings and the literature might also be explained by the asymmetry of task difficulty in the current design of the letter paradigm (e.g., Schneider & Anderson, 2010). More specifically, the letter-categorisation task is harder than the luminance-discrimination task, because the former requires recognition or letter identity, which is a higher and more demanding level of information processing compared to the requirement of recognition of luminance level (e.g., Pernet et al., 2005). This asymmetry of difficulty can obscure findings by creating different levels of required cognitive effort in switching (Allport et al., 1994). In addition to the impact generated by the variations in task-switching paradigms, this asymmetry of task difficulty may also disproportionately impact older participants compared to young participants. Further investigations controlling for task difficulty between two base-tasks would be needed for generating a deeper understanding of the effect of stimulus difficulty in the letter paradigm.

The experimental studies did not find sufficient evidence supporting a link between current life complexity and task-switching measured by RT and accuracy. This non-significant finding was further supported by the results of analyses examining the association between current life complexity and task-switching performance as measured by EZ-Diffusion Model parameters. We posit four possible explanations.

The first possible explanation is that our participants, especially our older participants, have a relatively active current life and are high performing in cognitive functioning. Although the composite complexity score reflected variations in our participants' selection of current life complexity, their breadth of involvement was close to ceiling level. As captured by the CLCQ, 72% of the young participants and 68% of the older participants engaged in all ten (i.e., the maximum) activity categories. This sample characteristic is the result of the intentional selection of healthy participants. This may result in them either not yet experiencing a decline in cognitive ageing, or being able to use compensatory strategies even in the face of decline. A previous functional magnetic resonance imaging (fMRI) study found reduced efficiency and successful compensation in the prefrontal cortex while healthy older participants were responding to a task-switching paradigm (Hakun et al., 2015). In their study, the task-switching performance was not significantly different between young and older adults, indicating that compensation may have already occurred at the neurological level, before the age-related behavioural changes in the laboratory setting (i.e., task-switching) would be observed. However, due to the nature of cross-sectional studies, which reduces the possibility of detecting time-related changes, compensation is not detectable in the CLCQ composite complexity score at the current stage and/or in the current design. The investigation of this association in healthy participants is an important first step to build a basis for further investigation of this association in participants who experience age-related pathology and/or changes of current life complexity over time. Future studies could also consider utilising other extracted variables, for instance breadth of involvement, depth of involvement, concentration, or inclusiveness of activities (see Chapter Two) to capture the

compensation reflected by the involvement in daily activities.

The second possible explanation is based on the multi-dimensional nature of the investigated concepts. It is possible that task-switching alone may not be sufficient to be strongly associated with an individual's choice in maintaining their current life complexity. Findings from the wider literature regarding daily activities may be useful in broadening future enquiry. In previous literature, daily activity engagement has been associated with: language and memory (Sposito et al., 2015); a slower decline in memory over time (Armstrong et al., 2022); physical activeness (Amaral Gomes et al., 2021); and abstraction and task-switching (Mueller et al., 2013). Furthermore, cognitive processing, when represented by the function of task-switching, can also be considered an interplay between inhibiting old tasks and updating new tasks (Kiesel et al., 2010), which may also be an important factor. Other studies have investigated associations between engagement in daily activities and other domains of cognition, including fluid intelligence (consisting of processing speed and task-switching; Bielak et al., 2019) and working memory, episodic memory, and processing speed (Weaver & Jaeggi, 2021). Weaver and Jaeggi suggested that prior education, rather than engagement in current daily activities, is more closely related to general cognitive ability in older adults. This aligns with the assumptions of the effects of cognitive reserve (Barulli & Stern, 2013), which also needs to be taken into account when considering the multi-dimensional structure of the relationship between lifestyle and cognitive function.

The third possible explanation for the lack of a significant association between current life complexity and task-switching was that there are fundamental differences between the

concept of current life complexity assessed by the CLCQ and other validated measures of activity engagement or activity lifestyle. The concept of current life complexity is distinct from cognitive reserve (e.g., operationalised as educational level as in Hindle et al. (2014) and Seblova et al. (2020)), as cognitive reserve is a measure of past cognitive history, and current life complexity is a measure of current cognitive experience. The concept of current life complexity is also distinct from the traditional activity engagement measurements (e.g., Hultsch et al., 1999), as it intends to capture the complexity aspect of current lifestyle. In its relationship with cognitive ageing, the important element that was assumed to be responsible for changing cognitive performance is the compensatory mechanism underlying the changes of complexity over time. Hence, to observe its effect, it is ideal to conduct longitudinal studies (e.g., Hughes et al., 2018) or to examine purposive samples of participants (e.g., a sample with MCI).

It is also possible that small sample size resulted in a reduction of the variability in participants' responses, making the study under-powered to detect the existing effects. We ran power analyses before conducting the present study, and found that similar types of cognitive studies also had a similar sample size. However, there was still the possibility that the effect sizes we used in the power analyses was overestimated. Campbell and Cullen (2023) found similar phenomenon when attempted to estimate effect sizes of physical activity on influencing cognitive functions. Whether our current non-significant findings reflect the reality of the association, or the result of under-powered studies, needs further investigation. This can be disambiguated by conducting a similar study with a larger sample size, or by testing older samples or pre-clinical samples.

In conclusion, while we did not find evidence to support an association between task-switching performance and cognitive life complexity, we have built a foundation for future research to take a multi-dimensional approach: the association and interaction between lifestyle factors and the association and interaction between cognitive functions.

Chapter Five

General Discussion

Chapter Five: General Discussion

This thesis developed the concept of current life complexity, and investigated its relationship with task-switching function in the context of cognitive ageing in healthy adults. Successful ageing, that is maximising cognitive ability and maintaining engagement in an active life, can be promoted through preventative practices and interventions (Daffner, 2010). Because of the current lack of treatment to reverse the decline in functional ability, targeting of modifiable factors becomes essential (Barnett et al., 2015). One such factor is cognitive lifestyle. The benefits of an engaged, varied cognitive lifestyle are explained by theoretical frameworks, for instance: the STAC model (Reuter-Lorenz & Park, 2014) and the Enrichment Effect Model (Hertzog et al., 2008), both of which posit that a cognitively engaged lifestyle preserves brain structure and scaffolds compensatory mechanisms in ageing. These theories are supported by empirical studies where concepts similar to cognitive lifestyle have been conceptualised as: cognitive reserve (e.g., Garcia-Gorro et al., 2019); instrumental activities of daily living (e.g., Vaughan & Giovanello, 2010); naturalistic multi-tasking (e.g., McAlister & Schmitter-Edgecombe, 2013); and activity engagement (e.g., Bielak et al., 2019; Carlson et al., 2012). Activity engagement focuses on cognitive enhancement which is introduced by engaging in multiple daily activities (see Bielak & Gow, 2023, for an updated review). Activity engagement can be operationalised in many ways (Bielak, 2010); however, at the time of writing, there is not a single agreed-upon measure of this concept. In this thesis, we refined the focus of cognitive lifestyle, more specifically activity engagement, with an approach drawn from the model of selective optimisation with compensation (Baltes & Baltes, 1993). Under the context of cognitive ageing, a person's level

of investment across categories of activities can reflect the extent of their available cognitive resources, the efficiency of their compensatory mechanisms, and their current state of cognitive functional ability. In other words, individuals' capacity to adapt to age-related changes in daily life. This "level of investment" was conceptualised as current life complexity, and defined as the level of engagement in everyday activities during daily life that require individuals to invest cognitive resources. Stemming from the shared behavioural component of "adapt to changes" (Diamond, 2013; Friedman & Robbins, 2022; Lezak et al., 2012), task-switching function was selected as a more well-established in-laboratory anchoring point for assessing real-life current life complexity.

The primary aim of the thesis was to investigate the relationship between current life complexity and task-switching function in young and older adults. The outcomes of the research contribute to the investigation into the relationship between cognitive enhancement introduced by everyday experiences and task-switching in the context of age-related changes in functional ability—cognitive ageing. The thesis also associated the real-world (i.e., current life complexity) with the in-laboratory (i.e., task-switching function) levels of functional ability in cognitive ageing. The methodological approach of the thesis emphasises the need to understand how psychological instruments evolve over time, and the need to address the experience-based participant's feedback appropriately—both in terms of self-report questionnaires and in-laboratory experimental paradigms. Participants' and researchers' genuine consensus of survey questions (e.g., Allen et al., 2023) and experimental instructions (e.g., Bartolo et al., 2020) is an important factor that contributes to measurement that captures the construct it is intended to assess, and produced good quality data.

Chapter One introduced and reviewed the theoretical framework and understanding underlying the concepts of current life complexity and task-switching, and developed the theoretical connections between these two concepts. Chapters Two, Three and Four, took two different routes toward examining the most suitable instruments to measure current life complexity (Chapter Two) and task-switching (Chapter Three, and Study 1 and 2 in Chapter Four). Chapter Two reported a literature review and online survey studies that selected, developed, and validated a new questionnaire to measure current life complexity. Chapter Three was a systematic review that presented an evaluation of task-switching paradigm manipulations, with a focus on base-tasks and switch-rules. Based on the conclusions from the systematic review, Studies 1 and 2 in Chapter Four investigated experimentally the comparisons of digit and letter paradigms with different stimulus difficulty. The purpose of these comparisons was to select the most appropriate task-switching paradigm to assess task-switching in both young and older adults. Gathering all the evidence from previous investigations in the thesis, Study 3 in Chapter Four examined the association between current life complexity and task-switching in young and older adults. The current Chapter provides an overview and synthesis of these findings, and discusses the possible theoretical and practical implications of the research reported in the thesis. Strengths and limitations are considered. Finally, key conclusions are drawn, which serve as the basis of potential directions for future investigation.

5.1 Overview of Findings

Before examining the relationship between current life complexity and task-switching, it is important to be clear about how current life complexity and task-switching are measured. The concept of current life complexity is introduced in this thesis. Because of the distinctive focus on breadth and depth, the possibility that existing measures for related concepts may be suitable for assessing current life complexity was investigated. The instruments reviewed were as follows: Cognitive Reserve Questionnaire (e.g., Garcia-Gorro et al., 2019), Instrumental Activities of Daily Living (IADL; e.g., Vaughan & Giovanello, 2010), naturalistic day-out task (e.g., McAlister & Schmitter-Edgecombe, 2013), daily time-use record (e.g., Jarosz, 2023), Florida Cognitive Activity Scale (FCAS; Schinka et al., 2005), Activities Characteristics Questionnaire (ACQ; Bielak, 2017), Lifestyle Activity Questionnaire (LAQ; Carlson et al., 2012) and Victoria Longitudinal Study Activity Lifestyle Questionnaire (VLS-ALQ; e.g., Hultsch et al., 1999). Accordingly, a literature review and online studies were conducted to select, develop and evaluate the most suitable instrument to assess the concept. Due to the shared underlying compensatory mechanisms in limited cognitive resources, current life complexity is hypothesised to be associated with the efficiency of cognitive control. Task switching—the ability to alternate between tasks—was selected as an in-laboratory measure of cognitive control. The first paradigm for measuring task-switching was developed in 1927 (Jersild, 1927), and has since been associated with bilingualism (de Bruin et al., 2015a), current physical activity level (Dai et al., 2013), and instrumental activities of daily living (Vaughan & Giovanello, 2010). In this time, there has been variation in aspects of the paradigm considered central to the interpretation of cognitive

testing, such as cueing (Gaál & Czigler, 2015), preparation time (Kunimi et al., 2016) and stimulus characteristics (Kray & Eppinger, 2006). To select an appropriate measure of task-switching, it is important to examine the potential impact that paradigm variability may have on findings relating to task-switching performance in ageing. The thesis began with parallel explorations of the measurement of concepts similar to current life complexity, and the measurement of task-switching in ageing, in order to select the most appropriate instruments to capture these two concepts.

5.1.1 Current Life Complexity

This thesis developed the concept of current life complexity, which is defined as the level of engagement in everyday activities during daily life that require individuals to invest cognitive resources. The concept is developed as a measure that approaches cognitive lifestyle from the perspective of conceptualising the underlying cognitive complexity, created by engaging in multiple different daily routines. There are a number of cognitive lifestyle concepts that are similar to current life complexity, such as: cognitive reserve (e.g., Garcia-Gorro et al., 2019); instrumental activities of daily living (e.g., Vaughan & Giovanello, 2010); naturalistic multi-tasking (e.g., McAlister & Schmitter-Edgecombe, 2013); and activity engagement (e.g., Bielak et al., 2019; Carlson et al., 2012). However, the concept of current life complexity focuses on the collective contribution of different cognitive aspects of lifestyle, which is distinct from the traditional reductionist approach of investigating cognitive lifestyle, which has the tendency to focus on the effect of engaging in a short list of cognitively-demanding daily activities (e.g., reading). The novelty of current life complexity

is introduced by its ability to capture a dynamic interaction of breadth, depth and variabilities of engagement, and thus sensitivity to potential real-life level compensation. The principle of this collective investigation aligns with the holistic approach that is frequently applied in the field of cognitive ageing (e.g., Dryjanska et al., 2017; Fahey, 2020), and successful ageing (e.g., Estebsari et al., 2020) as there are multiple mutually influential factors that all contribute to result in the outcome of cognitive ageing.

In Chapter Two, the literature on cognitive lifestyle concepts was reviewed to identify pre-existing measurements that may be appropriate for assessing current life complexity, and the advantages and disadvantages were evaluated. The measurement of cognitive reserve (e.g., Garcia-Gorro et al., 2019) had an emphasis on historical experience, instead of current experience, as addressed by current life complexity. The IADL was a measurement of instrumental competence, with a focus on relatively demanding daily activities (e.g., Vaughan & Giovanello, 2010); however, it was not a measurement of long-term living patterns. The naturalistic day-out task provided a direct observation of everyday activities (e.g., McAlister & Schmitter-Edgecombe, 2013), but it was also an intensive test of current performance, lacking the aspect of long-term patterns of activity engagement. The time-use record was a direct record of daily routine (e.g., Jarosz, 2023), which was appropriate in capturing current life complexity; however, this came with the cost of high participant and financial burden, and lack of scalability to a large sample size. The FCAS was an attempt to quantify the simulation provided by everyday activity engagement (e.g., Schinka et al., 2005), with a focus on the most cognitively-demanding activities, but not with the complexity aspect of activity engagement. The ACQ had an intense focus on the activity pattern in the past day

(Bielak, 2017), which was opposite to the long-term patterns and daily involvement in activities needed to assess current life complexity. The LAQ provided a scoring approach that took into account both the variety and frequency of activity engagement, but focused on a limited number of activities (Carlson et al., 2012).

The VLS-ALQ was an activity lifestyle measurement that captured the engagement in cognitively-demanding activities, and the frequency of involvement with a comprehensive list of daily activities (Hultsch et al., 1999). The VLS-ALQ has undergone substantial modification over time (e.g., Jopp & Hertzog, 2010; Marr et al., 2021). After comparing the advantages and disadvantages of the relevant pre-existing instruments under the context of measuring current life complexity, the VLS-ALQ (Hultsch et al., 1999) was selected. Pilot testing revealed that administering VLS-ALQ with participants in a face-to-face setting was feasible, but participants experienced difficulty with understanding and responding to the questions. In self-report questionnaires, participants' accurate understanding of questions was related to increased engagement with the questions (Kemper et al., 2020), and better data quality (Allen et al., 2023). To more accurately capture the concept of current life complexity, a more participant-friendly modification of the VLS-ALQ was required.

Based on the conclusions of the literature review and our pilot study, online survey studies were conducted to develop and validate the Current Life Complexity Questionnaire (CLCQ; modified based on the items from the VLS-ALQ). The results of the online survey studies indicated that meaningful variables of the composite complexity score, breadth of involvement, depth of involvement, concentration of activities, and inclusiveness of activities could be extracted from the responses to the CLCQ. The development and initial validation

of the CLCQ provided a basis for investigating a novel aspect of cognitive lifestyle, current life complexity, in relation to task-switching. The CLCQ can be subject to further validation with various samples. The development of the CLCQ in the current thesis provided a productive approach that could be directly applied in larger scale longitudinal or cohort studies (e.g., Alzheimer's Disease Neuroimaging Initiative, ADNI; Petersen et al., 2010).

5.1.2 Task-Switching in Ageing

While it is clear that the task-switching paradigm originally proposed by Jersild (1927) has evolved over time, to date there has been no comprehensive overview of how the paradigm has varied, and the impact of these variations on the meaning of findings. For the purpose of the thesis, it was important to understand what was tested comprehensively, and what was the most suitable design to capture task-switching function in young and older populations. In Chapter Three, a systematic review was conducted to capture research that has applied the task-switching paradigm in healthy older adults. The purpose of the systematic review was to investigate with the emphasis on comparing the potential implications of different task-switching paradigm manipulations on task-switching outcomes in ageing. The systematic review revealed that base-tasks and switch-rules were the major variation made on the task-switching paradigms. To the best of our knowledge, the impact of these variations on task-switching performance was not directly evaluated in older adults. Among the reviewed studies, the digit tasks were the most commonly used base-task, and the word-cued switching was the most commonly used switch-rule. The selection of base-tasks and switch-rules influenced the magnitude of the effects introduced by task-switching on

reaction time and/or accuracy.

An important observation from the systematic review was that ceiling effects play a role in reducing switch-costs when the base-task was lacking in difficulty, so that the performance accuracy reached 95%–100%. Due to the nature of the paradigm design, the studies reviewed were less likely to report switch costs measured by accuracy. This observation was consistent with the meta-analyses of task-switching performance reported by Chen and Hsieh (2023) and Wasylyshyn et al. (2011) in older adults. However, their focus was not on paradigm manipulation. The importance of recognising and addressing ceiling level of accuracy was also discussed in Ging-Jehli and Ratcliff (2020). The investigation of how paradigm differences may change performance accuracy is especially crucial, because it impacts the ability to detect the compensatory trade-off between speed and accuracy noted in older adults by Van Asselen and Ridderinkhof (2000). The systematic review in the current thesis evaluated task-switching performance of young and older adults by grouping reviewed studies with their base-tasks and switch-rules. This systematic review informed the paradigm selection of the experimental study in Chapter Four.

The purpose of Study 1 and Study 2 in Chapter Four was to extend what was observed in the systematic review by experimentally evaluating different task-switching paradigms. This evaluation consisted of two studies, undertaken to determine and select the most suitable task-switching paradigms used to measure task-switching performance in young and older adults more efficiently. Study 1 of Chapter Four compared the results between the digit paradigm and the letter paradigm, with a focus on switch cost magnitude and possible ceiling effects. This involved the development and evaluation of a modification of the letter

paradigm used in Ging-Jehli and Ratcliff (2020), selected as a paradigm that was anticipated to be more difficult, thus being more suitable to address potential ceiling effects in switch costs measured by accuracy. This paradigm consisted of a letter-categorisation task and a luminance-discrimination task. The comparison was conducted within-subjects, between the task-switching performance for the letter paradigm and the more commonly used digit paradigm. The digit paradigm was a modification of the digit paradigm used in Dai et al. (2013). It consisted of a digit-comparison task and a digit-parity task, and was expected to be more reliable in reflecting the switch costs measured by both reaction time (RT) and accuracy. Results indicated that although the switch costs were larger in the letter paradigm compared to the digit paradigm in both young and older participants, these differences between paradigms were not significant. There was considerable variability in task-switching performance on the letter paradigm, which, according to participants' verbal feedback may be attributed to the difficulty of the letter stimuli. Study 2 of Chapter Four was conducted to examine the effect of letter stimulus difficulty on task-switching performance. The difficulty was manipulated through changing the level of noise contained in the letter stimuli, from 25% noise in the easy condition and 30% noise in the difficult condition. Again, although the switch-costs were larger in the difficult letter condition, compared to the easy letter condition, in both young and older participants, these differences were not statistically significant. Taken together, Study 1 and Study 2 indicated that the digit task-switching paradigm provides the clearest in-laboratory measure of task-switching performance for both young and older adults.

These findings will serve to guide future paradigm selection for assessing task-switching

performance for both age groups. When selecting paradigms to measure cognitive constructs, a balance between sophisticated designs with structural complexity and direct conceptual alignment is critical, as was discussed by Robinson (2001) in the context of language production tasks. In the context of task-switching paradigms, the letter paradigm explored in this thesis is one example of a design that increased structural complexity. Complex paradigm designs can be sophisticated in measuring corresponding manipulations, but simultaneously, can introduce unexpected cognitive demands. For instance, Wu et al. (2022) suggested that the complexity of a task amplified the switch costs measured by a task-switching paradigm. Reiser et al. (2022) correspondingly found a similar effect of task complexity in a real-life motor-based task. Often, simple but well-structured paradigms are more effective, and can better help with isolating the targeted construct (Embretson & Gorin, 2001; Sanbonmatsu et al., 2021; L. Zhang et al., 2024). As noted by Makombe (2017), this design approach reduces confusion in researchers. This consideration is particularly relevant in older adults, who are more susceptible to the influence of task complexity and fatigue due to higher cognitive demands (López-Rodriguez et al., 2025). The ideal balance between task difficulty and conceptual alignment is still a subject of investigation.

Although cognitive experimental conditions need to be carefully designed and strictly controlled, real-life cognitive functioning is less straightforward. In the attempt to relate in-laboratory findings with real-life applications of cognitive function, the trade-off between precision of experimental design and real-life applicability has always been an inevitable challenge. One of the motivations to investigate the relationship between current life complexity and task-switching was to attempt to obtain practical real-world applicability for

having a healthy lifestyle, while maintaining the precision of a carefully controlled experimental design in the study of cognitive ageing. Additionally, the ecological validity of experimental studies could be improved by designing in-laboratory experiments that more closely mimic real-life scenarios (e.g., a naturalistic task-switching task, McAlister & Schmitter-Edgecombe, 2013).

Complex but sophisticated paradigms are critical methods to investigate multi-dimensional human behaviours; however, the interaction between these components needs to be addressed (Sanbonmatsu et al., 2021). The appropriate balance between the need for a task to be sufficiently difficult that ceiling effects are avoided, and the need not to be confounded by conceptual alignment with the construct being investigated, is unlikely to be obtained by just one investigation. The findings of the current thesis in regards to task-switching paradigms contributes to this continuous need for compromising between difficulty and sufficiency of the experimental design. By providing a clear example of how study paradigms evolve over time, the findings of the thesis can promote a promising starting point for future selection of task-switching paradigm variations.

5.1.3 The Relationship Between Current Life Complexity and Task-Switching

The conclusion from Chapter Two, Study 1 and Study 2 of Chapter Four, and Chapter Three were combined to generate the investigation of the relationship between current life complexity and task-switching in the Study 3 of Chapter Four. Guided by the concept of selective optimisation with compensation (Baltes & Baltes, 1993), current life complexity can be considered a real-world reflection of the combined results of the individuals' available

cognitive resources, their current state of cognitive functional abilities, and the efficiency of their compensatory mechanisms. Individuals can maintain a higher level of current life complexity when cognitive resources are sufficient, but may reduce current life complexity as a compensatory strategy when resources become limited. Such behavioural compensation is conceptually similar to cognitive compensation seen in task-switching performance, such as reducing voluntary switching (Butler & Weywadt, 2013) or sacrificing speed to maintain accuracy (Van Asselen & Ridderinkhof, 2000). To gain further understanding in the nature of age-related changes in behavioural and cognitive compensation, the association between current life complexity and task-switching function (i.e., as measured by switch-costs in the digit paradigm) were investigated. The results suggested that there was no significant association between these two concepts.

There were four possible explanations of these results. First, participants in Chapter Four, Study 3 had a higher current life complexity while compared to the larger Australian population sample in Chapter Three. This suggested that our sample of participants, particularly the older participants, were more active and high-performing compared to the Australian population norms. Their high-performing status, can be the result of sufficient cognitive resources, or successful use of real-life compensatory strategies. These strategies include the use of technological support, environmental cues, and daily schedules, all of which can be beneficial for remaining engaged in a relatively complex daily life (Beech et al., 2024; Weakley et al., 2019). Due to the effect of these compensatory strategies, it is reasonable to expect that before the onset of severe cognitive decline, the decline in cognitive performance might not be detectable through daily functional abilities. The second possible

explanation was based on the multi-dimensional nature of current life complexity and executive function. This explanation is discussed in the following section, with regard to our approach to the investigation. The third explanation of the non-significant finding may stem from the nature of current life complexity. The concept of current life complexity is different from how cognitive reserve is typically measured, which captures past cognitive history. The assessment of current life complexity is also different from the traditional activity checklists for assessing activity engagement. By linking current life complexity to compensatory mechanisms, it is theorised that current life complexity would have an effect on age-related changes in cognitive functional ability. This underlying characteristic of current life complexity makes its relationship with cognitive performance more likely to be detected in longitudinal studies or in specific populations, like those with MCI. Alternatively, the null result could also be due to limited statistical power from a small sample size. Although a priori power analyses were conducted, the assumed effect sizes may have been overestimated.

5.2 Research Implications

5.2.1 Theoretical Implications

Referring back to the typical trajectory of cognitive ageing described in Chapter One, the pattern of functional ability is gradually decline at first, with the decline becoming more dramatic when reaching a specific change point (Barulli & Stern, 2013). In healthy ageing, this is more likely to be the point when compensatory mechanisms fail to mask decline. Before this change point, compensatory mechanisms can be in place to support a healthy

level of performance. In task-switching, this compensation is typically represented by a reaction time-accuracy trade-off (e.g., Van Asselen & Ridderinkhof, 2000). The studies in this thesis did not find any significant indication for cognitive compensation from the observation of in-laboratory task-switching. However, the findings suggest that older adults had a non-statistically significant tendency to take extra caution to maintain the accuracy of their performance when the task was changed in the task-switching paradigm. There are two likely explanations for this. First, our participants were active and high-performing, hence, may not yet have reached the stage of requiring compensation in task-switching functioning. Second, a reaction time-accuracy trade-off is not the only compensatory mechanism that could be used to maintain task-switching performance. Instead of observations from a behavioural level, compensation might be a mechanism operating at a neurological level, which is explained by the revised STAC model (Reuter-Lorenz & Park, 2014), and supported by empirical evidence with regard to task-switching (e.g., Eich et al., 2023), inhibition (e.g., Fernandez-Ruiz et al., 2018), and cognitive control (e.g., Liu et al., 2023). This proposal could be clarified by future research investigating the association between behavioural compensatory mechanisms and neurological compensatory mechanisms in task-switching performance in later-life.

The theoretical framework provided by the Enrichment Effect model (Hertzog et al., 2008) and the model of selective optimisation with compensation (Baltes & Baltes, 1993) were integrated to construct the foundations of the real-life measurement of later-life functional ability. Based on this integration, the level of investment a person can make across categories of activities can reflect the extent of their available cognitive resources, the

efficiency of their compensatory mechanisms, and their current state of cognitive functional ability. This level of investment was conceptualised as current life complexity. The current findings are also not sufficient to confirm there was an indication of behavioural compensation in daily functional ability indicated by current life complexity. Instead, participants presented a high level of maintenance in daily functional ability, especially given that one aspect of current life complexity measurement (i.e., breadth of involvement) was close to ceiling in both young and older adults. Although there were suggestions that the reduction in activity engagement over time was a potential indicator for compensatory decisions made because of cognitive impairments (e.g., Hughes et al., 2018), this is still a growing area of research. This can again be explained as a result of our participants being active and high-performing, hence, and not yet reaching the stage of requiring compensation in real-life functioning.

Other possible explanations should also be considered with regard to the nature of the complexity in psychological measurement, and real-life lifestyle choices. Cognitive enhancement, gained from engagement in cognitively-demanding activities, can be interpreted from different aspects, with no consensus on which is the optimal solution for psychological measurement (Bielak & Gow, 2023). The concept of current life complexity provided a novel approach, from a holistic perspective, with meaningful variables addressing breadth of involvement, depth of involvement, variability in depth, concentration of activities, and inclusiveness of activities. The breadth of involvement and concentration of activities can be used to capture variations with regard to experience types, which was the focus of the activity engagement measurement (e.g., FCAS; Schinka et al., 2005). The depth

of involvement and variability in depth can be used to capture frequency of involvement. The inclusiveness of activities represented participants' ability to cope with multiple different experiences within a day, which was of interest to Bielak et al. (2019). All of this suggests that the multi-dimensional nature of cognitive lifestyle might be more comprehensively represented by a multi-dimensional approach, incorporating all aspects of breadth of involvement, depth of involvement, variability in depth, concentration of activities, and inclusiveness of activities. This holistic approach aligns with the ecosystem framework of investigating the effect of activity engagement, as proposed by Stine-Morrow and Manavbasi (2022). When examining the lifestyle-cognition relationship, a holistic approach that combines multiple relevant parameters to create a comprehensive assessment may be more informative than selecting a single measure as the gold standard for representing either concept.

Another explanation is rooted in individual differences in preferences of lifestyle choices. Individuals have differing preferences for forms of physical activity (e.g., Kudlacek et al., 2025; Liu & Csikszentmihalyi, 2020), and reliable constructs such as introversion and extroversion suggest that people have preferences for the frequency and nature of social activities (e.g., Furnham, 1981).When the categories of the daily activities were investigated separately for their cognitive benefits, the major focus was on physical and social activities (e.g., de Frias & Dixon, 2014). This may relate to the central focus of physical activity in the cognitive aspect of successful ageing models (e.g., Estebsari et al., 2020), the known physiological pathways between exercise and cognitive function (e.g., Walsh et al., 2020), and the growing literature showing the beneficial effects of the social component in physical

activity (e.g., Taylor et al., 2021). Furthermore, individual differences in patterns of engagement across activities may be considered in correspondence with neurodivergence (e.g., van Rijswijk et al., 2024), where greater/less depth of involvement in one category is not a consequence of compensation or decline, but a natural manifestation of a different preference and capacity. The current design of the CLCQ incorporates a question asking for participants perceived barriers for engaging in activities. This enquiry could be expanded with additional questions that are more sensitive to individual's personal preferences.

5.2.2 Practical Implications

With the development and initial validation of the new self-report instrument, the CLCQ, current life complexity can be directly assessed. The practical implications of this development connects its use to a broad range of research interest. As suggested, in successful ageing (e.g., Estebsari et al., 2020) and neural compensation models (Reuter-Lorenz & Park, 2014), in addition to the cognitive enhancement gained through daily experiences, cognitive interventions offer an alternative pathway for potential cognitive improvement. As reviewed by Hendrickx et al. (2020), interventions can take the approach of targeting lifestyle habits. Study protocols were proposed to assess the effect of behavioural interventions on activity engagement (e.g., Scott et al., 2022). The CLCQ can be considered as a tool to directly assess the baseline and outcome of the lifestyle interventions, by providing a comprehensive overview on how participants' daily activity patterns changed before and after the lifestyle interventions.

Another practical implication can be considered from the perspective of social

infrastructure construction, community development, and health care, especially in regard to build supporting systems for older adults. More support can be dedicated to the activities people are frequently engaged in, and/or activities people are interested in, but were not able to engage in due to lack of infrastructure (Wood et al., 2022). Urban green infrastructure is associated with health-promoting factors such as physical activity and mental stress reduction (Dennis et al., 2023), and there is a significant association between environment and transport, and leisure and physical activity level (Witten et al., 2012). There is qualitative evidence that environmental barriers, design of activities, and motivations from surrounding people were important factors related to physical activity engagement among individuals with Mild Cognitive Impairment (MCI) and dementia (van der Wardt et al., 2020). Social infrastructure, by providing places for fostering social connections, is also an important component to consider when creating comfortable living environments for residents, especially older adults (Lewis et al., 2022). The CLCQ can be modified and administered as an exploratory instrument of activity preferences in local communities, and to inform decision-making when generating a planned system that is able to incorporate interplay between infrastructure and communities. The CLCQ can also be used to track the success of infrastructure implementation in facilitating cognitively complex lifestyles.

5.3 Strengths and Limitations

5.3.1 Participant Sample

The thesis was a foundation and an initial exploration of the relationship between current life complexity and task-switching in young and older adults. This had implications

for sample size, and selection of participants. Investigations regarding lifestyle typically find small effect sizes (e.g., in Bielak et al., 2019). Our sample size was relatively modest compared to large initiatives with a population level of data collection (e.g., the Charlotte County Healthy Ageing Study reported in Schinka et al., 2005). However, smaller samples are typically found for cognitive in-laboratory studies (Chapter Three). With the consideration of maximising the efficient use of participants' time and energy, while maintaining reasonable precision of study outcomes, Johanson and Brooks (2010) recommended a total of 24 to 36 participants for initial scale development. From the perspective of pilot testing, a sample of 59 was recommended to detect a problem with the scale, with 5% probability (Viechtbauer et al., 2015). According to this recommendation, our sample sizes were adequate for initial development and investigation of the baseline understanding of a concept (i.e., current life complexity) and its associations with other well-established concepts (e.g., task-switching function).

Due to the foundational nature of the concept of current life complexity, investigation focussed on physically and cognitively healthy young and older participants. As suggested by Jager et al. (2025), investigations in homogenous samples, such as in healthy participants, is beneficial for improving generalisability of findings to that group, and studies in more homogenous samples require smaller sample sizes to obtain precise outcomes, compared to studies in more heterogenous samples. It was expected that once cognitive decline has occurred, compensation would no longer be detectable. Thus, in order to examine cognitive and behavioural compensation in older adults, participants with apparently preserved functional ability need to be the target sample. The group of participants reported in Chapter

Two Study 2 was recruited as an online sample from a widely representative Australian population, hence the development and initial validation of the CLCQ was less confounded by the potential bias in the cognitively healthy study samples. The group of participants reported in Chapter Four Study 3 was recruited from Canberra, Australia's Capital City. Canberra is a designed city (Young, 1985), and active efforts were put into the urban construction to make it an age-friendly city (Kendig et al., 2014). The population of Canberra have a tendency of working in more intellectually-demanding occupations, such as government workforce, defence, and the tertiary education sector (Australian Bureau of Statistics, 2021). In the studies reported in Chapter Four, older participants were community-living Canberrans, a population known to be highly-educated and cognitively active in their daily life (e.g., Anstey et al., 2012).

The majority of young participants in Study 1 of Chapter Two and all studies of Chapter Four were university undergraduate students, who are typically characterised as people in younger adulthood, with the experience of more years of education (Hooghe et al., 2010). According to the results reported by a time-use recall study (Richardson et al., 2018), a relatively large proportion of students' time was committed to completing university coursework and sleep, leading to increased homogeneity in their daily routines. However, despite this homogeneity, variability was presented due to different life commitments, such as physical activities, screen time, and work. When interpreting the lifestyle patterns captured by the CLCQ, these characteristics of student sample can make the investigation less generalisable to the wider population. There is also evidence that undergraduate students have differing motivations for participating in research relating to the compulsory nature of

obtaining research credit, and thus may engage with experimental instructions and procedures differently from volunteers sourced from the general population (Beanland et al., 2020). There is a tendency to under-report and under-utilise the demographic characteristics of student participants in statistical analysis (Goodwin et al., 2024). To address this issue, the characteristics of student participants reported in the current thesis is presented with the same level of information precision as older participants; hence, accurate interpretation and generalisation can be made based on the available information.

As a part of our study design, cognitive screening tests (i.e., MoCA: Julayanont et al., 2015; VOSP: Warrington & James, 1991) were used to exclude older participants exhibiting indicators of severe cognitive decline. Demographic questions about neurological impairments, difficulty with vision and hearing were also asked of young and older participants. This practice of selecting a cognitively-healthy sample aligned with prior research investigating the relationship between activity engagement and cognitive functioning abilities (e.g., Bielak et al., 2019; Weaver & Jaeggi, 2021) and task-switching (e.g., Ging-Jehli & Ratcliff, 2020); although these studies used the Mini-Mental State Examination (MMSE, Folstein et al., 1975) rather than the MoCA. However, this practice was distinct from other studies investigating a similar relationship between activity engagement and cognitive abilities (e.g., Armstrong et al., 2022; Schinka et al., 2005), where these studies belonged to larger population-based research projects, with project-level participant recruitment criteria that practiced screening for medical and neuropsychological issues based on clinical measurements. These differences in the methods of screening can leads to differences in participants' characteristics in terms of their cognitive functional

abilities at the point of study recruitment.

Future refinement of the current work should be carried out in larger samples that include a variety of participants with different cognitive characteristics. In regard to adequate sample size, the power analysis we conducted for capturing a small effect (i.e., the effect of lifestyle) recommended 327 participants. For the purpose of detecting potential compensation in healthy older adults, and supporting generalisability, collecting current life complexity data from a diverse range of communities is needed. The diversity of the sample can be increased by recruiting participants who are culturally or nationally representative, or by purposively including individuals who are more likely to have a diversity in lifestyle, such as people pursuing a study program (Richardson et al., 2018), people who work versus people who retired (Motegi et al., 2016), or populations living in rural versus urban settings (Pickett et al., 2023).

Another approach for increasing diversity is to consider working with participants with Subjective Cognitive Decline (SCD), which is characterised by reporting a subjective decrease in cognitive function that cannot be detected by objective neuropsychological tests or daily functional abilities (Jessen et al., 2020; Maffoni & Magnani, 2025). Individuals with SCD are typically classified as cognitively healthy with no cognitive impairment, however, they are at a higher risk of developing cognitive impairment (Li et al., 2022; Wang et al., 2021). Administering the CLCQ in individuals with SCD could provide a means to broaden the understanding of whether SCD may involve behavioural compensation, such as reduced breadth or depth of activity engagement, in a way that masks detectable impairment using other measures. Working with populations experiencing SCD can also help with evaluating

the measures extracted from the CLCQ, where the qualitative self-report of changed daily experiences can be compared to the quantitative lifestyle patterns captured by the CLCQ.

Similarly, using the CLCQ in samples experiencing MCI may be an appropriate starting point for extending our understanding of lifestyle complexity in cognitive decline. MCI is a clinical and research-based condition where modest cognitive decline greater than age norms is noticed (Winblad et al., 2004). This decline is accompanied by behavioural impairments (Sheikh et al., 2018), but relatively intact daily independent functioning. In a four-year longitudinal study with participants experiencing MCI, Katayama et al. (2021) found that participants maintaining their lifestyle with engagement in multi-domain activities were less likely to meet the diagnostic criteria for MCI at the conclusion of the study, or more likely to maintain functioning without progressing to more serve decline. Another four-year longitudinal study found that higher levels of activity engagement measure by FCAS can be perceived as a protective factor against progression from healthy to MCI (Hughes et al., 2018). Alternatively, lower level of activity engagement can be interpreted as a potential marker for cognitive impairment (Hughes et al., 2018). However, the lifestyle measurements in both studies have taken the traditional approach of focusing on the activities that are the most likely to reflect cognitive functional abilities (Hughes et al., 2018; Katayama et al., 2021). Ideally, measuring longitudinal changes in current life complexity in people experiencing MCI can advance our understanding in how pathology influences current life complexity, and help clarify whether the lack of compensation identified in our current study was due to the high-functioning, healthy sample.

The current thesis primarily takes a cross-sectional approach. However, when investigating behavioural and cognitive compensation, an ideal suggestion might be to conduct examination over time, like the research that focuses on the change point in age-related functional ability (Sprague et al., 2020). Longitudinal designs, typically defined as a research approach that involves data collection from the same group of participants repeatedly over an extended period of time (Hunziker & Blankenagel, 2021), can also be used to follow-up the age-related and/or life-event-related changes in both current life complexity and its relationship with task-switching function. This can be particularly informative to longitudinally follow-up participants in the stages of important life course transitions. For instance, retirement (e.g., Motegi et al., 2016), university graduation (e.g., Zsolt et al., 2007), and loss of capacity for independent living, such as losing one's driver's license (e.g., Spinney et al., 2020) are all important transitions that can introduce critical lifestyle changes that will likely impact life complexity. Although studies have investigated activity engagement longitudinally (e.g., Weaver & Jaeggi, 2021), the additional consideration of how current life complexity impacts cognition over time makes the optimal longitudinal timeframe for exploring current life complexity unclear. In the life transition literature that takes a longitudinal approach, participants have been followed from 4 to 30 years (a retirement study, Manly et al., 2022), with a typical follow-up period of 10 years for ageing studies (e.g., Qi et al., 2024). As a well-established concept, task-switching as measured by a task-switching paradigm has been explored longitudinally over 5 years by Hasanzadeh et al. (2025), and by using other measures such as the Trail Making Test (e.g., Boggero et al., 2016). A recommendation of 5 to 10 years follow-up for future longitudinal studies might be

optimal for the further investigation of current life complexity and its relationship with task-switching.

5.3.2 Instruments and Methodology

The self-report and retrospective nature of the CLCQ introduced both strengths and weaknesses because of the design of the instrument. The self-report design of the CLCQ allows for unsupervised implementation, which can be scalable to larger population-based data collection. Despite this, the CLCQ suffers from reduced accuracy which is related to it being a self-report questionnaire (Bhandari & Wagner, 2006). Also, the retrospective design of the CLCQ allows for faster data collection, which compared to a prospective design, avoids the risk of participants withdrawal from the study, and limits the required waiting time for completing the data collection. However, its retrospective nature can introduce reporting bias and inaccuracy due to memory (Öztaş Ayhan & Işiksal, 2005), which can make the outcome measures less reliable. Future investigation on further validations of the CLCQ can be conducted to compare retrospective data collected by the CLCQ with prospective data collected by diary records, where the same time periods are covered. Rather than providing only a single outcome measure, the CLCQ utilises a multi-dimensional scoring approach, with different scores accounting for distinct aspects of current life complexity. This strength of the CLCQ also leads to its weakness, as classic psychometric procedures cannot be appropriately applied to validate this scale.

Qualitative research has shown the importance of a reciprocal relationship between the researcher and participant (Anderson & Henry, 2020; see also Alam, 2024). Feedback

provided by participants can support the refinement of the questions, which can result in improvements in: the alignment of the questions with the experience and perspectives of the target population; the clarity and accessibility of the instrument, and the validity and the reliability of outcomes collected by the instrument (DeVellis & Thorpe, 2022, Kooijmans et al., 2024). The current thesis included this approach within the area of quantitative research. The CLCQ was developed while incorporating the feedback from the participants. After the investigation of existing instruments and pilot testing of the VLS-ALQ, initial results emphasised the necessity of developing a new instrument that took into account participant feedback on legibility and response burden. The same principle can apply to in-laboratory experimental designs. The measurement quality of the task-switching paradigm was assessed with an approach that valued feedback from participants, and the researcher–participant relationship. After evaluating manipulations on task-switching paradigm, absorbing participant feedback, in the current thesis we conducted direct comparisons between paradigms to select the most appropriate task-switching paradigm for measuring task-switching in young and older adults. This approach acknowledged that our research was conducted with and/or alongside our participants, instead of done to the participants. Our approach echoes with the Empowering the Participant Voice initiative, which aimed to collect participant's feedback on a timely basis, for the purpose of building trust between researchers and participants, and improving research quality (Kost et al., 2024).

The methodology of the thesis addressed an important but sometimes overlooked consideration in psychological research, which is the fact that instruments, including both self-report questionnaires and computer-based test paradigms, are not static, instead were

subject to ongoing manipulation and refinement over time. These manipulations and refinements can be due to research interest in the mechanisms underlying the instrument. In studies of cognitive lifestyle, Marr et al. (2021) modified and validated the VLS-ALQ, to incorporate items that reflected the characteristic of their target population. Similar patterns of development of instruments over time were also found in: the self-report instruments for assessing well-being (Linton et al., 2016); the self-report questionnaires for assessing Big Five personality traits (Vicentini et al., 2025); and the Positive and Negative Affect Schedule (Wedderhoff et al., 2021).

The birth and wide application of the computer is one of the most crucial historical milestones for the development of experimental paradigms over time (Kush et al., 2012). Since then, most measurements have been transformed into computer-based tasks from pen and paper tasks. In studies of task-switching paradigms, Nessler et al. (2012b) manipulated the paradigm to investigate the effect of cue informativeness on task-switching performance. This methodological consideration has been identified and discussed in other areas of psychological research, which also involve working with evolving measures of instruments. In Hughes (2011), a similar consideration was discussed with the broader scope, on the 20 years of development in the measures of executive functions. The current thesis addressed and expanded on this trend of research, by thoroughly considering the appropriateness of integrating technology-related daily activities to reflect the lifestyle characteristics of the Australian population, and carefully evaluating the impact of task-switching paradigm manipulations. These implementations and considerations in relation to appropriateness further emphasise the importance of paying careful attention to: the components of the

instruments that were changed; the reason for changing the psychological instruments; and the historical timing of the changes. This information can consequently inform our considerations of instrument selection and outcome interpretations.

5.3.3 Approach of Investigation

The approach that was taken to investigate the relationship between current life complexity and task-switching was a relatively simple and direct one-to-one examination of association. However, as addressed in Chapter One of the thesis, both current life complexity and control mechanisms (operationalised as task-switching function) were multi-dimensional concepts.

In a longitudinal study reported by Armstrong et al. (2022), higher levels of leisure activity engagement was associated with slower decline in memory among participants with MCI. Better memory ability at the initial stage of the study was associated with better maintenance of the levels of leisure activity engagement over time in both healthy older adults and participants with MCI (Armstrong et al., 2022). Based on this finding, it is possible that other in-laboratory functional abilities, such as memory function measured by in-laboratory tasks, might provide a stronger association with current life complexity, than control mechanisms represented by task-switching function. However, it is also possible that daily functioning is influenced by a broader, more complex interactions between multiple cognitive functions rather than a single cognitive function such as task-switching. Bielak et al. (2019) provided evidence for the association between the variety and frequency of activity engagement with fluid intelligence, with measures of processing speed, task-switching

(measured by Trail Making Test Part B), reasoning, and working memory. Therefore, task-switching performance alone may not be sufficient to associate individuals' decisions regarding maintaining/reducing their current life complexity, as real-life functional ability is likely a composite result of multiple cognitive functions. Although, in alignment with the current thesis, a non-significant association has been found between daily activity engagement and a global cognitive measure, which consisted of measures of working memory, episodic memory, and processing speed (Weaver & Jaeggi, 2021). Hence, the possibility of lacking the association between current life complexity and in-laboratory representation of functional abilities cannot be excluded.

A more comprehensive multi-dimensional approach, that reflects the non-linear relationship between current life complexity and control mechanisms in considering age-related changes in cognitive functional ability, could be developed to simulate the association between cognition and lifestyle more precisely. The findings of the thesis contribute to establishing a base for further investigation into the idea of “Use it or lost it” (Bielak, 2010; Bielak & Gow, 2023). Also, as suggested in Bielak and Gow (2023), the methodological approach of investigating the relationship between current life complexity and task-switching has contributed to the current trend of exploration into the link between real-world measures of behavioural patterns and in-laboratory measures of cognitive mechanisms.

5.4 Conclusion

The WHO (World Health Organisation, 2020) proposes that people should have the opportunity to age healthily, where a fundamental component of successful ageing is

maintaining and developing functional ability in later-life. To understand the cognitive mechanisms underlying the maintenance and development of functional ability in the face of age-related changes, the relationship between patterns of engagement in everyday activities and cognitive control needs to be comprehensively investigated. The primary purpose of this thesis was to investigate the relationship between current life complexity and task-switching function in young and older adults. Chapter Two developed and validated the Current Life Complexity Questionnaire, a multi-dimensional tool capturing both breadth and depth of daily activity involvement. The systematic review in Chapter Three identified the digit-based task-switching paradigm as an efficient way to capture task-switching performance in young and older adults, which was confirmed by the consequent experimental study. Chapter Four found no significant association between current life complexity and task-switching.

This thesis explored the relationship between everyday cognitive engagement and cognitive control mechanisms in young and older adults by linking real-world cognitive experience (i.e., current life complexity) with laboratory-based cognitive measures (i.e., task-switching function). The findings underscore the importance of acknowledging evolution in psychological questionnaires and paradigms, and incorporating participant feedback to enhance the validity and interpretability of findings. These insights contribute to a foundation for future research into the relationship between lifestyle and cognition, and provide a methodological approach that can be applied to the investigation of constructs with a similar nature.

Establishing connections between lifestyle and cognition paves the way towards a better foundational understanding that addresses an essential question from the ageing community

through the lens of cognitive psychology: What can we do to promote successful ageing? While we do not yet have, and may never have, an answer that solves all age-related cognitive problems, approaches that provide opportunities for healthier and happier ageing experience will emerge as our understanding of cognitive ageing deepens.

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Appendices

Appendix A: R Packages Used for the Statistical Analysis and Visualisation

A.1 R Packages References Generated Based on the Output of the "grateful" Package (Version 0.2.12; Rodriguez-Sanchez & Jackson, 2024)

Table A1

Summary of R Packages Used in the Thesis

Package	Version	Citation
base	4.3.2	R Core Team (2023)
blandr	0.6.0	Datta (2017)
corrplot	0.95	Wei & Simko (2024)
extrafont	0.19	Chang (2023)
flextable	0.9.7	Gohel & Skintzos (2024)
ggExtra	0.10.1	Attali & Baker (2023)
gridExtra	2.3	Auguie (2017)
irr	0.84.1	Gamer et al. (2019)
knitr	1.45	Xie (2014); Xie (2015); Xie (2023)
lme4	1.1.35.1	Bates et al. (2015)
lmerTest	3.1.3	Kuznetsova et al. (2017)
metafor	4.4.0	Viechtbauer (2010)
performance	0.13.0	Lüdecke et al. (2021)
psych	2.3.9	Revelle (2023)
RColorBrewer	1.1.3	Neuwirth (2022)
reshape2	1.4.4	Wickham (2007)
rmarkdown	2.29	Xie et al. (2018); Xie et al. (2020); Allaire et al. (2024)
sjstats	0.18.2	Lüdecke (2022)
tidyverse	2.0.0	Wickham et al. (2019)
viridis	0.6.5	Garnier et al. (2024)

Note. References for R packages listed in the table can be found in the following section A.1.1.

A.1.1 Package Citations

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A.2 Code for Calculating Partial Eta-Squared in the Systematic Review (Chapter Three)

R Code:

```
## Define the Function for Partial Eta-Squared

partial_eta_approximator <- function(F_stat, df_num, df_denom){
       (F_stat*df_num) / ((F_stat * df_num) + df_denom)
       }


## An Example For Calculating Local-Switch Costs Measured by RT

Dataset$eta_square_Approx <- NA

for(i in 1:nrow(Dataset)){
        Dataset$eta_square_Approx[i] <-
        partial_eta_approximator(Dataset$F_stats[i], Dataset$df1[i],
        Dataset$df2[i])
        }
```

Appendix B: Examples of VLS-ALQ and CLCQ

ORIGINAL FREQUENCY CATEGORIES VERSION OF THE VICTORIA LONGITUDINAL STUDY—ACTIVITY LIFESTYLE QUESTIONNAIRE

(with one example of a category of activity—TV-Related Activities; 4 items)

1. Watching TV comedy/adventure
   - ☐ Never
   - ☐ Less than once a year
   - ☐ About once a year
   - ☐ Two or three times a year
   - ☐ About once a month
   - ☐ Two or three times a month
   - ☐ About once a week
   - ☐ Two or three times a week
   - ☐ Daily

2. Watching TV game show
   - ☐ Never
   - ☐ Less than once a year
   - ☐ About once a year
   - ☐ Two or three times a year
   - ☐ About once a month
   - ☐ Two or three times a month
   - ☐ About once a week
   - ☐ Two or three times a week
   - ☐ Daily

3. Watching TV documentary
   - ☐ Never
   - ☐ Less than once a year
   - ☐ About once a year
   - ☐ Two or three times a year
   - ☐ About once a month
   - ☐ Two or three times a month
   - ☐ About once a week
   - ☐ Two or three times a week
   - ☐ Daily

4. Watching news on TV
   - ☐ Never
   - ☐ Less than once a year
   - ☐ About once a year
   - ☐ Two or three times a year
   - ☐ About once a month
   - ☐ Two or three times a month
   - ☐ About once a week
   - ☐ Two or three times a week
   - ☐ Daily

CURRENT LIFE COMPLEXITY QUESTIONNAIRE—CATEGORICAL VERSION
(with one example of a category of activity—TV-Related Activities; 6 items)
(We use **Red** and **Bold** font to emphasise the important information, where we want the participants to pay extra attention.)

1. Please select **ALL** of the **TV-related activities** that you have been involved in during the **past year**:
   - ☐ Watching TV comedy/adventure
   - ☐ Watching TV game show
   - ☐ Watching TV documentary
   - ☐ Watching news on TV
   - ☐ Others, please specify other TV-related activities: _____

2. Please think about the **past year**.
   Please use the slider to indicate **the number of days** over the **past year** that you were involved in **this whole category of TV-related activities (i.e., all of the activities you have just selected)**.

   Enter the **exact number** on the slider; for example, if you were involved in this category of activities for **166** days of the **past year**, please indicate **'166'** on the slider.

   Never in the Past Year (0) Every Day of the Past Year (365)

3. Please think about the **past year**.
   Taking into consideration **the whole category of TV-related activities (i.e., all of the activities you have just selected)**, how **many hours** would you spend on **TV-related activities** in **a typical day** over the **past year**?
   Typical:
   0 24

4. Please think about the **past year**.
   Maybe on some days, you do **a lot of TV-related activities—more** than is typical for you.
   Taking into consideration **the whole category of TV-related activities (i.e., all of the activities you have just selected)**, what would be the **maximum number of hours** of **TV-related activities** that you engaged in on one day over the **past year**?
   Maximum:
   0 24

5. Please think about the **past year**.
   Maybe on some days, you do **very little TV-related activities—less** than is typical for you.
   Taking into consideration **the whole category of TV-related activities (i.e., all of the activities you have just selected)**, what would be the **minimum number of hours** of **TV-related activities** that you engaged in on one day over the **past year**?
   Minimum:

   0 24

6. Please think about the **past year**.
   Maybe on some days, you will have been involved in **TV-related activities multiple times** in the **one day**.
   Taking into consideration **the whole category of TV-related activities (i.e., all of the activities you have just selected)**, what would be the **typical number of time periods** that you engaged in **TV-related activities** on **one day**?

   Here is an example based on physical activities:

   For example, in one day, Alice spent **1 hour in the morning (going for a walk), 1 hour in the afternoon (going for a walk), and 2 hours in the evening (sailing)**.
   For Alice, the answer to this question for physical activities would be **3 different time periods**.

   Number of time periods: _____

Appendix C: Activities Used in Different Versions of the Lifestyle Questionnaire

Table 1.
Activities Used in the Lifestyle Questionnaires

Activity Category	Activity	Versions of Questionnaire That Included the Activity
Physical		
	Weight lifting, strength, calisthenics	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Aerobics (e.g., cardio, fitness, workout)	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Flexibility (e.g., stretching, yoga, tai chi)	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Outdoor (e.g., sailing, fishing, backpacking)	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Exercise (e.g., jogging, biking, swimming)	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Recreational (e.g., tennis, bowling, golf)	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Going for a walk	VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
Craft		
	Repairing a mechanical device (e.g., air conditioner, washing machine)	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Doing household repairs (e.g., unclogging a toilet, fixing a door)	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Doing woodwork/carpentry	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Buying items requiring setting up/assembling	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
Games		
	Playing word games (e.g., cross-word, categories)	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Playing knowledge games (other than board games)	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Playing board games	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Doing jigsaw puzzles	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Doing cross-word puzzles	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Playing card games	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Playing computer / smartphone based	VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ

	games	
TV-Related		
	Watching TV comedy/adventure	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Watching TV game show	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Watching TV documentary	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Watching news on TV	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
Private Social		
	Going out with friends	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Visiting relatives	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Attending parties in person (e.g., birthday)	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Talking to friends on the phone	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Making dinner for friends	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Eating out at a restaurant	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Chatting with friends on the internet	VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
Public Social		
	Engaging in political activities	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Giving a public talk	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Attending club meetings	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Attending organised social events	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Volunteering	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Using social media	VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
Travel-Related		
	Travelling out of town	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Travelling out of state	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Travelling abroad	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ

Experiential		
	Business not related to job	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Collecting (e.g., stamps)	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Reading physical materials for leisure (e.g., novels)	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Reading physical newspaper	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Gardening indoors or outdoors	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Writing physical letters	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Sewing, knitting, needlework	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Listening to the radio	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Attending a concert/play	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Attending sports events	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Going to galleries/museums	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Going to pubs/social clubs	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Reading online	VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
Developmental		
	Reading physical books as part of job	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Attending public lectures	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Taking a course at university	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Creative writing	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Going to library	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Studying a foreign language	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	On-the-job training	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Going out to the movies	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ

Technology		
	Using computer software (e.g., Word, Excel, PowerPoint)	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Using an electronic calculator	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Doing arithmetic calculations	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Photography	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Playing a musical instrument	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Preparing own income tax	VLS-ALQ (previous), VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Shopping / ordering delivery online	VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Watching videos (e.g., drama, shows, movies) online	VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Reading on electronic devices (e.g., E-books, online news, etc.)	VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ
	Writing emails	VLS-ALQ (Likert), VLS-ALQ (modified), CLCQ

Note. VLS-ALQ (previous): Previously validated versions of VLQ-ALQ that has been published (Citation). VLS-ALQ (Likert): The version of the VLS-ALQ used in the pilot study in Chapter Two of the thesis. VLS-ALQ (modified): The version of the VLS-ALQ that modified the responses, changing it from Likert scale to slider scale. CLCQ: Current Life Complexity Questionnaire.

Appendix D: CLCQ Scoring Manual

The scoring will have Four Parts:

1. Calculate the number of activities by adding the selected activities with other activities not listed.
   - This is a measure of breadth of involvement.
   - Each category will have an individual score, and there will be a total composite score.
2. Scoring Current Life Complexity, with the following measures:
   - Composite Complexity Score
   - Breadth of Involvement
   - Depth of Involvement
   - Variability in Depth of Involvement
   - Concentration (Gini Index)
   - Inclusiveness of the Activities.
3. Minimum and Maximum could be used to look at variation of involvement within a person.
   - Look at the variation in the window (range) of the involvement
   - This could be meaningful both within a person (across different categories) and between people (across different participants and categories).
4. The different time period could be used to look at reported switching of activities within a day.
   - This is a measure of switching.

Cleaning and Scoring

1. **NA is interpreted as 0 in this questionnaire, as long as the participants have completed the whole questionnaire**
   - In the following cases, the participant will be excluded from the analysis:
     - Researcher's observation: the participant has skipped multiple questions
     - Threshold of completeness: 20% of missing data
     - Lacking agreement between questions
     - Failing to pass the Catch questions (will be added in the online survey version).
2. **Number of activities as an indication of the composite complexity score**
   - Each activity will be counted as 1 point towards the Activity Complexity Score
   - Activity Complexity Score = the number of activities selected + the number of distinct activities listed in the "Others" option.
   - For the "Others" activity to be included and counted towards the score, it must:
     1. Not be duplicating activities that have been provided in the questionnaire.
     2. Not be duplicating activities that have been listed in the other categories by the participant.
     3. Not be activities that are not possible to happen in real life (e.g., practicing witchcraft).
     4. Not be activities that performed the same action on different contents (e.g., watch different types of movies, reading different types of books).
     5. Not be specific examples of a broader activity (e.g., reading and reading fiction).
   - For each of the categories:
     - The expected minimum would be zero.
     - The expected maximum would be scored as illustrated in the table below:

Categories	Listed Activities	Others	Total
Physical Activities	7	7	14
Games	7	7	14
Crafts	4	4	8
TV-Related	4	4	8
Private Social	7	7	14
Public Social	6	6	12
Travel	3	3	6
Experiential	12	12	24
Developmental	8	8	16
Technology-Related	10	10	10

- The maximum for the "Others" activity will not exceed the number of activities listed in the same category.

❖ For the composite total score:

- Also add in the activities listed at the end of the questionnaire, the inclusion criteria should be the same as the "Others" activity in each category
- Zero is theoretically possible, but not expected
- 63 could be considered as a very complex lifestyle
- The maximum expected would be 136.

3. The following measures are calculated based on the number of activities selected and the indicated frequency of involvement in the past year

Breadth of Involvement

The breadth of involvement (Count, possible range between 0 and 10) is a count of the number of categories with more than one activity selected and/or reported. A larger breadth of involvement indicates that the participant has a wider range of investment across different activity categories.

Equation:

$$Breadth\ of\ Involvement = \sum_{i=1}^{10} I\ (A_i + O_i \geq 1)$$

- A_i is the number of selected activities in category i
- O_i is the number of other reported activities in category i
- There are a total of 10 categories
- I(·) is an indicator function that equals 1 if the condition inside the parentheses is true (i.e., if the sum of activities in a category is greater than or equal to 1), and 0 otherwise.

Depth of Involvement

Participants directly report the number of days (Continuous, possible range between 0 and 365) for each activity category. No further calculations are required. A larger depth of involvement indicates that the participant is deeply invested in the selected activity category.

Equation:

$$Depth\ of\ Involvement = \{D_i\}_{i=1}^{10}$$

- D_i is the number of days reported for activity category i.

Variability in Depth of Involvement

The variability in time of involvement (possible range being within the positive continuous number) is the standard deviation of the number of days involved in the activities across 10 activity categories. A larger variability in depth of involvement indicates that the participant showed greater variations in their level of investment across activity categories.

Equation:

$$Variability\ of\ Time\ of\ Involvement = \sqrt{\frac{1}{10}\sum_{i=1}^{10}(D_i - \overline{D})^2}$$

- D_i is the number of days of involvement in category i
- $\overline{D} = \frac{\sum_{i=1}^{10} D_i}{10}$ is the mean number of days of involvement across the 10 categories.

Concentration (Gini Index)

The concentration of activities (Gini Index, possible range between 0 and 1; Gastwirth, 1972) reflects how concentrated each participant's selections of activities are, across 10 activity categories. A concentration score close to 0 means that the participant has equal involvement across activity categories (i.e., low concentration). A concentration score close to 1 means that the participant has focused involvement on a few activity categories (i.e., high concentration). It is calculated based on the normalised proportion.

Equation:

$$Normalised\ Proportion\ (P_i) = \frac{A_i + O_i}{N}$$

- Ai is the number of selected activities in category i
- Oi is the number of other reported activities in category i
- N is the total number of listed activities across all categories.

Equation:

$$Concentration\ (Gini\ Index) = 1 - \frac{\sum_{i=1}^{10} P_i^2}{\left(\sum_{i=1}^{10} P_i\right)^2}$$

The entropy score of concentration (See Supplementary Material Section G) was also calculated and plotted. A similar pattern of results was presented. Here, we only present the concentration scores based on Gini-index, as it is theoretically closer to its real-word interpretation, which is the level of concentration in activities selected across 10 activity categories.

Inclusiveness of the Activities

The inclusiveness of the activities (continuous, possible range between 0 and 10) could be calculated based on 10 depth of involvement measures, by adding them up and dividing them by 365. A higher score means the participant was more inclusive when involved in the selected activities. A lower score means the participant was less inclusive when involved in the selected activities.

Equation:

$$Inclusiveness\ of\ the\ Activities = \frac{\sum_{i=1}^{10} D_i}{365}$$

- D_i is the number of days reported for activity category i.

4. **Window as an indication of the depth of involvement (Minimum – Maximum hours of involvement)**
   - For each of the categories, the expected minimum hours would be any number **greater than, but not equal to, zero**.
   - The expected maximum hours would be any number **smaller than and equal to 24**.

5. **Number of different time periods within a day**
   - For each of the categories:
     - The expected minimum would be zero
     - The expected answers would most likely be less than 24
     - 24 – 72 could be theoretically possible, but very unlikely
     - Greater than 72 would not be expected.
   - For the composite total score:
     - Zero is theoretically possible, but not expected
     - The maximum expected would be less than 240.

Appendix E: Supplementary Results for Chapter Two (Online Survey Studies)

E.1: Other Activities Mentioned by Participants

Activities that were specifically relevant for young participants:

- Studying for assessments, writing reports / thesis
- Grocery shopping
- Taking care of pets.

Activities that were specifically relevant for older participants:

- Sodoku (Numbers game)
- Watching sports, reality show on TV
- Jewellery, and clothes making
- Listening to audio book
- Taking care of children/grandchildren
- "Sewing, knitting and needlework" in the craft category instead of the experiential category (listed in the CLCQ).

Activities that were relevant for both young and older participants:

- Watching movies, drama
- Cooking and eating
- Crochet.

E.2 Concentration Scores Calculated by Entropy Score

E.2.1 Calculation of Concentration (Entropy Score)

The concentration of activities calculated based on the Entropy Score (Shannon, 2001; continuous, possible range 0–3.32 for 10 activity categories) reflects how concentrated each participant's selection of activities is, across 10 activity categories. A higher entropy score indicates a more diverse involvement across multiple activity categories, whereas a lower entropy score indicates a more concentrated involvement within a few activity categories.

Equation:

$$Concentration\ (Entropy) = -\sum(p_i * \log(p_i))$$

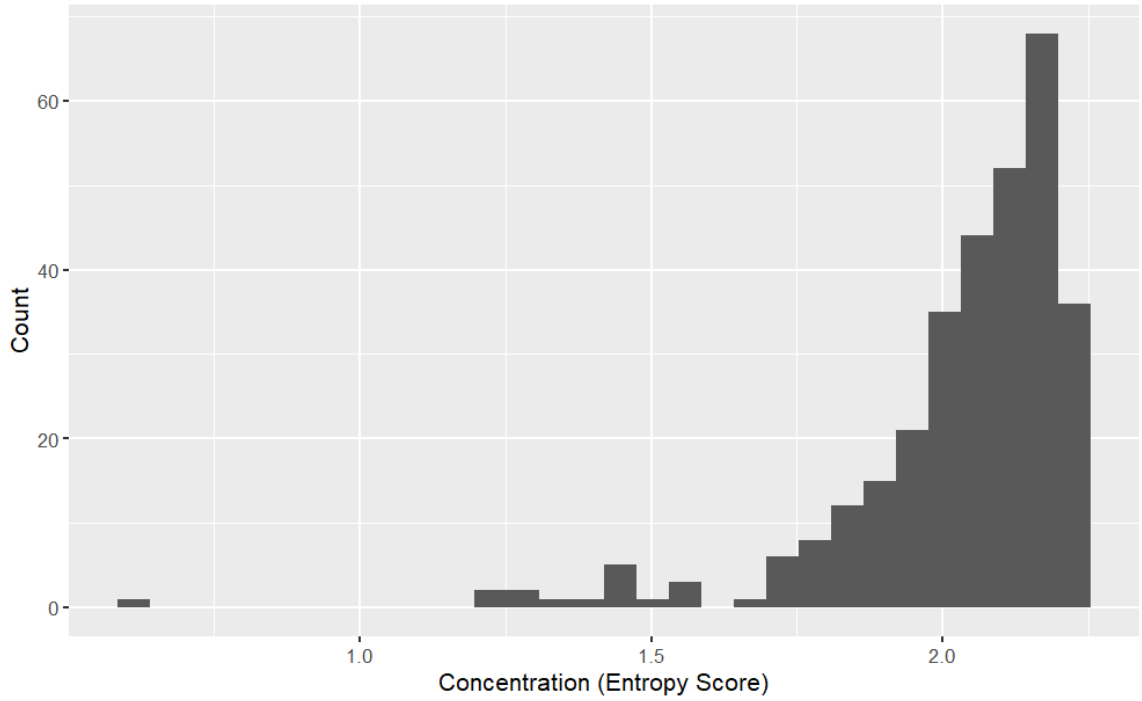
- Where p_i is the proportion for activity category i.

E.2.2 Results of Concentration based on Entropy Score

The entropy score had a mean of 2.19 (*SD* = 0.18, range = 0.99–2.34; see Figure E1), indicating that our participants had a moderate level of concentration in the distribution of activity categories. The majority of the participants had a balanced mix of activities, with a few records that are either more concentrated (lower entropy score) or more evenly spread (higher entropy score). Differences were observed between the concentrations calculated by the Gini index and concentrations calculated by the entropy score. However, this might be because the Gini index and the entropy score were measuring related but distinct properties of concentration, with different scaling and sensitivity to the level of concentration.

Figure E1

A Histogram Distribution of the Concentration of Activities Score (Entropy Score)

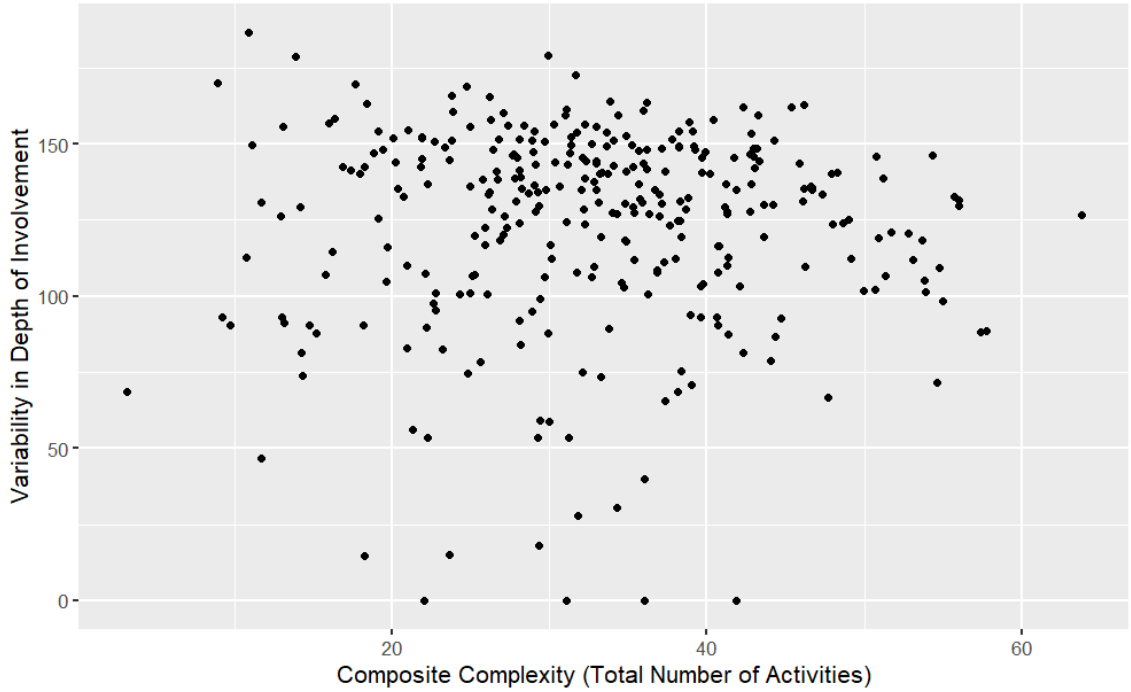


Note. Figure presents the distribution of concentration calculated in a total of 314 participants. Y-axis is an indication of frequencies, the frequency of participants for each concentration score on the x-axis. The figure suggests that the concentration score is left-skewed in our participants, with a greater number of participants scoring at the higher end of the scale and fewer at the lower end.

E.3 Variability in Depth of Involvement

Figure E1

Composite Complexity Score (Total Number of Activities) versus Variability in Depth of Involvement (Number of Days)



Note. Figure presents the relationship with the composite complexity score. The majority of our participants had a large score for variability in the depth of involvement across category of activities, suggesting that their depth of involvement varied greatly across categories. Each point on the figure indicates one participant.

Appendix F: Supplementary Information for Chapter Three (Systematic Review)

Appendix F includes additional information of study designs and results supplemented to the systematic review study reported in Chapter Three of the thesis. Table F1 includes content relevant to methods of the systematic review, Table F2–G6 and Figure F1–F5 include content relevant to results of the systematic review.

Table F1

Summary of Information Extracted

Variable	Note	Form
Basic Journal Article Information		
Place of Study	In which country did the study take place?	Categorical
Included Studies	Number of sub-studies included in the selected articles. (Each study was reported on a new row of the excel extraction sheet.)	Numeric
Study Number	Ordinal study number of the reported study for the current row (i.e., study number 1 out of 3 included studies identified within a given included journal article).	Numeric
Sample Size	Total number of participants.	Numeric
Older Adult Sample Size	If the study was included because the sub-sample fulfilled the inclusion criteria, we extracted the sub-sample size of older adults (e.g., 20 older adults out of a total sample of 40 participants).	Numeric
Comparison Group	Brief explanation of the characteristics of the comparison group.	String
Comparison Group Sample Size	Number of participants in the comparison group. Each comparison group had its own column.	Numeric
Multi-lingual Participants	Whether participants reported in the study spoke more than one language (0 = no, 1 = yes).	Boolean
Language Spoken	A list of languages spoken by participants. When information was available, languages were listed from first language to second language.	String
Age Mean	Mean age of the participants. (Older group, and each comparison group had their own column.)	Numeric
Age SD	The standard deviation of the mean age. (Older group, and each comparison group had their own column.)	Numeric
Age Minimum	Youngest participant's age. (Older group, and each comparison group had their own column.)	Numeric
Age Maximum	Oldest participant's age. (Older group, and each comparison group had their own column.)	Numeric
Gender (Number of Women)	Number of women participants. (Older group, and each comparison group had their own column.)	Numeric
Experimental Paradigm Information		
Type of Task-Switching Base-Tasks	Description of the type of tasks participants were required to switch between (i.e., description of characteristics of a single trial; e.g., shape-discrimination task).	String
Type of Task Switch-Rules	Description of how switch behaviour was introduced to participants (e.g., switching voluntarily, memorising the switch-rules, and cueing before the task, etc.).	String

Table F1

Summary of Information Extracted

Variable	Note	Form
Number of Pure Blocks	Number of pure blocks each participant completed.	Numeric
Number of Trials (Pure)	Number of pure test trials each participant completed.	Numeric
Number of Mixed Blocks	Number of mixed blocks each participant completed.	Numeric
Number of Trials (Mixed)	Number of mixed test trials each participant completed.	Numeric
Number of Practice Blocks	Number of practice blocks each participant completed.	Numeric
Number of Trials (Practice)	Number of practice trials each participant completed.	Numeric
Stimulus Presentation Time	Time Duration of stimulus presented on the screen. If this varied, used the format: Varied (list of different times).	Numeric (with unit)
Preparation Time Between Trials	Time Duration between each trial. If this varied, used the format: Varied (list of different times).	Numeric (with unit)
Switch Costs Information		
Number of Switch Costs	Number of different types of switch-costs reported in the article (e.g., local-switch costs or global-switch costs).	Numeric
Names of Switch Cost	Names of reported switch cost. Each switch cost had their own row. (e.g., RT Global-Switch Cost).	String
Switch Analysis Type	Statistical tests used to analyse the switch performance (e.g., ANOVA).	String
Switch Mean	Performance mean for switch trials.	Numeric
Switch SD	Performance SD for switch trials.	Numeric
No-Switch Mean	Performance mean for no-switch trials.	Numeric
No-Switch SD	Performance SD for no-switch trials.	Numeric
Mean Switch-Cost	Performance mean for switch-costs.	Numeric
SD Switch-Cost	Performance SD for switch-costs.	Numeric
Switch Significance	The reported significance of the switch-cost statistical tests (0 = non-significant, 1 = significant).	Boolean
Switch Analysis Results	The detailed results of the analysis. If the exact number (e.g., F-statistics) was not reported in the article, provided a short phrase or sentence that described the result (e.g., $F<1$).	String

Table F1

Summary of Information Extracted

Variable	Note	Form
Error Trials Included	If the measure was in RT, were error trials included in the RT calculations (Yes, No, or Unspecified).	Categorical
Additional Relevant Information (e.g., factors related to task-switching, but not manipulated by the paradigm)		
Other Related Factors	Number of explicit investigations of other factors related to task-switching. If an article included multiple studies, each study should be calculated independently, and have their own row.	Count
Other Related Factors: Category	Category of factors that were suggested to be related to task-switching. Categories included: ◆ Age ◆ Variations on task-switching paradigm ◆ Executive function or Cognitive function ◆ Neurological ◆ Lifestyle ◆ Other Interactions between multiple variables were listed separately from the main effect, using the category "Interaction".	Categorical
Other Factors: Name	The name of the factor related to task-switching. Each factor had their own row.	String
Measurement Category of Other Factors	Category of measurement used to represent other factors (e.g., objective measure, self-report, validated questionnaire).	String
Measurement Name	The name of the tool or questionnaire used to represent the identified factor.	String

Table F1

Summary of Information Extracted

Variable	Note	Form
Key Hypothesis	Report of the following information of the key hypothesis related to factors other than the paradigm itself: ◆ Conceptual relationship with task-switching proposed in the article (i.e., hypothesis and justification for making this hypothesis). ◆ Whether the key hypothesis was supported. ◆ Statistical analysis used to analyse the key hypothesis. ◆ The result of the statistical analysis. If the exact number (e.g., *F*-statistics) was not reported in the article, provided a sentence that described the results (e.g., *F*<1).	String
Mediator/Moderator	Report of the following information of the mediator/moderator related to factors other than the paradigm itself: ◆ Was a mediator or moderator mentioned in the hypothesis. ◆ Was the effect of the mediator or moderator supported. Briefly explain. ◆ Statistical analysis used to analyse the effect of the mediator or moderator. ◆ The result of the statistical analysis. If the exact number (e.g., *F*-statistics) was not reported in the article, provided a sentence that described the results (e.g., *F*<1).	String
Longitudinal Design Information		
Longitudinal Design	Was the study a longitudinal design (0 = no, 1 = yes).	Boolean
Longitudinal Hypothesis	Conceptual explanation or expectation about longitudinal change over time.	String
Number of Time Points	Number of longitudinal time points for each participant.	Numeric
Time Duration Between Data Collection	Time duration between the first and last point of data collection.	Numeric (time unit)
Longitudinal Relationship	The result of the statistical analysis on the longitudinal change overtime. If the exact number (e.g., *F*-statistics) was not reported in the article, provided a sentence that described the results (e.g., *F*<1).	Numeric /string
Task-Switching Definition Information		
Definition of Task-Switching	If the study included a definition of task-switching, report the definition.	String

Table F1

Summary of Information Extracted

Variable	Note	Form
Task-Switching Concept	The authors' suggestions on what the task-switching paradigm was measuring.	String
Source of Switch Cost	The suggested theoretical source of switch-costs.	String
Risk of Bias Information		
Risk of Bias	Based on the questions provided by (Rosella et al., 2016, https://ars.els-cdn.com/content/image/1-s2.0-S0033350615004370-mmc1.pdf), was there a risk of bias (No = 0, Yes = 1).	Boolean
Note for the Bias	Explain potential risk of bias.	String

Note. "Variable" column is a description of the information. "Note" column contains a detailed description of the expected variables. "Forms" column is an indication of the expected variable form of the extracted information.

Table F2

References for Studies Reviewed in Chapter Three

Study Number	Reference
Study 30	Mulligan, B. P., Segalowitz, S. J., Hofer, S. M., & Smart, C. M. (2020). A multi-timescale, multi-method perspective on older adult neurocognitive adaptability. *The Clinical Neuropsychologist, 34*(4), 643–677. https://doi.org/10.1080/13854046.2020.1723706
Study 53	West, R., & Moore, K. (2005). Adjustments of Cognitive Control in Younger and Older Adults. *Cortex, 41*(4), 570–581. https://doi.org/10.1016/S0010-9452(08)70197-7
Study 56	Madden, D. J., Costello, M. C., Dennis, N. A., Davis, S. W., Shepler, A. M., Spaniol, J., Bucur, B., & Cabeza, R. (2010). Adult age differences in functional connectivity during executive ontrol. *NeuroImage*, *52*(2), 643–657. https://doi.org/10.1016/j.neuroimage.2010.04.249
Study 66	Rey-Mermet, A., & Meier, B. (2015). Age-related effects over bilingual language control and executive control. *Aging, Neuropsychology, and Cognition, 22*(1), 72–94. https://doi.org/10.1080/13825585.2014.889070
Study 67	Themanson, J. R., Hillman, C. H., & Curtin, J. J. (2006). Age and physical activity influences on action monitoring during task switching. *Neurobiology of Aging, 27*(9), 1335–1345. https://doi.org/10.1016/j.neurobiolaging.2005.07.002
Study 70	Kray, J., Eppinger, B., & Mecklinger, A. (2005). Age differences in attentional control: An event-related potential approach. *Psychophysiology, 42*(4), 407–416. https://doi.org/10.1111/j.1469-8986.2005.00298.x
Study 78	Eppinger, B., Kray, J., Mecklinger, A., & John, O. (2007). Age differences in task switching and response monitoring: Evidence from ERPs. *Biological Psychology, 75*(1), 52–67. https://doi.org/10.1016/j.biopsycho.2006.12.001
Study 82	Mayr, U. (2001). Age differences in the selection of mental sets: The role of inhibition, stimulus ambiguity, and response-set overlap. *Psychology and Aging, 16*(1), 96–109. https://doi.org/10.1037/0882-7974.16.1.96
Study 85	Butler, K. M., & Weywadt, C. (2013). Age differences in voluntary task switching. *Psychology and Aging, 28*(4), 1024–1031. https://doi.org/10.1037/a0034937

Table F2

References for Studies Reviewed in Chapter Three

Study Number	Reference
Study 86	Gazes, Y., Rakitin, B. C., Habeck, C., Steffener, J., & Stern, Y. (2012). Age differences of multivariate network expressions during task-switching and their associations with behavior. *Neuropsychologia, 50*(14), 3509–3518. https://doi.org/10.1016/j.neuropsychologia.2012.09.039
Study 88	Bojko, A., Kramer, A. F., & Peterson, M. S. (2004). Age Equivalence in Switch Costs for Prosaccade and Antisaccade Tasks. *Psychology and Aging, 19*(1), 226–234. https://doi.org/10.1037/0882-7974.19.1.226
Study 89	Hahn, S., Andersen, G. J., & Kramer, A. F. (2004). Age Influences on Multi-Dimensional Set Switching. *Aging, Neuropsychology, and Cognition, 11*(1), 25–36. https://doi.org/10.1076/anec.11.1.25.29360
Study 95	Eich, T. S., MacKay-Brandt, A., Stern, Y., & Gopher, D. (2016). Age-Based Differences in Task Switching Are Moderated by Executive Control Demands. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, gbw117. https://doi.org/10.1093/geronb/gbw117
Study 110	Friedman, D., Nessler, D., Johnson, R., Ritter, W., & Bersick, M. (2007). Age-Related Changes in Executive Function: An Event-Related Potential (ERP) Investigation of Task-Switching. Aging, *Neuropsychology, and Cognition, 15*(1), 95–128. https://doi.org/10.1080/13825580701533769
Study 111	Kopp, B., Lange, F., Howe, J., & Wessel, K. (2014). Age-related changes in neural recruitment for cognitive control. *Brain and Cognition, 85*, 209–219. https://doi.org/10.1016/j.bandc.2013.12.008
Study 121	Chang, W. P., Shen, I. H., Wen, C.P., & Chen, C. L. (2020). Age-Related Differences Between Young and Old Adults: Effects of Advance Information on Task Switching. *Perceptual and Motor Skills, 127*(6), 985–1014. https://doi.org/10.1177/0031512520930872

Table F2

References for Studies Reviewed in Chapter Three

Study Number	Reference
Study 127	Lien, M. C., Ruthruff, E., & Kuhns, D. (2008). Age-related differences in switching between cognitive tasks: Does internal control ability decline with age? *Psychology and Aging, 23*(2), 330–341. https://doi.org/10.1037/0882-7974.23.2.330
Study 128	Hirsch, P., Schwarzkopp, T., Declerck, M., Reese, S., & Koch, I. (2016). Age-related differences in task switching and task preparation: Exploring the role of task-set competition. *Acta Psychologica, 170*, 66–73. https://doi.org/10.1016/j.actpsy.2016.06.008
Study 132	Calabria, M., Branzi, F. M., Marne, P., Hernández, M., & Costa, A. (2015). Age-related effects over bilingual language control and executive control. *Bilingualism: Language and Cognition, 18*(1), 65–78. https://doi.org/10.1017/S1366728913000138
Study 134	Zhu, Z., Hakun, J. G., Johnson, N. F., & Gold, B. T. (2014). Age-related increases in right frontal activation during task switching are mediated by reaction time and white matter microstructure. *Neuroscience*, 278, 51–61. https://doi.org/10.1016/j.neuroscience.2014.07.076
Study 136	Gaál, Z. A., & Czigler, I. (2015). Age-related processing strategies and go–nogo effects in task-switching: An ERP study. *Frontiers in Human Neuroscience,* 09. https://doi.org/10.3389/fnhum.2015.00177
Study 137	Jimura, K., & Braver, T. S. (2010). Age-Related Shifts in Brain Activity Dynamics during Task Switching. *Cerebral Cortex, 20*(6), 1420–1431. https://doi.org/10.1093/cercor/bhp206
Study 138	Gold, B. T., Powell, D. K., Xuan, L., Jicha, G. A., & Smith, C. D. (2010). Age-related slowing of task switching is associated with decreased integrity of frontoparietal white matter. *Neurobiology of Aging, 31*(3), 512–522. https://doi.org/10.1016/j.neurobiolaging.2008.04.005
Study 143	Hahn, S., Kramer, A. F., & Gopher, D. (1997). Aging and Executive Control in Task Switching. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 41(1), 105–109. https://doi.org/10.1177/107118139704100125

Table F2

References for Studies Reviewed in Chapter Three

Study Number	Reference
Study 149	Terry, C. P., & Sliwinski, M. J. (2012). Aging and Random Task Switching: The Role of Endogenous Versus Exogenous Task Selection. *Experimental Aging Research, 38*(1), 87–109. https://doi.org/10.1080/0361073X.2012.637008
Study 162	Verhaeghen, P., & Hoyer, W. J. (2007). Aging, Focus Switching, and Task Switching in a Continuous Calculation Task: Evidence Toward a New Working Memory Control Process. *Aging, Neuropsychology, and Cognition, 14*(1), 22–39. https://doi.org/10.1080/138255890969357
Study 165	Serbruyns, L., Leunissen, I., van Ruitenbeek, P., Pauwels, L., Caeyenberghs, K., Solesio-Jofre, E., Geurts, M., Cuypers, K., Meesen, R. L., Sunaert, S., Leemans, A., & Swinnen, S. P. (2016). Alterations in brain white matter contributing to age-related slowing of task switching performance: The role of radial diffusivity and magnetization transfer ratio. *Human Brain Mapping, 37*(11), 4084–4098. https://doi.org/10.1002/hbm.23297
Study 271	Verstynen, T. D., Lynch, B., Miller, D. L., Voss, M. W., Prakash, R. S., Chaddock, L., Basak, C., Szabo, A., Olson, E. A., Wojcicki, T. R., Fanning, J., Gothe, N. P., McAuley, E., Kramer, A. F., & Erickson, K. I. (2012). Caudate Nucleus Volume Mediates the Link between Cardiorespiratory Fitness and Cognitive Flexibility in Older Adults. *Journal of Aging Research, 2012*, 1–11. https://doi.org/10.1155/2012/939285
Study 272	Madden, D. J., Spaniol, J., Costello, M. C., Bucur, B., White, L. E., Cabeza, R., Davis, S. W., Dennis, N. A., Provenzale, J. M., & Huettel, S. A. (2008). Cerebral White Matter Integrity Mediates Adult Age Differences in Cognitive Performance. *Journal of Cognitive Neuroscience, 21*(2), 289–302. https://doi.org/10.1162/jocn.2009.21047
Study 341	Mayr, U., & Kliegl, R. (2000). Complex semantic processing in old age: Does it stay or does it go? *Psychology and Aging, 15*(1), 29–43. https://doi.org/10.1037/0882-7974.15.1.29

Table F2

References for Studies Reviewed in Chapter Three

Study Number	Reference
Study 391	Wetter, S. R., Delis, D. C., Houston, W. S., Jacobson, M. W., Lansing, A., Cobell, K., Salmon, D. P., & Bondi, M. W. (2005). Deficits in Inhibition and Flexibility are Associated with the APOE-E4 Allele in Nondemented Older Adults. *Journal of Clinical and Experimental Neuropsychology, 27*(8), 943–952. https://doi.org/10.1080/13803390490919001
Study 401	Glisky, E. L., Alexander, G. E., Hou, M., Kawa, K., Woolverton, C. B., Zigman, E. K., Nguyen, L. A., Haws, K., Figueredo, A. J., & Ryan, L. (2021). Differences between young and older adults in unity and diversity of executive functions. *Aging, Neuropsychology, and Cognition, 28*(6), 829–854. https://doi.org/10.1080/13825585.2020.1830936
Study 409	West, R., & Travers, S. (2008). Differential effects of aging on processes underlying task switching. *Brain and Cognition, 68*(1), 67–80. https://doi.org/10.1016/j.bandc.2008.03.001
Study 489	Ging-Jehli, N. R., & Ratcliff, R. (2020). Effects of aging in a task-switch paradigm with the diffusion decision model. *Psychology and Aging, 35*(6), 850–865. https://doi.org/10.1037/pag0000562
Study 494	Kray, J., & Eppinger, B. (2006). Effects of associative learning on age differences in task-set switching. *Acta Psychologica, 123*(3), 187–203. https://doi.org/10.1016/j.actpsy.2005.12.009
Study 540	Hakun, J. G., Zhu, Z., Johnson, N. F., & Gold, B. T. (2015). Evidence for reduced efficiency and successful compensation in older adults during task switching. *Cortex, 64*, 352–362. https://doi.org/10.1016/j.cortex.2014.12.006
Study 545	de Bruin, A., Bak, T. H., & Della Sala, S. (2015). Examining the effects of active versus inactive bilingualism on executive control in a carefully matched non-immigrant sample. *Journal of Memory and Language, 85*, 15–26. https://doi.org/10.1016/j.jml.2015.07.001
Study 554	Vaughan, L., & Giovanello, K. (2010). Executive function in daily life: Age-related influences of executive processes on instrumental activities of daily living. *Psychology and Aging, 25*(2), 343–355. https://doi.org/10.1037/a0017729

Table F2

References for Studies Reviewed in Chapter Three

Study Number	Reference
Study 568	Dai, C.-T., Chang, Y.-K., Huang, C.-J., & Hung, T.-M. (2013). Exercise mode and executive function in older adults: An ERP study of task-switching. *Brain and Cognition, 83*(2), 153–162. https://doi.org/10.1016/j.bandc.2013.07.007
Study 569	Li, D., Huang, C.-J., Liu, S.-C., Chang, K.-H., & Hung, T.-M. (2019). Exercise type relates to inhibitory and error processing functions in older adults. *Aging, Neuropsychology, and Cognition, 26*(6), 865–881. https://doi.org/10.1080/13825585.2018.1540688
Study 570	Tsai, C.-L., & Wang, W.-L. (2015). Exercise-mode-related changes in task-switching performance in the elderly. *Frontiers in Behavioral Neuroscience*, 9. https://doi.org/10.3389/fnbeh.2015.00056
Study 576	Sombric, C. J., Harker, H. M., Sparto, P. J., & Torres-Oviedo, G. (2017). Explicit Action Switching Interferes with the Context-Specificity of Motor Memories in Older Adults. *Frontiers in Aging Neuroscience,* 9. https://doi.org/10.3389/fnagi.2017.00040
Study 607	Eich, T. S., Parker, D., Liu, D., Oh, H., Razlighi, Q., Gazes, Y., Habeck, C., & Stern, Y. (2016). Functional brain and age-related changes associated with congruency in task switching. *Neuropsychologia, 91*, 211–221. https://doi.org/10.1016/j.neuropsychologia.2016.08.009
Study 612	Gazes, Y., Habeck, C., O'Shea, D., Razlighi, Q. R., Steffener, J., & Stern, Y. (2015). Functional network mediates age-related differences in reaction time: A replication and extension study. *Brain and Behavior, 5*(5). https://doi.org/10.1002/brb3.324
Study 621	DiGirolamo, G. J., Kramer, A. F., Barad, V., Cepeda, N. J., Weissman, D. H., Milham, M. P., Wszalek, T. M., Cohen, N. J., Banich, M. T., Webb, A., Belopolsky, A. V., & McAuley, E. (2001). General and task-specific frontal lobe recruitment in older adults during executive processes: A fMRI investigation of task-switching. *Neuroreport, 12*(9), 2065–2071. https://doi.org/10.1097/00001756-200107030-00054
Study 627	Erickson, K. I. (2008). Genetic contributions to age-related decline in executive function: A 10-year longitudinal study of COMT and BDNF polymorphisms. *Frontiers in Human Neuroscience*, 2. https://doi.org/10.3389/neuro.09.011.2008

Table F2

References for Studies Reviewed in Chapter Three

Study Number	Reference
Study 694	Qin, S., & Basak, C. (2020). Influence of Multiple Cardiovascular Risk Factors on Task-Switching in Older Adults: An fMRI Study. *Frontiers in Human Neuroscience*, 14, 561877. https://doi.org/10.3389/fnhum.2020.561877
Study 732	Kunimi, M., Kiyama, S., & Nakai, T. (2016). Investigation of age-related changes in brain activity during the divalent task-switching paradigm using functional MRI. *Neuroscience Research, 103*, 18–26. https://doi.org/10.1016/j.neures.2015.06.011
Study 763	Gajewski, P. D., & Falkenstein, M. (2015). Lifelong physical activity and executive functions in older age assessed by memory based task switching. *Neuropsychologia, 73*, 195–207. https://doi.org/10.1016/j.neuropsychologia.2015.04.031
Study 833	Enriquez-Geppert, S., & Barceló, F. (2018). Multisubject Decomposition of Event-related Positivities in Cognitive Control: Tackling Age-related Changes in Reactive Control. *Brain Topography, 31*(1), 17–34. https://doi.org/10.1007/s10548-016-0512-4
Study 857	Head, D., Rodrigue, K. M., Kennedy, K. M., & Raz, N. (2008). Neuroanatomical and cognitive mediators of age-related differences in episodic memory. *Neuropsychology, 22*(4), 491–507. https://doi.org/10.1037/0894-4105.22.4.491
Study 861	Steffener, J., Barulli, D., Habeck, C., & Stern, Y. (2014). Neuroimaging explanations of age-related differences in task performance. *Frontiers in Aging Neuroscience,* 6. https://doi.org/10.3389/fnagi.2014.00046
Study 882	Meiran, N., Gotler, A., & Perlman, A. (2001). Old Age Is Associated With a Pattern of Relatively Intact and Relatively Impaired Task-Set Switching Abilities. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 56*(2), P88–P102. https://doi.org/10.1093/geronb/56.2.P88
Study 943	Albinet, C. T., Boucard, G., Bouquet, C. A., & Audiffren, M. (2012). Processing speed and executive functions in cognitive aging: How to disentangle their mutual relationship? *Brain and Cognition, 79*(1), 1–11. https://doi.org/10.1016/j.bandc.2012.02.001
Study 963	Zhu, Z., Johnson, N. F., Kim, C., & Gold, B. T. (2015). Reduced Frontal Cortex Efficiency is Associated with Lower White Matter Integrity in Aging. *Cerebral Cortex, 25*(1), 138–146. https://doi.org/10.1093/cercor/bht212

Table F2

References for Studies Reviewed in Chapter Three

Study Number	Reference
Study 1036	Van Asselen, M., & Ridderinkhof, K. R. (2000). Shift Costs of Predictable and Unexpected Set Shifting in Young and Older Adults. *Psychologica Belgica, 40*(4), 259. https://doi.org/10.5334/pb.966
Study 1100	Kramer, A. F., Hahn, S., & Gopher, D. (1999). Task coordination and aging: Explorations of executive control processes in the task switching paradigm. *Acta Psychologica, 101*(2–3), 339–378. https://doi.org/10.1016/S0001-6918(99)00011-6
Study 1140	Fong, D. Y., Chi, L. K., Li, F., & Chang, Y. K. (2014). The benefits of endurance exercise and Tai Chi Chuan for the task-switching aspect of executive function in older adults: An ERP study. *Frontiers in Aging Neuroscience,* 6. https://doi.org/10.3389/fnagi.2014.00295
Study 1211	Steffener, J., Gazes, Y., Habeck, C., & Stern, Y. (2016). The Indirect Effect of Age Group on Switch Costs via Gray Matter Volume and Task-Related Brain Activity. *Frontiers in Aging Neuroscience*, 8. https://doi.org/10.3389/fnagi.2016.00162
Study 1230	Gajewski, P. D., Hengstler, J. G., Golka, K., Falkenstein, M., & Beste, C. (2011). The Met-allele of the BDNF Val66Met polymorphism enhances task switching in elderly. *Neurobiology of Aging, 32*(12), 2327.e7-2327.e19. https://doi.org/10.1016/j.neurobiolaging.2011.06.010
Study 1267	Simon, A., & Bock, O. (2017). The role of cognition for different stages of visuomotor adaptation in younger and older adults. *Human Movement Science, 52*, 215–222. https://doi.org/10.1016/j.humov.2017.02.011
Study 1270	Prakash, R. S., Hussain, M. A., & Schirda, B. (2015). The role of emotion regulation and cognitive control in the association between mindfulness disposition and stress. *Psychology and Aging, 30*(1), 160–171. https://doi.org/10.1037/a0038544
Study 1278	Lawo, V., Philipp, A. M., Schuch, S., & Koch, I. (2012). The role of task preparation and task inhibition in age-related task-switching deficits. *Psychology and Aging, 27*(4), 1130–1137. https://doi.org/10.1037/a0027455
Study 1281	Pettigrew, C., & Martin, R. C. (2016). The role of working memory capacity and interference resolution mechanisms in task

Table F2

References for Studies Reviewed in Chapter Three

Study Number	Reference
	switching. *Quarterly Journal of Experimental Psychology, 69*(12), 2431–2451. https://doi.org/10.1080/17470218.2015.1121282
Study 1370	Hawkes, T. D., Siu, K. C., Silsupadol, P., & Woollacott, M. H. (2012). Why does older adults' balance become less stable when walking and performing a secondary task? Examination of attentional switching abilities. *Gait & Posture, 35*(1), 159–163. https://doi.org/10.1016/j.gaitpost.2011.09.001
Study 1519	Idowu, M. I., & Szameitat, A. J. (2023). Executive function abilities in cognitively healthy young and older adults—A cross-sectional study. *Frontiers in Aging Neuroscience*, *15*, 976915. https://doi.org/10.3389/fnagi.2023.976915
Study 1526	Li, T., Xia, H., Li, H., He, Q., & Chen, A. (2023). Functional Connectivity Alterations of Cognitive Flexibility in Aging: Different Patterns of Global and Local Switch Costs. *The Journals of Gerontology: Series B*, gbad092. https://doi.org/10.1093/geronb/gbad092
Study 1550	Nagy, B., Czigler, I., Csizmadia, P., File, D., Fáy, N., & Gaál, Z. A. (2023). Investigating the involvement of cognitive control processes in innovative and adaptive creativity and their age-related changes. *Frontiers in Human Neuroscience*, *17*, 1033508. https://doi.org/10.3389/fnhum.2023.1033508

Note. Complete references are provided for all reviewed studies. Study numbers were assigned during the screening stage. Studies not presented in this table were excluded based on the inclusion and exclusion criteria of the systematic review.

Content Relevant to Results

Figure F1

Publication Year for the Records (N = 66) Included in the Systematic Review

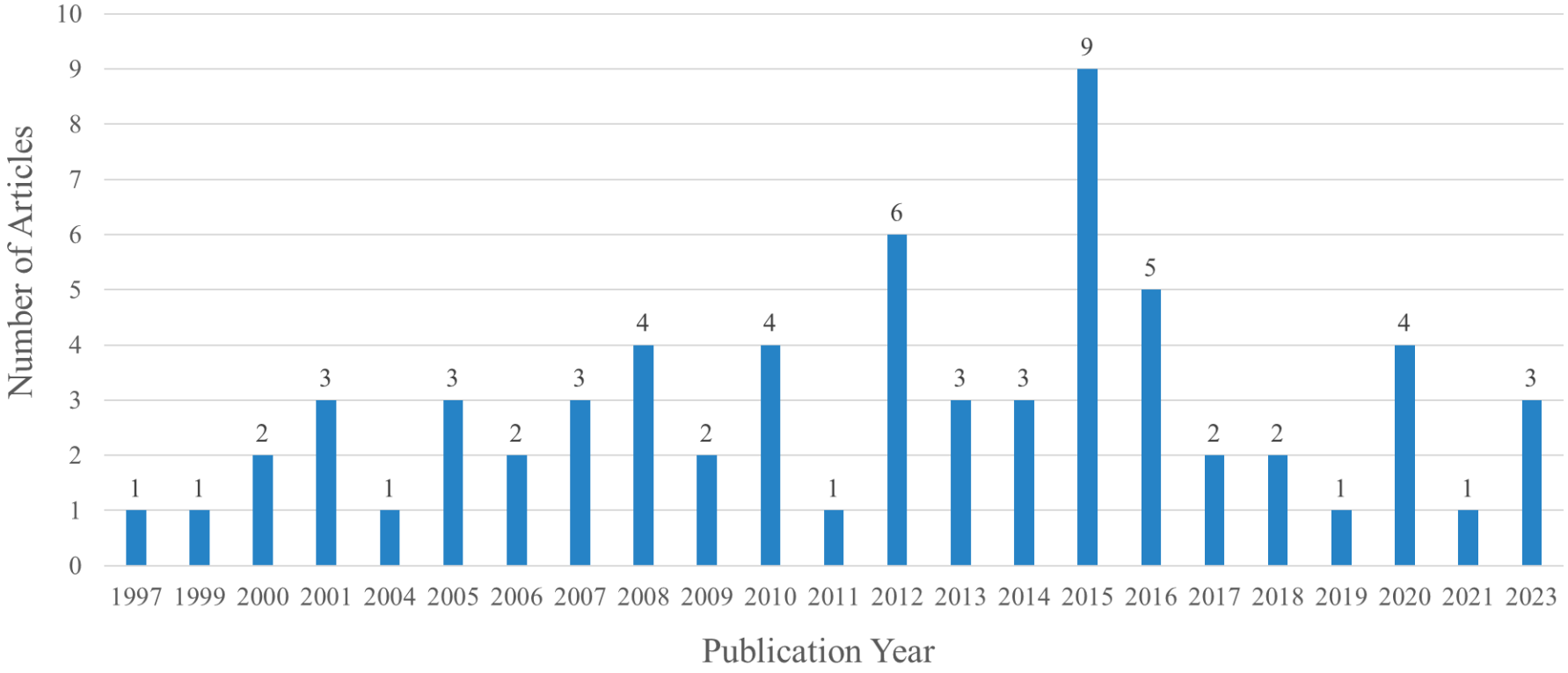


Table F3
Summary of Base-Tasks

Base-Tasks Category	Base-Tasks	Study Count	Year Range
Digit Tasks			
	Digit parity (odd/even), digit comparison (greater/less than 5)	14	2006-2020
Colour and Shape Tasks			
	Shape discrimination (e.g., circle/square), colour discrimination (e.g., red/green)	9	2010-2018
	Form discrimination (line either horizontal or vertical, cross), colour discrimination (cyan/magenta/white)	1	2001
Colour and Letter Tasks			
	Colour (or luminance) discrimination (e.g., red/green/blue), letter discrimination (e.g., I/S/O)	4	2008-2020
	Stroop Task in task-switching paradigm	6	2005-2008
Digit and Letter Tasks			
	Digit characteristics (odd/ even), letter characteristics (consonant/ vowel)	5	2008-2020
	Digit characteristics (greater/less than 5), letter characteristics (consonant/ vowel)	3	2000-2023

Table F3
Summary of Base-Tasks

Base-Tasks Category	Base-Tasks	Study Count	Year Range
Switch Between Three Tasks			
	Digit characteristics (odd/even), letter characteristics (uppercase/lowercase), and colour discrimination (red/blue)	2	2015
	Shape discrimination (circle/square), colour discrimination (red/green), and form discrimination (plus vs line)	1	2001
	Digit characteristics (greater/less than 5, odd/even, larger/smaller font)	2	2011, 2015
	Shape characteristics (circle/square, red/blue, small/large)	2	2012
Spatial Tasks			
	Location of the stimulus (upper/lower, right/left)	3	2001
	Eye position (look toward or away from stimuli)	1	2004
	Visuospatial task (corresponding or opposite space-key mapping)	1	2012
Semantic and Non-Semantic Tasks			
	Semantic discrimination (e.g., fruit/vegetable), size discrimination (large/small)	4	2009-2017

Table F3
Summary of Base-Tasks

Base-Tasks Category	Base-Tasks	Study Count	Year Range
	Semantic characteristic (animal/nonanimal), syllable characteristic (one/two syllables)	1	2006
Digit and Element Number Tasks			
	Digit value (less than/more than 5), element number (whether array of numbers has more than or less than five elements, all same number)	4	1999-2001
Letter Tasks			
	Letter characteristics (upper/lower, consonant/vowel)	4	2014-2016
Words Generation Tasks			
	Participant generates exemplars based on given category (switch category)	2	2000
Task Unique to a Single Study			
	Continuous calculation (average when numeric stimuli differed by two / addition or subtraction when numbers differed by one)	1	2007
	Shape discrimination (circle/diamond), size discrimination (small/large)	1	2016
	Letter discrimination (vowel/consonant), position discrimination (lower/upper)	1	2012
	Digit discrimination (1/2) or colour discrimination (blue/yellow)	1	2023

Table F3
Summary of Base-Tasks

Base-Tasks Category	Base-Tasks	Study Count	Year Range
Multiple Paradigms	Switch between either shape-discrimination (same/different shape) or colour-discrimination (same/different colour) tasks, inner-stimulus or outer-stimulus, or double-switch	1	2023
	1. Letter classification (A, E, I, U, C, G, K, Z) or digit characteristics (odd/even), informatively cued task 2. Letter classification or digit characteristics (odd/even), non-informatively cued task 3. Colour (Green, Orange, Light Blue) or shape classification task (Triangle, square, hexagon), informatively cued task	1	2015
	1. Digit characteristics (greater/less than 5), letter characteristics (consonant, vowel) 2. Digit characteristics (greater/less than 5, odd/even)	1	2015
	1. Space discrimination (left/right), word discrimination (left/right) 2. Space discrimination (matching the direction of arrow, opposite to the arrow)	1	2012
	1. Linguistic (presented picture, then verbally name the object in Catalan/Spanish) 2. Non-linguistic (shape discrimination: square/circle/triangle, Colour discrimination: green/blue/unspecified)	1	2013

Note. Study Count: Number of studies used the listed base tasks.

Table F4

Local-Switch Costs (Reaction Time) Effect Sizes Descriptive Summary

Grouped by	***N***	***Min.***	***Max.***	***Mean***	***Median***
Base-Tasks					
Colour/Digit	1	0.41	0.41	0.41	-
Colour/Letter	6	0.11	0.53	0.27	0.24
Colour/Shape	5	0.16	0.80	0.62	0.74
Digit/Element	1	0.47	0.47	0.47	-
Digit/Letter	3	0.16	0.80	0.42	0.29
Digits	5	0.76	0.97	0.83	0.81
Spatial	2	0.74	0.74	0.74	0.74
Three Tasks	3	0.48	0.67	0.55	0.49
Switch-Rules					
Colour	5	0.16	0.80	0.38	0.29
Memorise	1	0.48	0.48	0.48	-
Double	6	0.49	0.97	0.77	0.80
Unspecified	1	0.41	0.41	0.41	-
Verbal	1	0.67	0.67	0.67	-
Visual	3	0.74	0.74	0.74	0.74
Words	9	0.11	0.80	0.43	0.29
All Studies	26	0.11	0.97	0.54	0.51

Note. N = Number of reported ANOVA test results. The number of studies in each category is unevenly distributed. The interpretation of categories with less studies should be considered with extra caution, as smaller studies numbers made their results less generalisable to the represented group.

Table F5

Local-Switch Costs (Accuracy) Effect Sizes Descriptive Summary

	N	*Min.*	*Max.*	*Mean*	*Median*
Base-Tasks					
Colour/Digit	1	0.35	0.35	0.35	-
Colour/Letter	3	0.15	0.27	0.22	0.23
Colour/Shape	2	0.16	0.37	0.25	0.25
Digits	3	0.13	0.57	0.40	0.49
Semantic	1	0.54	0.54	0.54	-
Spatial	2	0.23	0.35	0.29	0.29
Three Tasks	2	0.16	0.50	0.33	0.33
Switch-Rules					
Memorise	1	0.50	0.50	0.50	-
Double	4	0.13	0.57	0.34	0.32
Unspecified	1	0.35	0.35	0.35	-
Visual	3	0.23	0.35	0.27	0.23
Words	5	0.15	0.54	0.29	0.27
All studies	14	0.13	0.57	0.32	0.25

Notes. *N* = Number of reported ANOVA test results. The number of studies in each category is unevenly distributed. The interpretation of categories with less studies should be considered with extra caution, as smaller studies numbers made their results less generalisable to the represented group.

Table F6

Global-Switch Costs (Reaction Time) Effect Sizes Descriptive Summary

Grouped by	***N***	***Min.***	***Max.***	***Mean***	***Median***
Base-Tasks					
Colour/Digit	1	0.63	0.63	0.63	-
Colour/Letter	2	0.81	0.84	0.82	0.82
Colour/Shape	2	0.76	0.77	0.76	0.76
Digit/Element	1	0.83	0.83	0.83	-
Digit/Letter	3	0.29	0.71	0.44	0.31
Digits	3	0.81	0.93	0.85	0.81
Letter/Position	1	0.80	0.80	0.80	-
Letters	2	0.85	0.87	0.86	0.86
Three Tasks	2	0.83	0.88	0.85	0.85
Switch-Rules					
Colour	6	0.29	0.87	0.74	0.82
Memorise	1	0.83	0.83	0.83	-
Double	2	0.81	0.93	0.87	0.87
Unspecified	1	0.63	0.63	0.63	-
Visual	1	0.77	0.77	0.77	-
Words	6	0.31	0.88	0.72	0.79
All Studies	17	0.29	0.93	0.75	0.81

Note. N = Number of reported ANOVA test results. The number of studies in each categories is unevenly distributed. The interpretation of categories with less studies should be considered with extra caution, as smaller studies numbers made their results less generalisable to the represented group.

Table F7

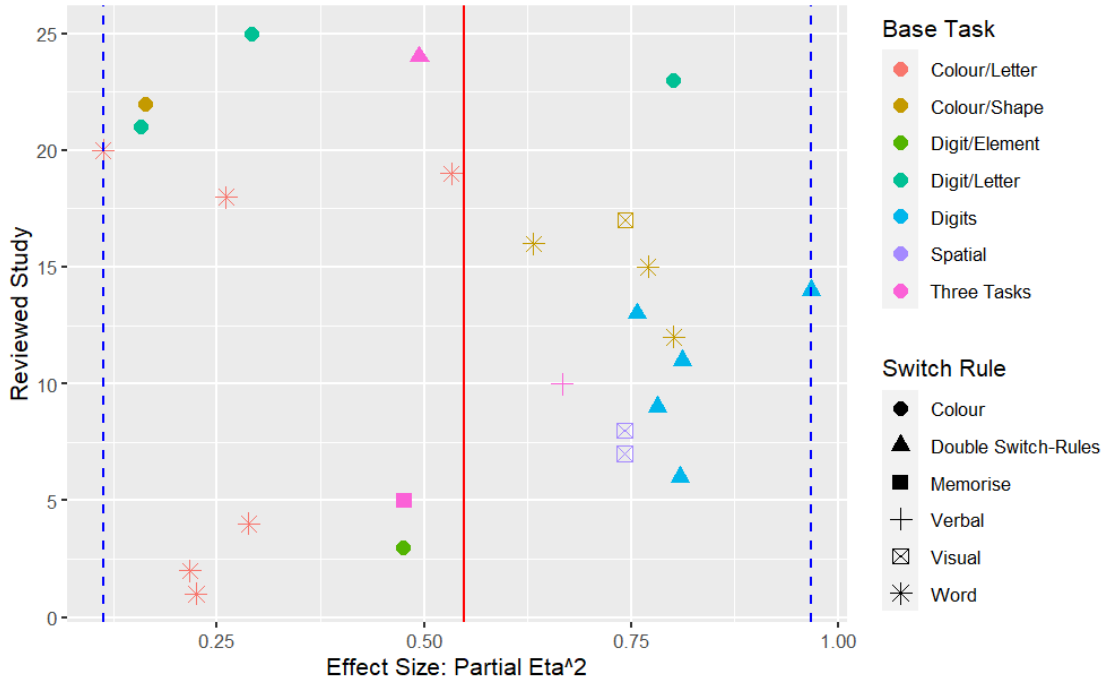
Global-Switch Costs (Accuracy) Effect Sizes Descriptive Summary

Grouped by	***N***	***Min.***	***Max.***	***Mean***	***Median***
Base-Tasks					
Colour/Digit	1	0.17	0.17	0.17	-
Colour/Letter	1	0.52	0.52	0.52	-
Colour/Shape	1	0.29	0.29	0.29	-
Digit/Element	1	0.42	0.42	0.42	-
Digit/Letter	1	0.38	0.38	0.38	-
Digits	2	0.25	0.44	0.34	0.34
Letter/Position	1	0.43	0.43	0.43	-
Letters	2	0.40	0.54	0.47	0.47
Three Tasks	2	0.30	0.46	0.38	0.38
Switch-Rules					
Colour	5	0.40	0.54	0.44	0.43
Memorise	1	0.46	0.46	0.46	-
Double	1	0.25	0.25	0.25	-
Unspecified	1	0.17	0.17	0.17	-
Visual	1	0.52	0.52	0.52	-
Words	3	0.29	0.38	0.33	0.30
All Studies	12	0.17	0.54	0.38	0.41

Note. N = Number of reported ANOVA test results. The number of studies in each category is unevenly distributed. The interpretation of categories with less studies should be considered with extra caution, as smaller studies' results are less generalisable to the represented group.

Figure F2

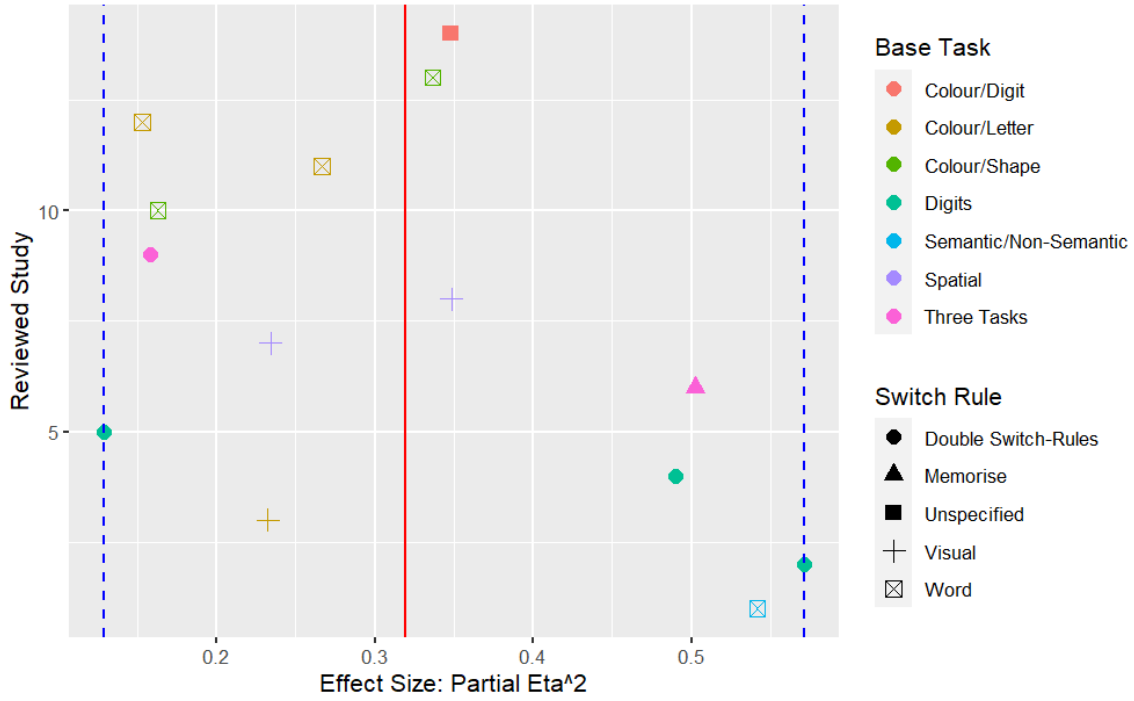
Effect Sizes of Local-Switch Costs Measured by Reaction Time (RT)



Note. This figure depicts effect sizes by study, grouped by base-task categories (colour) and switch-rule categories (shape). The red line indicates the mean of the effect sizes. The blue lines indicate the minimum and maximum effect sizes. As a special case, the study with Colour/Digit base-task and Unspecified switch-rule (partial eta-squared = 0.41) was excluded from the figure to increase figure clarity.

Figure F3

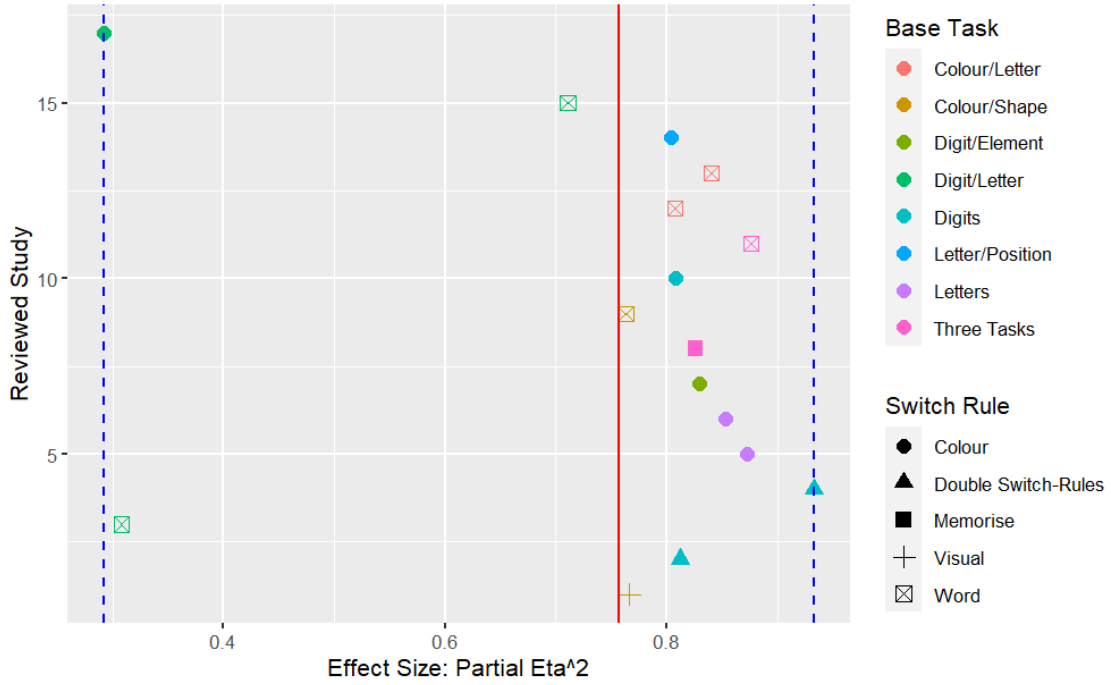
Effect Sizes of Local-Switch Costs Measured by Accuracy



Note. This figure depicts effect sizes by study, grouped by base-task categories (colour) and switch-rule categories (shape). The red line indicates the mean of the effect sizes. The blue lines indicate the minimum and maximum effect sizes.

Figure F4

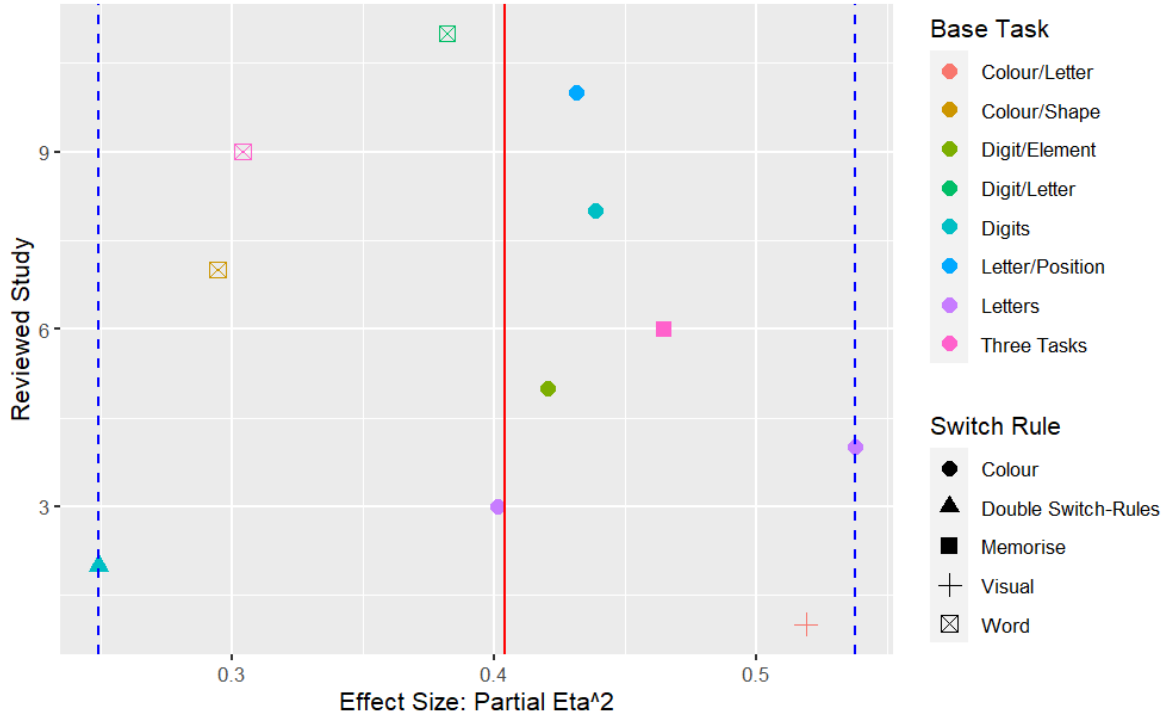
Effect Sizes of Global-Switch Costs Measured by Reaction Time (RT)



Note. This figure depicts effect sizes by study, grouped by base-task categories (colour) and switch-rule categories (shape). The red line indicates the mean of the effect sizes. The blue lines indicate the minimum and maximum effect sizes. As a special case, the study with Colour/Digit base-tasks and Unspecified switch-rules (partial eta-squared = 0.63) was excluded from the figure to increase figure clarity.

Figure F5

Effect Sizes of Global-Switch Costs Measured by Accuracy



Note. This figure depicts effect sizes by study, grouped by base-task categories (colour) and switch-rule categories (shape). The red line indicates the mean of the effect sizes. The blue lines indicate the minimum and maximum effect sizes. As a special case, the study with Colour/Digit base-task and Unspecified switch-rule (partial eta-squared = 0.17) was excluded from the figure to increase figure clarity.

Appendix G: Task-Switching Paradigm Design

Table G1

A Summary of the Number of Trials in Each Trial Type

Trial Types	Key Comparability	Number of Trials
Pure Block:		
Task-A	/	32
Task-B	/	32
Mixed Block:		
Switch	Comparable	32
Switch	Incomparable	32
No-switch	Comparable	32
No-switch	Incomparable	32

Note. Each block contains 32 trials. Each mixed block contained 4 trials from each trial type category. Switch tasks are tasks following a different task (i.e., When a Task-B trial is followed by a Task-A trial, the Task-A trial is a switch trial Task-A). No-switch tasks are tasks that are following the same task (i.e., When a Task-B isfollowed by a Task-B trial, the second Task-B trial is a no-switch Task-B trial). There were 64 comparable trials (i.e., the correct responses for two tasks were pressing the same button, e.g., 8 is an even number that is greater than 5, so that the correct response for both digit-parity and digit-comparison task was pressing the left button), and 64 incomparable trials (i.e., the correct responses for two tasks were pressing two different buttons, e.g., 9 is an odd number that is greater than 5, so that the correct responses for the digit-parity task was pressing the right button, but the correct responses for the digit-comparison task was pressing the left button).

Appendix H: Experimental Instructions

The instructions presented in section H.1 is an example based on the digit paradigm. The letter paradigm used the same instructions, with components relevant to the letter-categorisation task and luminance-discrimination task substituted. While giving this verbal instruction to participants, experimenter also pointed at components the instruction is referred to, in order to enhance participants' understanding of the experimental task.

H.1 Instructions

During the experiment, we will be using this response pad (show it to the participants), mainly this Green Button, and these two smaller Button, with your dominant hand.

In this task you will be asked to perform two simple tasks.

Please press the Green Button to start the first task.

H.1.1 Digit Comparison Task

You will first see a cue (e.g., Greater/Smaller) indicating you need to perform digit comparison task.

In this task you will be presented a digit, e.g. '4' or '6' in the middle of the screen.

Your task is to decide as fast as possible (Manipulated for different instruction emphasis) whether the digit, e.g. '6' is "Greater than 5" or "Smaller than 5".

Press the Left button if the digit is Greater than 5.

Press the Right button if the digit is Smaller than 5.

If you make a mistake, a red X appears. Simply correct your response and move on.

Press the Green Button to start practice.

H.1.2 Digit Parity Task

Next, please press the Green Button again to move on to the second task.

You will first see a cue (e.g., Odd/Even) indicating you need to perform digit comparison task.

In this task you will be presented a digit, e.g. '4' or '6' in the middle of the screen.

Your task is to decide as fast as possible (Manipulated for different instruction emphasis) whether the digit, e.g. '6' is “Odd number” or “Even number”.

Press the Left button if the digit is Odd Number.

Press the Right button if the digit is Even Number.

If you make a mistake, a red X appears. Simply correct your response and move on.

Press the Green Button to start practice.

H.1.3 Mixed Block: Two Tasks Together

We now combine the two tasks into one.

Just like before, a cue will be given followed by a digit appears in the middle of the screen.

Pay attention to the cue: The cue tells you which task to perform.

If the cue is “Greater/Smaller”, Do the Digit Comparison Task ('Greater or smaller than 5?')

If the cue is “Odd/Even”: Do the Digit Parity Task ('Odd or Even number?')

Respond as quickly and accurately as you can. If you make a mistake, you will get the chance to correct your mistake during practice.

Start practice the combined task when you are ready, by pressing the Green Button.

Practice is over and the actual task is about to start.

Pay attention to the symbol: The symbol tells you which task to perform.

If the cue is “Greater/Smaller”, Do the Digit Comparison Task ('Greater or smaller than 5?')

If the cue is “Odd/Even”: Do the Digit Parity Task ('Odd or Even number?')

Appendix I: Supplementary Results for Chapter Four (Experimental Studies)

I.1 Comparisons Between Bilinguals/Multilinguals and Monolinguals

The current section of Appendix presents additional results for comparisons of task-switching performance between monolingual participants and bilingual/multilingual participants in experimental studies reported by the Chapter Four. The Welch two-sample t-tests were used to adjust for different variances presented in monolingual and bilingual/multilingual groups.

I.1.1 Performance of the Digit Paradigm

Of 46 young participants recruited in Study 1 and Study 2 of Chapter Four, 23 were monolingual (Age mean = 21.87, age SD = 5.79, age range = 18–40; 16 women, 6 men, 1 prefer not to say), and 23 were bilingual/multilingual (Age mean = 25.22, age *SD* = 3.46, age range = 18–32; 17 women, 5 men, 1 prefer not to say).

The task-switching performance measured by the digit paradigm was analysed by an independent sample t-test, and the results suggested that there was no significant difference between monolingual participants and bilingual/multilingual participants (See Table I1).

J.1.2 Performance of the Letter Paradigms

Of 24 young participants completed the letter paradigm with difficult letter stimuli, 12 were monolingual (Age mean = 22.83, age *SD* = 6.85, age range = 18–40; 8 women, 3 men, 1 prefer not to say), and 12 were bilingual or multilingual (Age mean = 25.75, age *SD* = 2.70, age range = 18–30; 9 women, 3 men). The task-switching performance measured by the

difficult letter paradigm was analysed by independent t-tests, and the results suggested that there was no significant difference between monolingual participants and bilingual/multilingual participants (see Table I1).

Of 22 young participants completed the letter paradigm with easy letter stimuli, 11 were monolingual (Age mean = 20.82, age *SD* = 4.45, age range = 18–33; 8 women, 3 men), and 11 were bilingual or multilingual (Age mean = 24.65, age *SD* = 4.20, age range = 18–32; 8 women, 2 men, 1 prefer not to say). The task-switching performance measured by the difficult letter paradigm was analysed by independent t-tests, and the results also suggested that there was no significant difference between monolingual participants and bilingual/multilingual participants (see Table I1).

Table I1

Group Characteristics (Mean (SD)) Comparisons between Monolinguals and Bilinguals/Multilinguals within Young Participants

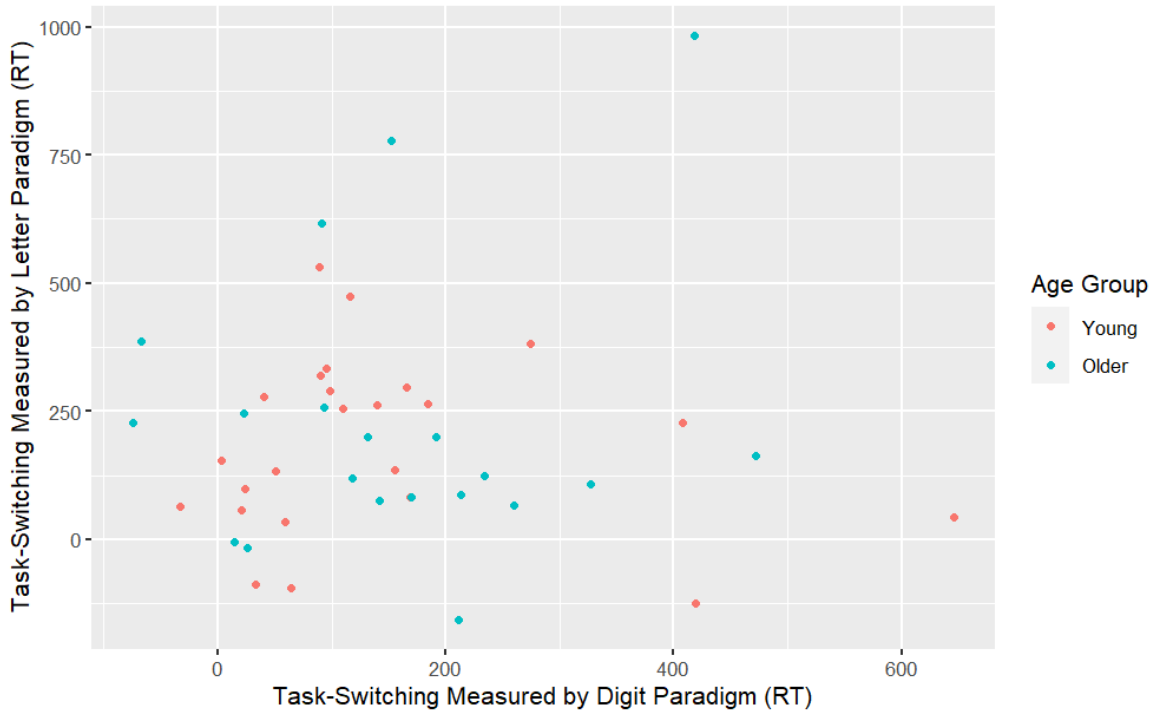
	Monolinguals	**Bilinguals**	***t (df), p***
Digit RT	**117.11** (186.41)	**171.70** (175.67)	-1.02 (43.86), 0.31
Digit Acc	**0.02** (0.04)	**0.01** (0.04)	0.77 (43.40), 0.45
Diff RT	**136.92** (152.30)	**231.41** (183.90)	-1.37 (21.26), 0.18
Diff Acc	**0.05** (0.04)	**0.009** (0.07)	1.76 (16.57), 0.10
Easy RT	**145.07** (131.54)	**93.83** (123.48)	0.94 (19.92), 0.36
Easy Acc	**0.03** (0.05)	**0.006** (0.03)	1.38 (14.44), 0.19

Note. Monolinguals = monolingual young participants. Bilinguals = bilingual and multilingual young participants. Diff = Difficult Letter Stimuli Condition, or difficult letter paradigm. Easy = Easy Letter Stimuli Condition, or easy letter paradigm. *t (df), p* = Independent *t*-test value (degree of freedom), *p*-value. Digit = Digit paradigm. RT = Local-switch costs measured by RT, in milliseconds. Acc = Local-switch costs measured by accuracy.

I.2 Task-Switching Performance Measured by Digit Paradigm and Letter Paradigm

Figure I1

Relationship Between Task-Switching Performance Measured by Digit Paradigm and Task-Switching Performance Measured by Letter Paradigm



Note. Colour of the dots is the indication of their age group. Heterogeneity was found in the relationship between task-switching performance measured by digit paradigm and task-switching performance measured by letter paradigm.

I.3 Raw RT and Accuracy Performance in Difficult and Easy Versions of Letter Paradigm

Table I2

Summary of Task-Switching Performance for Difficult and Easy Versions of Letter Paradigm in Young (N = 46) and Older (N = 40) Participants

Age Groups	Paradigm	Measure	Trial	*Mean*	*SD*
Young					
	Difficult Letter (*n* = 24)	RT	No Switch	1164.16	487.94
			Switch	1348.33	558.33
			Cost	184.17	172.04
		Acc	No Switch	0.88	0.07
			Switch	0.85	0.07
			Cost	0.03	0.06
	Easy Letter (*n* = 22)	RT	No Switch	977.23	318.21
			Switch	1096.68	382.72
			Cost	119.45	127.23
		Acc	No Switch	0.94	0.04
			Switch	0.92	0.06
			Cost	0.02	0.04
Older					
	Difficult Letter (*n* = 20)	RT	No Switch	1981.19	750.42
			Switch	2208.42	960.35
			Cost	227.23	275.98
		Acc	No Switch	0.89	0.06
			Switch	0.85	0.08
			Cost	0.03	0.06
	Easy Letter (*n* = 20)	RT	No Switch	1454.96	454.28
			Switch	1616.64	492.47
			Cost	161.68	110.97
		Acc	No Switch	0.93	0.05
			Switch	0.92	0.05
			Cost	0.02	0.06

Note. RT = Reaction time (in ms). Acc = Accuracy as a proportion of correct responses out of the total number. No Switch = No-switch trials. Switch = Switch trials. Cost = Local-switch costs.

I.4 EZ-DM Parameters

The EZ-DM parameters were computed based on the performance of the digit paradigm. The raw scores for no-switch and switch trials are presented in Table I3. The distributions of the EZ-DM parameters in young and older participants are presented in Figure I2. The association between current life complexity, measured by composite complexity score, and EZ-DM parameters are presented in Figure I3.

Table I3

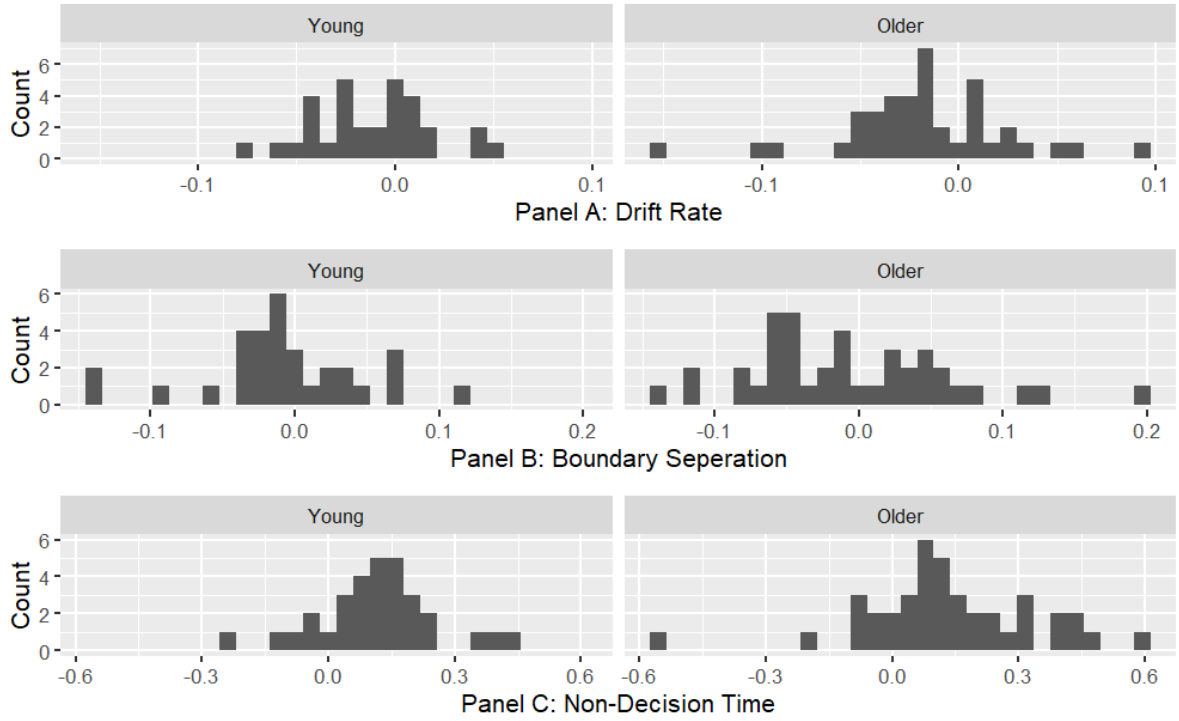
Descriptives of EZ-DM Parameters Based on the Performance of the Digit Paradigm in Young (N = 31) and Older (N = 40) Participants

Age Groups	Parameters	Trial	*Mean (SD) [Range]*
Young			
	Drift	No Switch	**0.19** (0.04) [0.09–0.31]
		Switch	**0.18** (0.05) [0.06–0.28]
	Boundary	No Switch	**0.21** (0.07) [0.11–0.37]
		Switch	**0.20** (0.07) [0.11–0.35]
	Non-Decision	No Switch	**0.25** (0.10) [0.00–0.43]
		Switch	**0.36** (0.13) [0.07–0.65]
Older			
	Drift	No Switch	**0.19** (0.06) [0.09–0.32]
		Switch	**0.18** (0.05) [0.09–0.27]
	Boundary	No Switch	**0.24** (0.06) [0.11–0.44]
		Switch	**0.24** (0.08) [0.11–0.42]
	Non-Decision	No Switch	**0.43** (0.21) [0.10–1.22]
		Switch	**0.56** (0.24) [0.00–1.26]

Note. No Switch = No-switch trials. Switch = Switch trials. Drift = Drift rate in digit paradigm. Boundary = Boundary separation in digit paradigm. Non-Decision = Non-decision time in digit paradigm.

Figure I2

Distributions of Local-Switch Costs measured by EZ-DM Parameters for Young (N = 31) and Older (N = 40) Participants



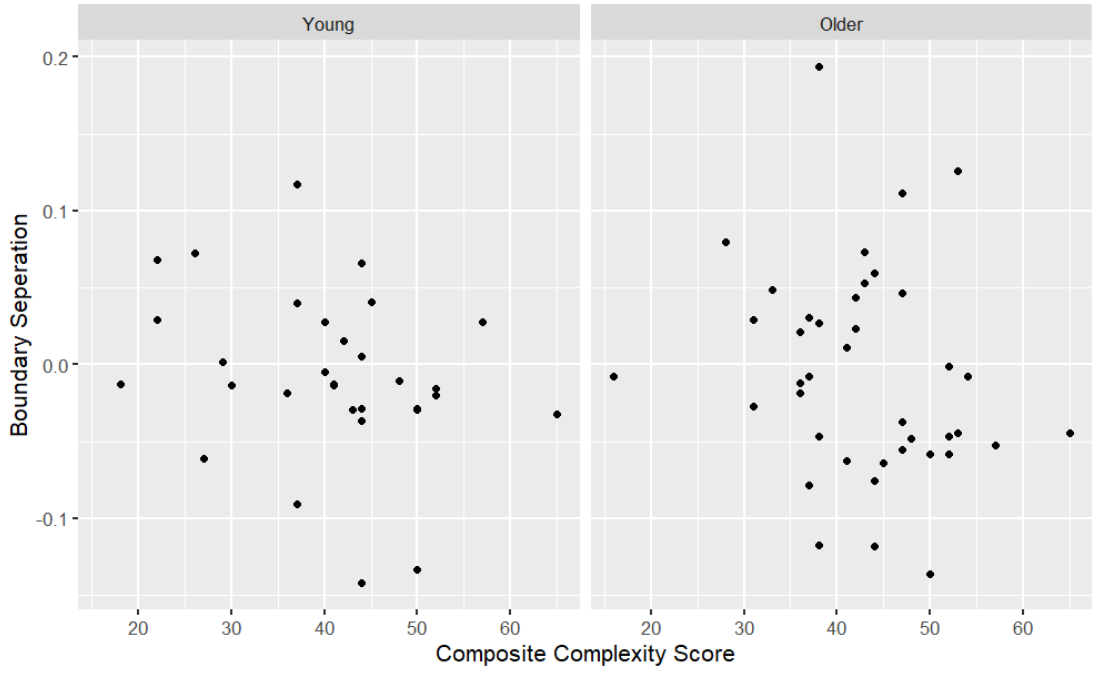
Note. The local-switch costs were measured in the digit paradigm. The presented variables are normally, or close to normally distributed.

Figure I3

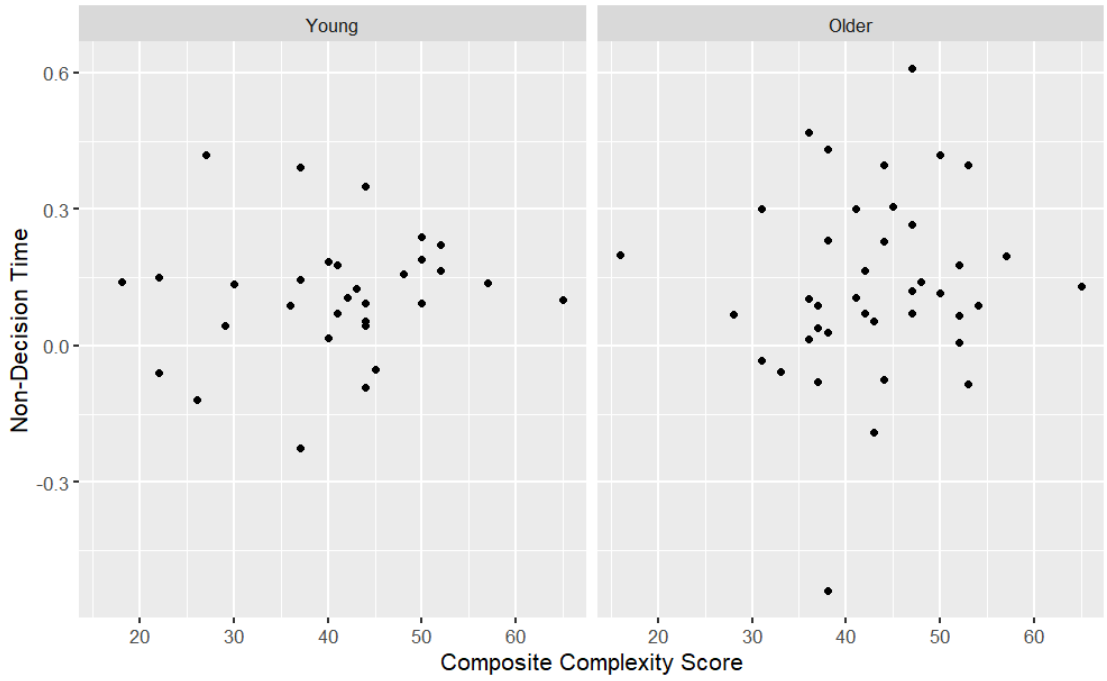
The Association Between Current Life Complexity and Local-Switch Costs Measured by EZ-DM Parameters for Young (N = 31) and Older (N = 40) Participants

Panel A: Drift Rate

Panel B: Boundary Separation



Panel C: Non-Decision Time

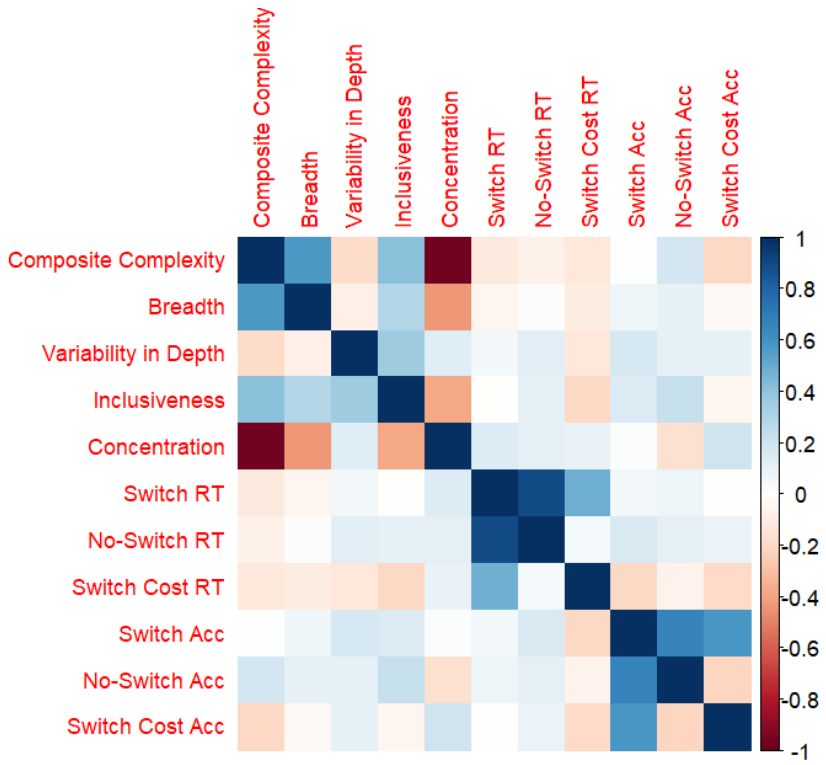


Note. The local-switch cost was measured in the digit paradigm. No clear associations between the composite complexity score and local-switch costs measured by EZ-DM parameters can be observed in the present figure.

I.5 Correlations Between Current Life Complexity Variables and Task-Switching Performance

Figure I.4

Correlation Matrix Between Current Life Complexity Variables and Task-Switching Performance



Note. RT = Reaction time. Acc = Accuracy. No-Switch = No-switch trials. Switch = Switch trials. Switch Cost = Local-switch cost in digit paradigm. Although there is a tendency that the more complex current lifestyle (i.e., larger composite score is associated with smaller cost of task-switching (i.e., smaller local-switch costs), none of the current life complexity variables and task-switching performance are strongly correlated.