EXPERIENCE AND BILINGUAL ADVANTAGE: AN EXPLORATION OF INDIVIDUAL VARIATION

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Experience and Bilingual Advantage: An Exploration of Individual Variation

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- Hui, N. Y., Fong, M. C. M., & Wang, W. S. Y. (2022). Bilingual prefabs: No switching cost was found for Hong Kong Cantonese-English code-switching. *Languages*, 7(3), 198. https://doi.org/10.3390/languages7030198

Hui Nga Yan

ABSTRACT

Bilingualism has been attracting interest from the cognitive science field for years as it is suggested to be a protective factor against cognitive decline in ageing. It is often reported that bilinguals performed better than monolinguals in inhibitory control tasks. The mechanism behind the better inhibitory control was that bilinguals would have to suppress the interference from the unwanted language all the time, and such linguistic control is thought to be, at least partially, overlapped with the general inhibitory control network. However, inconsistent results have been reported. It is common for the literature to compare monolinguals with bilinguals as two homogenous groups without considering the individual variations between and among them. Moreover, as the Adaptive Control Hypothesis (Green & Abutalebi, 2013) suggested, the interaction context affects the cognitive demand in controlling the languages. Three experiments were designed to explore how different aspects of bilingualism contribute to cognition and the bilingual advantage effect.

The first experiment recruited older adults to complete a comprehensive set of cognitive tests together with questionnaires on their language and demographic profiles. Comparing the monolinguals and bilinguals, we found the classic bilingual advantage effect: bilinguals scored higher in the Montreal Cognitive Assessment (MoCA), indicating better cognitive status. Moreover, within the bilinguals, the scores in the cognitive battery were predicted with demographic and linguistic variables using linear regression analysis. We found that L2 proficiency predicts better inhibitory control and verbal ability performance in lifelong bilinguals. We propose that, because our participants are L1-dominant speakers, only the sufficiently proficient L2 would provide enough interference in the practice of linguistic inhibition control.

The second experiment investigated the cognitive changes in older foreign language learners. Older adults were recruited to study in an elementary English course for six weeks, with cognitive tests taken before and after the course. Although the statistical results between the intervention group and the active and passive control groups were not significant, the language learning-induced differences were observed in some tasks, including the accuracy of Picture Naming and the Conflicting Effect in

the Attention Network Task. Correlation analysis suggested that successful language learners showed an improvement in inhibitory control and a decline in verbal fluency.

The third experiment investigated the organisation of the mental lexicon through an interesting language phenomenon in Hong Kong: dense code-switching. Whereas the literature often suggested that the comprehension of code-switching requires a switch in lexicon and is therefore challenging, we found that switching lexicon was needed only in the case of non-habitual word usage, regardless of whether it was unilingual and code-switching. From the result of this experiment, we proposed that the language input from the community had formed the bilingual prefabs, which integrated into the dominantly Cantonese lexicon.

Collectively, we suggest that the environment, language and cognition form a looping circle in that each component is interrelated. Moreover, they each affect the organisation of the bilingual mental lexicon and the retrieval of concepts from the lexicon. In view of that, we propose the Experience-based Bilingual Mental Lexicon Model, which is modified based on the Revised Hierarchical Model (Kroll & Stewart, 1994). Two critical assumptions are incorporated into the existing model: (1) the language lexicon is organised by experience but not by language origin, and (2) language dominance is dynamic. We believe the proposed model could better capture the dynamic change of language by experience. It could explain how individual differences contribute to the bilingual advantage effect.

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Hui, N. Y., Fong, M. C. M., & Wang, W. S. Y. (2021). Bilingual prefabs: Evidence from the predictable code-mixing in Hong Kong Cantonese. International Symposium on Bilingualism 13, Warsaw, Poland, 14 July 2021 [Poster]

Yuan, M.Y., **Hui, N.Y.**, Fong, M.C.M., Wang, W.S.Y. (2019). The "Cost-free" Code-mixing in Trilinguals: A Revision to the Adaptive Control Hypothesis". Cognitive Neuroscience Society 2019, San Francisco, US, 23 March 2019 [Poster]

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Chapter 1. INTRODUCTION

The global population is ageing rapidly. Like many major cities worldwide, Hong Kong is experiencing an ageing population and its accompanying problems, including cognitive decline. It would be beneficial to explore possible ways to improve or at least maintain the cognition of older adults. Bilingualism is believed to be one of the factors that can delay cognitive decline. However, not everyone benefits equally from bilingualism. In this dissertation, we examine the role of individual differences in linguistic, demographics, and cognitive reserve on the bilingual advantage in cognition, focusing specifically on Hong Kong's population. This chapter provides an overview of the dissertation.

1.1 AGEING AND LANGUAGE: AN OVERVIEW

Ageing is a problem faced by most parts of the world. In mid-2021, 19.4% of Hong Kong's population was 65 years or older, which is triple that of 1981 (Noesselt, 2021; "Population by Sex and Age Group," 2021); see Figure 1.1. Along with the increase in the number of older people in the population, Hong Kong's life expectancy in 2019 was 85.29, making it the highest in the world (WorldBank, retrieved on 10 April 2022). Longevity creates new challenges for society. In a simulation from 2004, it was estimated that Hong Kong would have to spend 2.2% to 4.9% of the total GDP on elderly care in 2036 (Chung et al., 2009). Normal ageing is associated with cognitive decline, including slower processing speed and poorer memory function (Christensen, 2001; Cullum et al., 2000). It was likely that the older adults would experience difficulty retrieving the name of a person or a place, or the tip-of-the-tongue phenomenon, which may make them feel frustrated (Maxim, 2009). However, the capability to live independently should not be compromised in normal ageing.

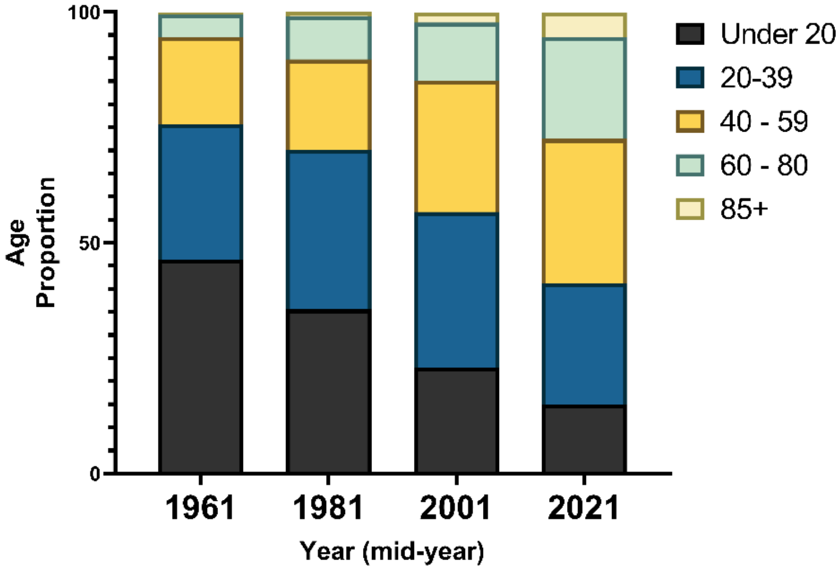

Figure 1.1. Population age profile in Hong Kong. Age information of the population in Hong Kong in 1961, 1981, 2001 and 2021 (in mid-year). Data were obtained from the Census and Statistics Department of Hong Kong.

On the other hand, pathological ageing brings an even more severe problem to society. It is estimated that about 11% of people who are 60 or above will develop dementia in 2039 in Hong Kong, and they will mostly depend on institutional care (Yu et al., 2012). The Clinical Dementia Rating Scale suggested that moderate dementia patients would need assistance in dressing or personal hygienic care, and severe dementia patients would lose the ability to do it themselves and rely entirely on their caregivers (Morris, 1991). The cost of caring for one early Alzheimer's Disease (AD) patient was estimated to be USD 9,239 per year, which would be doubled in 4 years (Zhu et al., 2006). It would become a heavy burden for society and the patient's caregivers. This problem is especially severe in China because of the one-child policy implemented since the 1980s, so that a working-age adult now would have to support two parents and four grandparents (Wang, 2019). As of the date of writing this dissertation, only one FDA-approved drug is claimed to be effective in treating Alzheimer's disease. However, its effectiveness is still under consideration by the medical community (Rubin, 2021). It is important to investigate alternative ways to at least slow down cognitive decline associated with both normal and pathological ageing.

Fortunately, not everyone develops dementia as they age, and not all people with pathologically impaired brain structures would display impaired behaviours. A study of a group of Catholic clergy found that some people retained normal cognition even if they exhibited profound AD-related brain changes (Snowdon, 1997; Snowdon & Nun, 2003; Wilson et al., 2002). According to the Cognitive Reserve Hypothesis, the engagement in intellectual activities may help some individuals be more resilient against pathological brain changes (Bartolotti et al., 2017; Stern, 2012).

Bilingualism is believed to be one of the factors contributing to the enhancement of the cognitive reserve (Reuter-Lorenz & Park, 2014). Bilinguals were reported to have a later Alzheimer's Disease onset age compared to monolinguals (Bialystok et al., 2007). Moreover, bilinguals performed better in tasks that required inhibitory ability, for instance, in the Simon task (Bialystok et al., 2004; Bialystok et al., 2014) and task-switching task (Prior & MacWhinney, 2010). Previous studies have found that the two languages of a bilingual are simultaneously and constantly activated (Marian & Spivey, 2003). In order to speak in the desired language, one has to inhibit the unwanted one. Evidence supporting the existence of bilingual advantage often suggests it is from the practice of linguistic control that transfers to the general inhibition. In this case, the cognitive control required in the inhibition process might be the key to the bilingual advantage effect. Research suggests that the difficulty of concept retrieval from the mental lexicon is determined by several factors, including the relative proficiency of the languages (Kroll & Stewart, 1994).

However, the finding on bilingual advantage was mixed, and some groups consistently could not find evidence of it (e.g., Kousaie & Phillips, 2012; Paap & Greenberg, 2013; Paap et al., 2015). It raises the question of whether such advantages depend on more specific circumstances, for instance, the proficiency of the second language (L2), the frequency with which the L2 was used, or the age of acquisition (AoA). The question of who and under what circumstances would benefit most from being bilingual is worth examining.

It is estimated that over 90% of experiment participants in the psychology field are from Western countries, yet they account for less than one-fifth of the total global population (Henrich et al., 2010). These individuals are referred to as WEIRD (**W**estern, **E**ducated, **I**ndustrialized, **R**ich and **D**emocratic) people by the authors, and, as implied by the paper's title, "*most people are not WEIRD*", or at least do not qualify for all five letters. Additionally, the study of bilingualism and cognition has been dominated by research groups in Europe and North America (van den Noort, Struys, & Bosch, 2019). In light of the fact that different kinds of language interaction require different amounts of processing effort (Green & Abutalebi, 2013), it is necessary to examine the phenomenon in a more diverse manner. The goal of this study is to fill the gaps in the literature, specifically concerning how language patterns in Hong Kong might affect older adults' cognition.

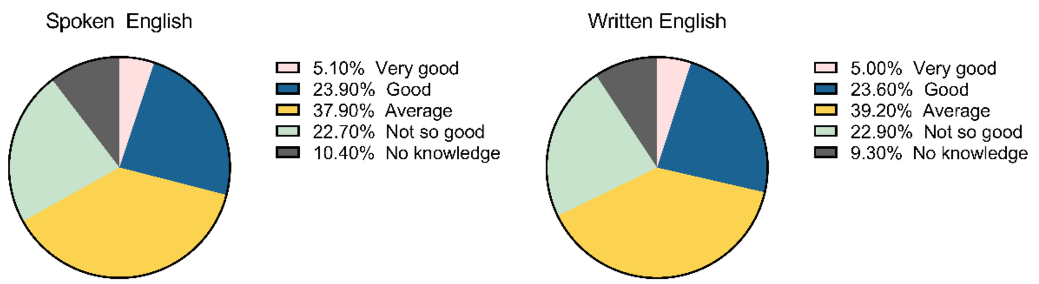

Figure 1.2. Self-rated English ability in Hong Kong. The proportion of persons aged 6 to 65 in Hong Kong rating their Spoken English (left) and Written English (right) ability as "very good", "good", "average", "not so good", and "no knowledge". Data were obtained from the Census and Statistics Department (2020).

Over 85% of the locals in Hong Kong claimed that Cantonese is their usual spoken language (*Proportion of Population Aged 5 and Over Able to Speak Selected Languages/ Dialects by Year*, 2017). English has been taught since kindergarten and is the language of instruction in many secondary schools and all universities. Because both Chinese and English are official languages, people are regularly exposed to both languages, which may range from seeing them on road signs to reading official documents. In spite of this, Cantonese remains the predominant language in the community and is used in most daily activities, whereas English is mainly used in educational institutions and tertiary industries. The 2018 Census interviewed about 560,000 people aged 6 to 65 and asked them to rate their spoken and written English ability (*Use of Language in Hong Kong in 2018*, 2020) and almost 90% of the population claimed they know at least a bit of English (see Figure 1.2). Previous studies on bilingual advantage often compare the pure monolinguals and the balanced bilinguals. However, as shown in Figure 1.2, most people rated themselves between the two extreme ends. The Hong Kong population varied widely in terms of their proficiency level in L2 and frequency of using the languages, which provides an opportunity to study bilingualism as a spectrum. Moreover, the dense Cantonese-English code-switching could cause difficulty in processing speech, thus potentially affecting the bilingual advantage effect observed.

Every individual is unique in their life experience, language profile, ageing process and cognitive changes. In this dissertation, we will investigate how the environment of Hong Kong, the language and the demographic profile of its residents affects cognition.

1.2 RESEARCH QUESTIONS

We hypothesise that the language experience would affect the cognitive demand of controlling the languages, which in turn affects the bilingual advantage effect. In this dissertation, we aimed to answer three research questions (RQs) with three experiments, each investigating different language properties.

RQ1: Is there a bilingual advantage in cognition?

RQ2: How do individual differences lead to the presence or absence of bilingual advantage in cognition?

RQ3: What affects the organization of the mental lexicon and the retrieval of concepts?

1.3 STRUCTURE OF THE DISSERTATION

This dissertation is divided into nine chapters.

Chapter 2 reviews relevant literature on the general background and theoretical basis of the project. Specifically, the Inhibitory Control Model (Green, 1998), the Adaptive Control Hypothesis (Green & Abutalebi, 2013), the Revised Hierarchical Model (Kroll & Stewart, 1994) and the Cognitive Reserve Hypothesis (Stern, 2012) will be reviewed in detail, as well as the debate on bilingual advantage. This chapter also introduces the STAC-r model (Reuter-Lorenz & Park, 2014) that provides a comprehensive view of the compensatory mechanism of ageing.

Chapter 3 reports the results from Experiment 1. Older adults were recruited to complete a set of cognitive tests and questionnaires related to language experience. A linear regression model was performed to explore the factors that affect bilingual advantage. This experiment aims to answer RQ 1 by directly comparing monolinguals and bilinguals. Also, the participant's background and language profile will be explored to see what would be the factors that affect cognition and answer RQ 2.

Chapter 4 explores the cognitive changes in older foreign language learners. Three groups of older adults were recruited to learn English (intervention group), leathercraft (active control) or nothing (passive control) in six weeks. A comparison of the cognitive performance between and after the intervention will be reported. This part addresses RQ 2 by investigating whether learning a new language, therefore becoming a new bilingual, would have effects on cognition.

Chapter 5 focuses on exploring the organisation of the mental lexicon through a special property of Hong Kong Cantonese - dense code-switching. An eye-tracking sentence comprehension experiment was conducted to understand the cognitive effort in processing code-switched sentences. Results showed that whereas non-habitual switches were cognitively demanding, habitual switches were not effortful to comprehend. This part addresses both RQ 2 and 3. We explored how code-switching might affect the mental lexicon and therefore affect the retrieval of concepts from it, thus influencing cognition.

Chapter 6 provides a summary of the findings and a general discussion that links all of the experiments in this project. Particularly, we discuss how the environment (e.g., L1-dominant society) and the language experiences (e.g., L2 usage, code-switching habit, AoA) affect cognition. Summarizing the three experiments, we aimed to answer RQ 3. We also propose an Experience-based Bilingual Mental Lexicon Model to illustrate the organisation of the lexicon, which adds the dynamic of languages to the existing bilingual mental lexicon models.

Chapter 7 discusses the significance and the limitation of the dissertation. We will also point out the possible direction of future study.

Chapter 8 lists all the references cited in this dissertation.

Chapter 9 is the Appendices.

1.4 ETHICAL STATEMENT

The project was conducted according to the guidelines of the Declaration of Helsinki and approved by the Human Subject Ethics Subcommittee of the Hong Kong Polytechnic University (Ref. No: HSEARS20200609002, date of approval: 14 Jun 2020). Informed consent was obtained from all participants involved in the study.

Chapter 2. LITERATURE REVIEW

This chapter provides a comprehensive review of the theories that establish the foundation of this dissertation. The section begins with an overview of the current understanding of bilingual advantage and the theories underlying it, including the Revised Hierarchical Model (Kroll & Stewart, 1994), Inhibitory Control Model (Green, 1998) and the Adaptive Control Hypothesis (Green & Abutalebi, 2013). Following this, the relationship between linguistic inhibition and general inhibition skills will be discussed in detail. Executive function is a complicated mechanism that includes a vast variety of cognitive abilities. Likewise, bilingualism is not an either-or phenomenon but a continuum with a wide range of variation between the two ends. With the two complicated features combined, it was understandable for the literature to report conflicting findings. As the Cognitive Reserve theory (Stern, 2012) pointed out, individual differences in life might contribute to the amount of cognitive reserve that protects against pathological changes. To understand bilingualism and its cognitive consequences, it is crucial that we do not oversimplify individual differences.

2.1 BILINGUAL ADVANTAGE: THE DEBATE

Cognitive ageing refers to the decline in cognition and brain function as the result of increased age (Gallo et al., 2022). In normal healthy ageing, most cognitive functions, including the speed of processing, working memory and long-term memory, were also found to be declining (Park & Reuter-Lorenz, 2009). The decline in behavioural performance is even more severe in pathological ageing, for example, Mild Cognitive Impairment (MCI) and Alzheimer's Disease (AD). In the field of bilingualism and ageing, Bialystok et al. (2007) were one of the pioneers that pointed out that being bilingual might delay the onset of AD. Using data from the memory clinic, they found that bilinguals experienced symptom onset at a mean age of 75.5 while monolinguals did so at a mean age of 71.4, indicating that bilinguals enjoyed symptom-free time for roughly 4.1 years longer than monolinguals. Similar results were replicated in a confirmatory study by the same team with different participants in Toronto (Craik et al., 2010) and also by other research teams in India (Alladi et al., 2013), Belgium (Woumans et al., 2014) and Cantonese-Mandarin bidialectal older adults in Guangzhou (Zheng et al., 2018).

This thesis, however, focuses on the cognition of non-pathological population. Regarding cognitive abilities, bilinguals were sometimes found to perform better than monolinguals in certain tasks. For instance, young and old monolinguals and bilinguals were recruited to perform a Stroop task (Bialystok et al., 2014). In their study, bilinguals were less affected by interference in both age groups. A similar effect was also found in the Simon task (Bialystok et al., 2004; Lee Salvatierra & Rosselli, 2011), the modified anti-saccade task (Bialystok et al., 2006), and the task-switching task (Prior & MacWhinney, 2010). Although these tests used various types of stimuli and required different responses, in general, they were all tapping into the inhibition ability. These tasks required participants to attend to one feature of the stimulus (e.g., the colour of the word in the Stroop task and the direction of the arrows in the Simon task) and, at the same time, ignore the interfering feature (e.g., the semantic meaning of the word in the Stroop task and the physical location of the arrows in the Simon task). Participants had to suppress the interference from the irrelevant properties of the stimuli in order to perform the task correctly. In addition to inhibition, bilingual advantage was also observed in episodic memory (Schroeder & Marian, 2012) and recollection (Wodniecka et al., 2010). In a systematic review, bilingualism is said to be reliably associated with improved cognitive abilities, particularly in attentional control and working memory (Adesope et al., 2010). Based on these findings, it is suggested that bilingual advantage may not be restricted to the inhibition of unwanted information. Instead, it might be the more general cognitive ability: executive control.

However, other studies have found more mixed outcomes. A meta-analysis of 46 studies showed that 54.3% of the reviewed papers reported bilingual advantage, 28.3% had mixed findings, and 17.4% found no difference between bilinguals and monolinguals (Van den Noort, Struys, Bosch, et al., 2019). There were also reports on advantages only in a specific population. For example, a delay in symptom onset age was found only in MCI but not in AD patients (Calabria et al., 2020). In another study, the delay of symptoms was only found in multilinguals but not bilinguals (Chertkow et al., 2010). Also, some studies found the numerically delayed onset of disease in bilinguals, but it did not reach a statistically significant level (Clare et al., 2016; Lawton et al., 2015).

Moreover, some research teams were unable to find any cognitive benefit from bilingualism. It is reported that there was no difference between older monolinguals and bilinguals in the numerical Stroop task (Antón et al., 2016), Sustained Attention to Response Task (Kousaie et al., 2014) and the Simon task (Kirk et al., 2014). A selective attention task was reported to find no difference between monolinguals and bilinguals young students (Paap et al., 2018). Paap et al. (2015) summarised their viewpoint of the bilingual advantage in the paper's title - "*bilingual advantages in executive functioning either do not exist or are restricted to very specific and undetermined circumstances*". The authors suggested that the so-called bilingual advantage effect is the result of a small sample size or even statistical manipulation (Paap et al., 2020). de Bruin et al. (2015) pointed out that it might be due to publication bias, in which journals preferred positive results to null results. However, since the number of rejected articles is not available to compare to the number of accepted ones (Bialystok et al., 2015), this was only speculation worthy of note.

2.2 THEORIES BEHIND BILINGUAL ADVANTAGE

People who support bilingual advantage often attribute the effect to the Inhibition Control Model (Green, 1998), which suggests that the two languages of the bilinguals are always activated together. The bilinguals had to constantly inhibit the unwanted language during a conversation, and such practice transfers to general inhibition ability. This includes three important concepts: the organisation of the bilingual mental lexicon, the activation of concepts, and the inhibition control. The following sub-sections will discuss the fundamental theories in detail.

2.2.1 The Organisation of Bilingual Mental Lexicon

How do bilinguals store and retrieve their two languages? It is well-supported that the two languages are never completely "switched off", but rather, they are parallelly activated. In a word comprehension study of bilinguals with eye-tracking (Spivey & Marian, 1999), it was reported that Russian-English bilinguals looked at the distractor that shared the same initial sound in a task-irrelevant language. For instance, when instructed to pick up the stamp in Russian (*marku*), they would also look at the *marker* pen because the two words shared the same initial syllable, even when English was not explicitly spoken in the task. Similarly, Shook and Marian (2019) found that the English-Spanish speakers looked at the image of a shovel (*pato* in Spanish) more than the unrelated distractors when asked to click on a "duck" (*pala* in Spanish) in English. A similar effect was also observed in language pairs with different scripts (Mishra & Singh, 2014) and in different modalities (Giezen et al., 2015). In other words, the two languages of a bilingual are always simultaneously activated even if one of them is irrelevant to the task.

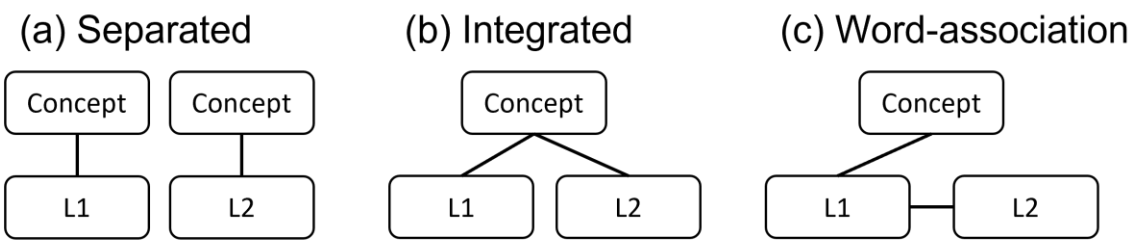

Figure 2.1. Three possible organisations of the bilingual lexicon. Simple illustration of the three possible bilingual lexicon organisations: (a) Separated, (b) Integrated, and (c) Word-association. Please see the main text for the description. “L1” and “L2” denote the word representation in the first and second languages, respectively.

The organisation of the bilingual mental lexicon has been discussed for many years. In general, there were three major schools of thought: separated, integrated, and word-association (Dong et al., 2005); see Figure 2.1 for illustration. Separate storage suggests that the two language representations (labelled as L1 and L2 in the figure) each connect to the concept separately. This model was later replaced by another hypothesis (Dong et al., 2005): integrated lexicon. The integrated lexicon, which some might call the “shared lexicon”, suggests that the concept is simultaneously linked to the two language representations. For instance, in the Conceptual Features Model, a language representation is linked with certain conceptual features, in which all or part of the features are shared with another language representation (De Groot, 1992; De Groot & Hoeks, 1995). Take "Aunt" as an example. The English word "Aunt" and its Chinese translation equivalent "阿姨" share the same conceptual features of "female" and "mother's sister". On the other hand, "Aunt" is associated with "father's sister", "women who married to parent's siblings" too, whereas in Chinese, more specific terms are used for each depending on the kinship. The Concept Mediation Model, on the other hand, suggested that the L1 and L2 each linked directly to the concept (Potter et al., 1984). The third one, concept word-association, suggested that L2 would first activate the L1, then the L1 activates the concept (Potter et al., 1984) because people usually learn the L2 via the association to its L1 translation. In other words, the L2 does not directly activate the concept.

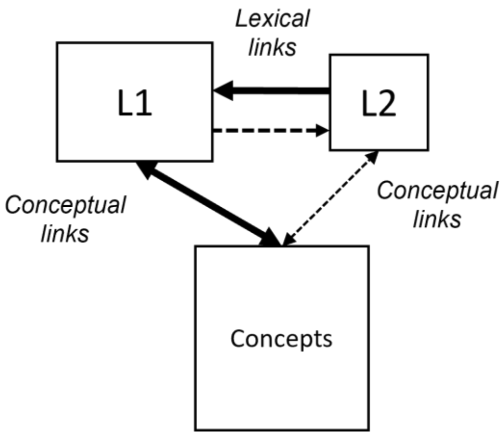

Figure 2.2. Revised Hierarchical Model. In this model, the two language representations both has direct association to the concept. Figure adapted from Kroll and Stewart (1994). Please see the main text for description.

The Revised Hierarchical Model (Kroll & Stewart, 1994) merged the idea of concept-mediation and word-association into one model. The translation equivalent of the two languages is each connected to the concept through the concept-mediation link and to each other through the lexical link. In other words, the expressions in the two languages are interrelated. This model also suggests an asymmetric association in L1 and L2 to the concept, as depicted as solid and dotted lines in Figure 2.2. Although both L1 and L2 link directly to the concept, the link between the L2 and the concept is weaker than the one between the L1 and the concept. Moreover, similar to the Parasitic model (Ecke, 2015; Ecke & Hall, 2014; Weinreich, 1953), it is suggested that proficiency affects the activation of concepts. People with lower L2 proficiency have to activate the concept via the L1, whereas people with higher L2 proficiency have developed a direct link from the L2 to the concept.

2.2.2 Activation and Inhibition of Concepts

If the two languages are always activated, then it raises another question - how could a bilingual avoid speaking in the unwanted language? The Inhibitory Control Model (IC Model; Green (1998)) was built upon the Revised Hierarchical Model (Kroll & Stewart, 1994) to illustrate the linguistic inhibition process. See Figure 2.3 for an illustration. The Conceptualiser is based on long-term memory and is language independent, which means it stores the concept abstractly but not the specific word for it. It is associated with a lemma that specifies the linguistic properties, including the language tag. The language task schema is the “mental devices or networks that individual may construct or adapt on the spot in order to achieve a specific task (Green, 1998)”. In other words, the schema determines what and how an individual prepares themselves for the language task in hand. The supervisory attentional system (SAS) modulates the activation level of the language task schemas in order to perform a specific language task. The IC model assumes that both languages remain active until one of the three conditions is fulfilled: (1) the goal is achieved, (2) the language is inhibited by another schema, and (3) the goal is changed by the SAS.

Take the Stroop task (Stroop, 1935) with a Chinese-English bilingual participant as an example. The Stroop task presents participants with a word written in an incongruent colour (e.g., the word "blue" written in red). Participants have to ignore the semantic meaning (blue) and name the colour (red). In this case, the task schema is "to read the colour and ignore the word meaning", which triggers the SAS to focus on the task. However, since reading the word is a more regular practice than reading the colour, the input (i.e., seeing the word) would affect the schema's activation level. Because the two languages of a bilingual activate simultaneously, the participants need to inhibit the unwanted language in order to complete the task correctly. Since the conceptualiser is language-independent, it stores only the information of the concept "red" but not specifically in any language. The inhibitory process would occur in the bilingual lexico-semantic system at the lemma level. Participants will only be able to produce the correct response if they (1) successfully focus on the task "read the colour", which is modulated by the SAS, and (2) inhibit the unwanted language, which is modulated in the bilingual lexico-semantic system.

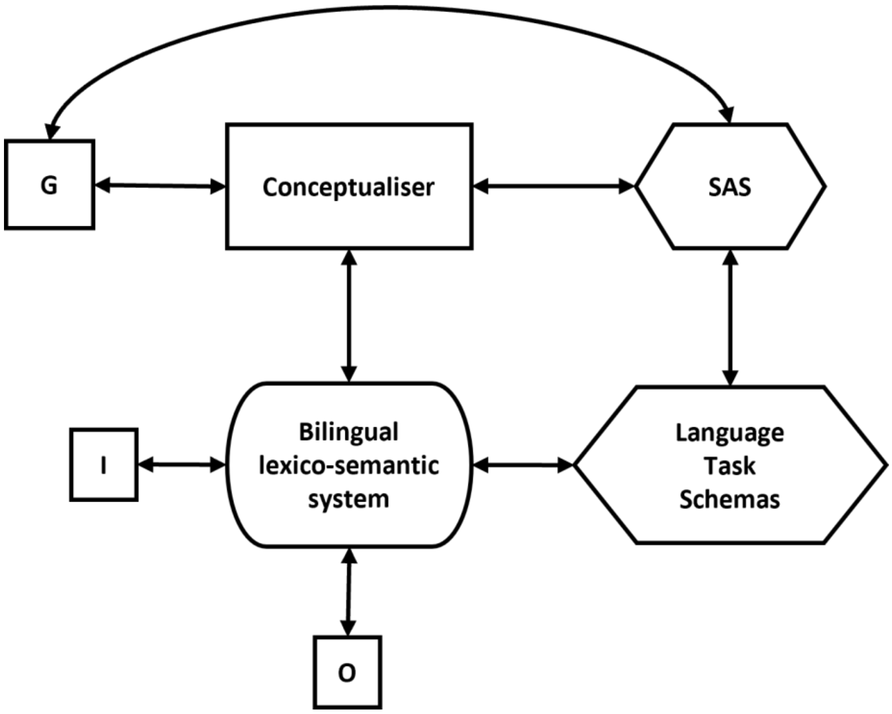

Figure 2.3. An illustration of the Inhibitory Control Model.G = Goal, I = input, O = Output, SAS = supervisory attentional system. Figure adapted from Green (1998). Please see the main text for description.

The activation level of each system is not equal. For instance, if the proportion of incongruent Stroop stimuli was higher, the schema "reading the colour" would be more dominant, and participants could respond faster (Tzelgov et al., 1992). In the language-switching task, participants would have to name the items in the cued language. The task schema would be more fixed if they are naming in the same language in consecutive trials. Nevertheless, once they were cued to switch, the task schema of "reading in Language A" is terminated and replaced by "reading in Language B". Therefore, a delay in switched trials than in non-switch trials would be observed (Meuter & Allport, 1999). The relative proficiency also affects how much cognitive control is needed (De Bruin et al., 2014). Individuals modulate the degree of control to achieve the goal of the language task.

A decade later, Green and Abutalebi (2013) proposed the Adaptive Control Hypothesis to further explain the different degrees of cognitive control in language tasks with a focus on speech production. This hypothesis suggests that cognitive control adapts to the cognitive demand from the interactional context. The authors proposed eight control processes (goal maintenance, conflict monitoring, interference suppression, salient cue detection, selective response inhibition, task disengagement, task engagement and opportunistic planning), in which three interactional contexts (single language, dual language and dense code-switching) modulate the cognitive control demand differently.

Single language refers to using one language in one environment and the other language in another specific environment. For instance, Language A (L_A) is used exclusively at home and Language B (L_B) exclusively at work. Compared to monolingual speakers in the same context, an increase in control is expected for goal maintenance and interference control because of the need to stay in the same language when speaking. Dual language context refers to using both languages in both environments, for example, using L_A with colleague A and L_B with colleague B in the same office. An increase in cognitive control in all processes except opportunistic planning is expected because both languages are actively used. A bilingual speaker has to be aware of who the interlocutor is, what language the interlocutor speaks, and to stay in the same language when the bilingual speaks. Also, if a third person who speaks only L_B joins the conversation, the bilingual would have to first realise this salient cue of "another language is needed" from the presence of the third person, disengage from the L_A and then engage in L_B. This interaction context is thought to be the most cognitively challenging among the three. Dense code-switching (CS) is defined as switching between languages within a single sentence. For example, in "知唔知個 project 嘅 deadline 係幾時？ (Do you know when the project's deadline is?)", both Cantonese and English are used within the sentence. In this interaction context, it is only expected to have increased control for opportunistic planning. This is because speakers make use of any language that comes to their mind first in this kind of communication. They do not have to inhibit any languages, so the cognitive control in the other processes is minimal. However, they would have to pay special attention to the morphosyntactic integration of the two languages. For instance, in the above example, when and where to insert the words "project" and "deadline" into the Cantonese sentence.

The dense CS context is especially interesting because it is a well-known phenomenon of Hong Kong Cantonese (Pennington, 1998). Having English words inserted into the otherwise pure-Cantonese sentence is so common that even monolinguals are observed to have picked up certain English words. As suggested by the Adaptive Control Hypothesis (Green & Abutalebi, 2013), the production of CS sentences demands cognitive control to accomplish because the speaker would need to pay attention to when and where to insert the CS words. Moreover, CS comprehension was considered even more cognitively demanding than production. Studies found that the processing of CS sentences was much longer than monolingual sentences, indicating its difficulty in comprehension (e.g., Altarriba et al., 1996; Macnamara & Kushnir, 1971; Valdés Kroff et al., 2018). If the cognitive benefit of bilingualism is related to the effort required to suppress unwanted information during a conversation, a natural hypothesis would be that the more CS in daily life, the more cognitive benefits from practising it. However, the CS pattern in Hong Kong is relatively fixed, in which certain words are more likely to be produced as a CS instead of in the Cantonese expression (e.g., people tend to use the English terms "printer", "fax" then their Cantonese equivalence "打印機'', "傳真"). The CS does not occur randomly based on the speaker's personal preference but from a community norm. In this case, the cognitive effort of speaking and comprehending in CS might not be as difficult as when CS occurred unexpectedly. The literature on the cognitive consequences of being under different CS patterns is scarce (see also Adamou & Shen, 2019; Gullifer et al., 2013). Linguistic variation in different populations under different community interactions should not be simply blended into a large category.

As pointed out by the Adaptive Control Hypothesis (Green & Abutalebi, 2013), different interaction contexts require different levels of cognitive demand. Bilingualism is not a categorical variation but a continuous spectrum (DeLuca et al., 2019) that includes many variations, including proficiency, AoA, frequency of use, and also how people switch from one to another language. In fact, a previous study compared different types of foreign language speakers (monolinguals, intermediate L2 learners, advanced L2 learners, simultaneous bilinguals and multilinguals) and found that memory capacity was modulated differently (Durand López, 2020). More attention should be put on studying how linguistic variation might affect the cognitive consequences.

2.2.3 Linguistic Inhibition and General Inhibition

Both the IC Model and the Adaptive Control Hypothesis suggested that bilinguals go through a series of inhibitory processes when they speak. Abutalebi and Green (2007) and later Green and Abutalebi (2013) suggested that brain regions, including the anterior cingulate cortex (ACC), pre-supplementary motor area (pre-SMA), basal ganglia and the prefrontal cortex (PFC), were involved in the control process of language production. These areas are known to be responsible for general control. For instance, the ACC was believed to be detecting response conflict (Badre & Wagner, 2004), which was a similar process to conflict monitoring in Green and Abutalebi (2013)'s terminology. The PFC was thought to be coordinating actions to achieve the internal goal (Koechlin et al., 2003), which is what Green and Abutalebi (2013) would call the "goal maintenance" process in language control.

Direct comparison by examining the activation pattern within the same participants in the language-inhibition task and general-inhibition task confirmed the hypothesis. In the language-switching and flanker tasks, the dorsal ACC was found to be activated for both tasks in young adults (Abutalebi et al., 2012). De Baene et al. (2015) found that highly proficient bilinguals recruited the distributed frontoparietal network, specifically the lateral and medial PFC and the inferior and superior parietal lobule, to do both tasks. Similarly, De Bruin et al. (2014) reported that bilinguals recruited domain-general regions, such as the right inferior frontal gyrus (rIFG) and the pre-SMA, for the language-switching task. The results supported that the bilinguals recruited some common brain regions to perform both language and general control tasks.

Combining the IC Model and the Adaptive Control Hypothesis with the neural data, a bilingual is constantly using cognitive control to inhibit the unwanted language in any communication, but with a different cognitive demand in different language interaction contexts. Because during linguistic control processes, the brain recruited regions that were overlapping with regions for general control, bilinguals had more practice in the activation of these regions. Hence, bilinguals were believed to be performing better than their monolingual peers in tasks that required general control. On the other hand, bilingual experience different cognitive demands in linguistic inhibition in different language scenarios (Valian, 2015); thus, its cognitive outcome is expected to differ. This leads to a speculation of whether the conflicting findings in the bilingual advantage effect are due to the disregard of the language environment or the demographic of the population being studied, or in other words, the individual differences. What would be the potential contributors if, as Paap et al. (2015) concluded, the bilingual advantage is restricted to a few specific situations? Instead of treating individual differences as confounds, the variation should be further investigated (Takahesu Tabori et al., 2018).

2.3 BILINGUALISM AND EXECUTIVE FUNCTION

Bilingualism does not provide an advantage in every cognitive domain. Sometimes, it is reported that bilinguals do not differ from monolinguals (e.g., Paap et al., 2018; Papageorgiou et al., 2019), or even performing worse than monolinguals. For instance, Roberts et al. (2002) found that bilingual adults scored significantly lower in the Boston Naming Test than monolinguals. Portocarrero et al. (2007) reported that bilingual US college students have lower receptive and expressive English vocabularies than their monolingual counterparts. It was believed that the lower performance in language tasks in bilinguals was because bilinguals used each language less frequently than monolinguals, and therefore the access to each of the languages was weaker (Lehtonen et al., 2018; Michael & Gollan, 2005). However, Bialystok (2009) pointed out that whereas the bilinguals performed worse only in tasks that relied on verbal recall, they outperformed monolinguals in tasks based on executive control.

Executive control, or executive function (EF), refers to a variety of cognitive abilities that contribute to the mental control process (Denckla, 1994). Different researchers included different cognitive components as part of the EF, for example, strategic planning (Denckla, 1994), working memory (Bialystok et al., 2014), cognitive flexibility, problem-solving and reasoning (Diamond & Lee, 2011). Among these, the most studied abilities were shifting, updating, monitoring, and inhibition (Miyake et al., 2000). Miyake et al. (2000) further suggested that there was unity (i.e., a common underlying ability) and separability (i.e., the uniqueness of each) between the three cognitive abilities. Using confirmatory factor analysis with data from earlier studies, Miyake and Friedman (2012) demonstrated that the commonly used behavioural tasks could be roughly separated into three domains, namely, the updating-specific (e.g., the letter memory, spatial 2-back), the shifting-specific (e.g., colour-shape switching, number-letter switching) and inhibition (e.g., Stroop, anti-saccade task). The three domains were correlated with each other. The most important part of the computation was that, after accounting for the unity, there was no unique variance left for inhibition. In other words, inhibition seemed to be the basic ability for all EF processes. Friedman and Miyake (2017) pointed out that whereas the three abilities could be further broken down into even more basic functions, they were also likely to combine for more complex EF, such as planning.

One of the reasons for the inconsistency in the literature might be due to "task impurity", that is, the exact cognitive ability that the common behavioural tasks tapped into was unclear (Valian, 2015). For example, the Stroop test (Stroop, 1935) was frequently used as a test to examine inhibition ability, in which participants have to suppress the urge to read the word. However, participants also need the ability of colour perception, speed in articulation, and enough literacy to perform the task as the experimenter would like them to. Using the rejected data from Experiment 1 in this dissertation as an example, a participant who was near illiterate had an interference score (Golden & Freshwater, 1978, a more positive value reflects a better inhibitory ability) much higher (0.33) than the average ($M = -6.10$). However, it was because he was (1) slow in reading in the Word condition and (2) not as affected by the word meaning as the literate participants in the Colour-Word condition. It did not reflect the actual inhibition ability. While this was an extreme case that researchers would rarely include in the data analysis, this example shows how impure in detecting certain cognitive abilities the tasks could be and, therefore, the results might be. Undoubtedly there would not be a task purely for testing one specific cognitive ability, so the best practice was to include more tasks that were believed to be related to the cognitive domain in the study (Valian, 2015).

Similar to the EF, bilingualism was also not as simple as it may seem. One could not simply classify the participants of the study as either "monolingual" or "bilingual" without considering the many differences between individuals. Some factors might contribute to the bilingual advantage effect differently. For instance, Donnelly et al. (2019) reported that people with later age of acquisition (AoA) had a larger effect size for interference cost than those with early AoA. Intermediate L2 learners and multilinguals were found to have better visuospatial and phonological short-term memory, showing that the proficiency of the L2 affected cognitive abilities (Durand López, 2020). Moreover, the language distance (Laketa et al., 2021) and the script similarity between the two languages of the bilinguals (Coderre & van Heuven, 2014), as well as the frequency of using the different languages (Yow & Li, 2015) were all reported to affect the cognitive outcome.

Besides the variables on the language, the demographic information of the participants was believed to be affecting the cognitive outcome. Morton and Harper (2007) found that children from higher social-economic status (SES) outperformed those from lower SES in the cognitive control tasks. Bilingualism is believed to promote faster processing speed in low SES bilinguals, but not in high SES bilinguals (Naeem et al., 2018). These results showed that SES might be a factor that influences the bilingual advantage effect observed in the literature. Samuel et al. (2018) found that young participants from East Asian cultures were likely to outperform those from Western culture in the Simon task, suggesting that culture might also be a factor interfering with the bilingual advantage effect.

Given the complexity of executive function together with the complexity of bilingualism, it is not surprising that inconsistency was found in the literature (Valian, 2015). In order to understand the cognitive outcome of bilingualism and the mechanism behind it, we should not overlook the importance of individual variation that comes from both the outer environment and the inner properties.

2.4 THE EVER-CHANGING BRAIN

2.4.1 Life Experience and Cognitive Reserve

Even in normal ageing, the brain shrinks (Peters, 2006) and cognitive behaviour declines with it (Park & Reuter-Lorenz, 2009). However, the changes in the brain structure are not always correlated with behaviour. The most well-known study on the differences between the brain and behavioural performance is perhaps Snowdon (1997)'s Nun Study. In that study, 678 nuns voluntarily agreed to take part in yearly cognitive assessments and donate their brains after their death. Despite living in a very similar style and having the same diet, the nuns showed distinctly different ageing patterns, ranging from perfectly normal to completely incapable of communication. Sister Mary, for example, scored 27 out of 30 on the Mini-Mental State Examination

(MMSE) when she was 101 years old, suggesting almost perfect cognitive function. However, the post-mortem autopsy revealed that her brain had developed plaques and tangles in the hippocampus and neocortex, which were typically found in AD patients (Snowdon, 1997). Sister Bernadette's brain had also reached Stage 6 in the Braak and Braak scale (Braak & Braak, 1991), indicating a severe AD case. Even so, she performed exceptionally well on her annual cognitive test a year prior to her death (Snowdon & Nun, 2003). In contrast, there were cases like Sister Matthia, who lived to 104 years old and had an intact brain, and cases like Sister Agnes, who could no longer communicate in her 70s (Snowdon & Nun, 2003). The cases from the nuns showed that there are *brain reserve* and *cognitive reserve*, which both protect the behavioural performance but from a different source. The brain reserve refers to the brain's ability to withstand age-related structural changes, whereas the cognitive reserve refers to the gap between brain damage and clinical outcome (Stern, 2009). Biological factors (e.g., apoE4 gene, beta-amyloid, cortical thickness) and life experience (e.g., education, multilingualism, intellectual stimulation) are believed to contribute to the amount of reserve (See Figure 2.4).

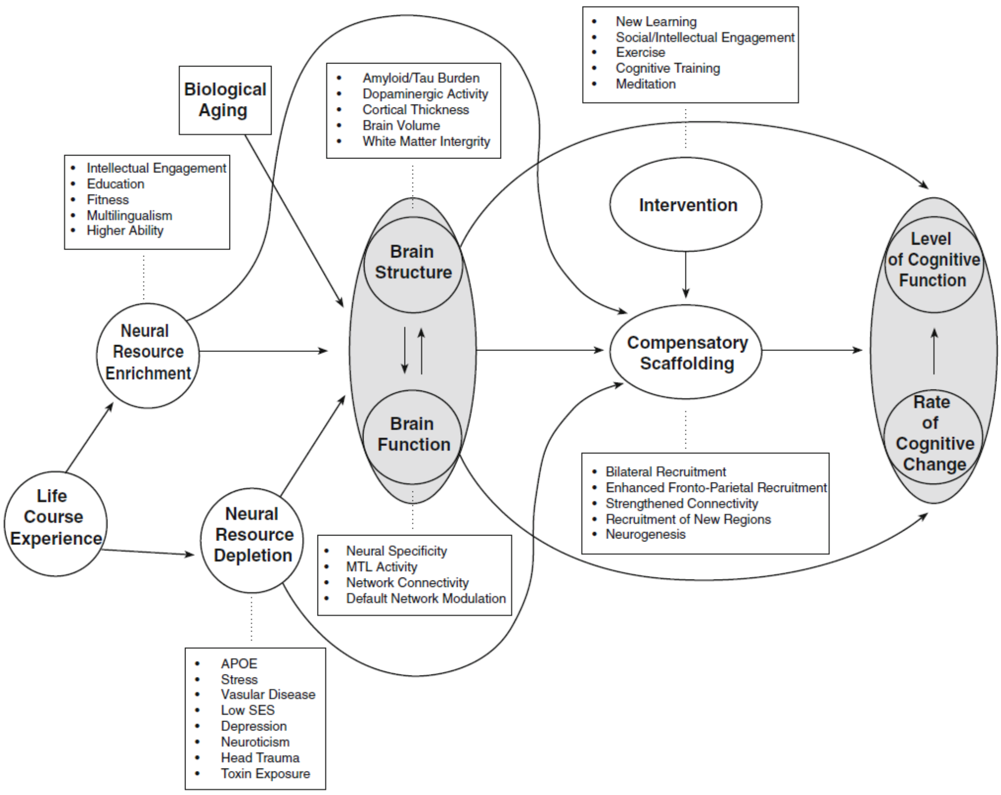

Figure 2.4. The STAC-r model The Scaffolding Theory of Aging and Cognition – Revised model. The model described positive and negative factors that contribute to the cognitive function in old age. See main text for description. Figure obtained from Reuter-Lorenz and Park (2014).

Life experience contributes to the amount of cognitive reserve. Stern (2012) explored how education, occupation and leisure activities were related to the onset age of dementia. He found that people with lower education (< 8 years) were 2.2 times more likely to develop dementia than those with a higher education level. People with low occupational attainment were 2.25 times more at risk, and those less active in leisure activities were 38% more likely to develop dementia. Individuals who possess a high level of cognitive reserve are able to withstand more brain damage than those with a low level. The protection, however, is not indefinite. If the pathology reaches the hypothetical point of severity in AD, those with high cognitive reserve would also begin to show a behavioural decline (Bialystok, 2021). Schweizer et al. (2012) found that bilinguals had greater atrophy compared to monolinguals, even when their cognitive abilities and education level were matched. Another study found that with the same level of cognitive ability in baseline measurements between the two groups, bilinguals had greater brain atrophy, specifically in parenchymal volume, compared to the monolinguals (Costumero et al., 2020). These studies collectively showed that bilinguals, who were believed to have a higher cognitive reserve, were able to sustain brain pathology and maintain their cognitive functions longer than the monolinguals.

2.4.2 Neuroplasticity and Cognitive Training

The Scaffolding Theory of Aging and Cognition – Revised (STAC-r, see Figure 2.4) was proposed to explain how life experience affects the neural resources both positively and negatively, and hence how cognition was affected (Reuter-Lorenz & Park, 2014). In the figure, apart from education and intellectual engagement that Stern (2012) suggested, multilingualism is one of the factors that could increase neural resources. On the other hand, low socioeconomic status (SES), the presence of apoE4, and depression are suggested to deplete neural resources. The neural enrichment and depletion directly affect the compensatory scaffolding process ("cognitive reserve" in Stern's term) or indirectly through the brain structural changes ("brain reserve"). Together with biological ageing, age-related changes like the accumulation of amyloid or tau, the decrease in brain volume and white matter integrity also affect brain structure and thus cognition. The decline in the brain adversely affects the cognitive level directly.

However, the compensatory scaffolding modulates the cognitive function from the lifelong neural resource enrichment and depletion. Interventions such as cognitive training and exercises were believed to contribute to the cognitive reserve, even if the activities were picked up at a later stage of life. The compensatory scaffolding refers to the mechanism utilised by older adults to achieve similar performance as younger adults. For instance, the Hemispheric Asymmetry Reduction in Older Adults (HAROLD) found that older adults were less lateralised than younger adults in memory and inhibitory control tasks (Cabeza, 2002). In addition to HAROLD, Davis et al. (2008) found that older adults had reduced occipital activity and increased frontal activity in episodic retrieval and visual perceptual tasks. They termed it the "Posterior-Anterior Shift in Ageing (PASA) model". Older adults were able to perform as accurately as younger adults by activating different brain regions, and the additional recruitment was made possible because of neuroplasticity.

Neuroplasticity, the term originally created by William James (James, 1887/2020), referred to the reorganization of the nervous system. In earlier times, it was thought that the brain was a fixed entity once we entered adulthood, and the neurons would die out as we aged. Ramon y Cajal, the father of neuroscience, had written, "Once development was ended, the founts of growth of the axons and dendrites dried up irrevocably. In the adult centers the nerve paths are something fixed, ended and immutable. Everything must die, nothing may be regenerated." in his 1913 textbook (quoted from Teter & Ashford, 2002). It was not until very recently, when neuroimaging techniques were well developed, that neurologists discovered the brain is not fixed at all. For instance, Bach-y-Rita (1972) discovered that after hours of training, blind people could identify geometric forms, letters or even human faces with vibrating electromechanical stimulators attached to the skin, which sent the signal to the brain to recognize the objects. In other words, blind people trained their brains to "see" with their skin. Later, it was reported that blind people showed activation of primary and secondary visual cortical areas during tactile tasks, whereas sighted participants showed deactivation (Sadato et al., 1996). Collectively, it shows that the brain is able to change to adapt to challenges. The neurological changes might be short or long-term in response to age-related changes or brain damage (Berlucchi & Buchtel, 2009), and it could be at every level, from molecular activity to brain-wide systems and behaviour (Costandi, 2016).

Neuroplasticity allows the brain to adapt to new environments and challenges even in old age. It opens an exciting path that suggests it is possible to delay cognitive decline through training. Researchers began to explore the possibility of cognitive training in the hope of improving cognition. By learning something new or joining intellectually stimulating activities, older adults were found to have improved cognitive abilities (Sitzer et al., 2006). Studies with older adults participating in mentally challenging games like crossword puzzles and Sudoku (Jackson et al., 2012), physical activities (Langlois et al., 2013), or a mixture of both physical and cognitive exercises (Kivipelto et al., 2013) reported improvement in cognitive tasks. Gajewski and Falkenstein (2012) found higher accuracy for the participants who attended cognitive training than those who had physical exercise, relaxation or no intervention. Wang and Covey (2020) found that working memory training could improve conflict monitoring in the untrained spatial 3-back task. Borella et al. (2013) trained the older adults with a working memory program and found improvement in the task. The benefit even persisted for eight months after the end of the intervention. One interesting phenomenon was that the training of one domain (e.g., working memory) might transfer to another cognitive domain (e.g., executive functions). This transfer happens because when the participant was trained in a particular domain, the other cognitive processes that engaged similar processes or neural regions would also benefit from it (Buschkuehl et al., 2008).

Given the encouraging results from the cognitive training studies, it was proposed that learning a foreign language in old age might also be effective in improving older adults' cognition (Antoniou et al., 2013; Antoniou & Wright, 2017). Second language learning is believed to involve an extensive brain network. For instance, working memory is needed when learning new vocabularies, and reasoning is needed when learning grammar rules (Wang, 2019). Moreover, the literature has found that a very short period of exposure to a language was enough to impose an effect on cognition. International adoptees, who were adopted to a country that speaks a language other than their mother tongue and who eventually lost their L1, were found to have a similar neural activation pattern to bilinguals than monolinguals (Pierce et al., 2015; Pierce et al., 2014). International adoptees who left their home country before one-year-old performed better in identifying the L1 phonemes (Oh et al., 2010). In addition, childhood overhearers, those who had been exposed to an L2 when they were very young but never learnt it themselves, spoke with a more nativelike accent when they were learning the L2 in adulthood (Au et al., 2002). It shows that brief exposure to a language many years ago was already enough to affect language processing (Takahesu Tabori et al., 2018). Could learning a second language in old age be used as an intervention to improve cognition?

Some researchers have attempted to use intensive language courses as cognitive training. However, the results have been contradictory. Bak et al. (2016) recruited participants (18 - 78 years old) for a one-week Gaelic course and found an improvement in attentional inhibition and switching tasks. Pfenninger and Polz (2018) reported a positive effect on executive function and self-confidence. Older adults who participated in foreign language learning reported having better subjective happiness (Pikhart et al., 2021) and higher quality of life (Pikhart & Klimova, 2020). However, Ramos et al. (2017) found no difference between the intervention and control group after learning an L2 for a whole academic year. In spite of the conflicting results, language learning as a cognitive training method has practical application in real life and therefore deserves further exploration.

2.5 SUMMARY

In recent years, evidence has supported and rejected the notion that bilinguals possess greater cognitive reserves than monolinguals. Those in favour of the bilingual advantage hypothesis believed that the constant practice in linguistic inhibition transferred to the general domain. Neural evidence supported that there was overlapping in linguistic and general inhibition, which allows the practice of former transfer to the latter. However, the current literature has largely overlooked the individual differences in the population's linguistic and demographic properties. Such differences might alter the cognitive demand in the control processes, which results in varied cognitive benefits. This dissertation aims to examine how individual differences, including the environment bilinguals live in, language profile including dense code-switching and demographic variables, affect cognition in older adults in Hong Kong. Moreover, the dissertation investigates whether older learners would benefit from the bilingual advantage effect.

Chapter 3. BILINGUAL ADVANTAGE, PRESENCE OR ABSENCE?

This chapter reports the first experiment in the project. In this experiment, older participants residing in Hong Kong, a dominantly Cantonese-speaking community, completed a comprehensive set of cognitive tests and the language history questionnaire. This experiment aimed at answering two research questions: (1) Is there a bilingual advantage in cognition in this population, and (2) How do the individual differences lead to the presence or absence of bilingual advantage in cognition?

The result of the Stroop task was published in Hui et al. (2020), but more participants were recruited after that. The results are reanalysed here.

3.1 INTRODUCTION

The presence or absence of bilingual advantage has been under debate for decades and has yet to come to a concrete conclusion. The bilingual advantage was thought to be an outcome of the constant need for inhibition when a bilingual speaks (Green, 1998). The bilinguals would need to inhibit the unwanted language because of the parallel language activation. The language inhibition was believed to share at least part of the neural network with the domain-general inhibition (Abutalebi & Green, 2007). As bilinguals had more training of the network than monolinguals, therefore, it was reported that bilinguals have a better performance in inhibitory control (Prior & MacWhinney, 2010; Verreyt et al., 2015). This led to an abundant amount of studies yielding supportive evidence on bilingual advantage in tasks related to inhibition ability, for example, the Stroop task (Bialystok et al., 2014), the Simon task (Bialystok et al., 2005; Martin-Rhee & Bialystok, 2008) and the flanker task (Ong et al., 2017). Although these tasks use different types of stimuli, the common characteristic of these tasks was that participants would have to attend to one feature of the stimuli while ignoring a simultaneously presented interfering feature. For instance, the Simon task required participants to press left or right according to the arrow's direction and ignore the physical location on the screen. The Stroop task required participants to read the colour of the word and ignore the semantic meaning. The flanker task required participants to focus on the arrow at the centre and ignore the flanking arrows. The process of inhibiting the interference was thought to be similar to when a bilingual has to inhibit the unwanted language that was simultaneously activated.

A recent study suggested that there was a common function for all executive functions (Miyake & Friedman, 2012). They observed that after accounting for the common EF, there were no residuals for inhibition. The authors concluded that inhibition might be a key component of all the cognitive abilities of executive function. In this case, if bilingualism was thought to be improving inhibition, then there was a possibility that bilingual advantage might extend to other cognitive abilities under the EF. Bialystok (2009) summarized that tasks that required executive control were more likely to show bilingual advantage than tasks relying on verbal recall. After carefully matching the participant's backgrounds, Czapka et al. (2020) reported a faster response time in bilingual children than in monolingual children, indicating an overall faster processing speed. Prior and MacWhinney (2010) found that bilinguals were more efficient in the task-switching task than monolinguals. In their study, participants would have to respond to two types of target features, the colour or the shape, according to the cue presented before the trial. The bilingual advantage effect was found only in the mixed block but not in the single-task block, suggesting that the bilingual advantage was in flexible mental shifting.

Moreover, bilinguals were also reported to have larger visuospatial and phonological memory capacities (Durand López, 2020). Schroeder and Marian (2012) found that bilinguals were better than monolinguals in episodic memory measured by a picture recall task. Working memory and episodic memory were sometimes included as part of the executive functions because of the need to ignore the previously relevant stimuli. Take the digit span task as an example; the digits presented in Trial 1 are important at that particular trial, but it would become a burden in Trial 2 if the participant did not forget what they heard in the previous trial. Grundy et al. (2017)

referred to the process as “disengagement of attention”. After processing the stimulus, the attention should be disengaged from the old trial and prepared for the next to avoid putting all cognitive resources into the stimulus that was no longer relevant. In other words, it was part of the executive control process for archiving the goal.

On the other hand, verbal tasks were found to be more challenging for bilinguals than monolinguals. In the verbal fluency task (a.k.a. semantic fluency), participants were asked to name as many exemplars in a category as possible in a limited time. It was observed that bilinguals had fewer utterances than monolinguals (Bialystok et al., 2008; Portocarrero et al., 2007). Sandoval et al. (2010) summarized three possible reasons behind this finding: (1) The dual-task analogy. Bilinguals were constantly interfered by the other language so that they would have to spare cognitive resources to inhibit the unwanted language. Therefore, they would need more time to produce an exemplar compared to monolinguals, who do not need to inhibit the interference.; (2) The weak link. Bilinguals have a lower frequency of use of each of their language compared to monolinguals. As the amount of time using one language was less, the link between the semantic concepts and the phonological form was weaker. Thus, the retrieval rate was affected.; and (3) The category size analogy. Bilinguals might only know the word for certain concepts in one of the two languages. For example, English scientific terms (e.g., hydrogen, test tube) are taught in schools with English as the medium of instruction (EMI school). Students seldom use these terms outside school, so it was likely that they would not know the translation of these. The three reasons are not mutually exclusive. It is possible that bilinguals showed lower scores in tests like Verbal Fluency because of the combination of the above reasons.

As Green and Abutalebi (2013) and Abutalebi and Green (2007) illustrated in the Adaptative Control Model, language production involves many cognitive processes, and each requires a different amount of cognitive effort (for a detailed review, see Ch. 2.2). For example, the single-language context was the least cognitively taxing among the three interaction contexts they proposed because the bilingual would only have to inhibit the unwanted language and stay in the same language all the time. On the other hand, the dual-language context required the bilinguals to also monitor who the interlocutor was and which language to speak, in addition to the controls needed in the single-language context.

However, we should remember that the model was built on the assumption that the bilingual was a balanced bilingual with equal, or nearly equal, proficiency in the two languages. In reality, many bilinguals are indeed non-balanced. Bilingual, as with monolingual, is not a homogenous group. Bilinguals differ from each other by many variables, including but not limited to the L2 proficiency, frequency of using the languages, the linguistic distance between the two languages and the age of acquisition. As suggested by Valian (2015), the complication of bilingualism might also affect how cognitively taxing it is in different language contexts, thus affecting the effect size of bilingual advantage. The study of bilingualism and cognition is now dominated by research groups in North America and Europe (van den Noort, Struys, & Bosch, 2019), in which their participants were primarily international students or heritage speakers who were more likely to use their L2 outside the home.

In Hong Kong, the L1 (Cantonese) remains the dominant language in the community, while the L2 (English) is primarily used in schools or work. In general, the L2 proficiency of the population is not as high as the L1. The weaker L2 might not be as cognitively taxing to inhibit. Would such language experience diminish the bilingual advantage effect in this population? In the experiment reports in this chapter, the performance in various cognitive tasks of the older adults in Hong Kong will be investigated. Specifically, we included tasks that examined cognitive abilities beyond executive function for a more comprehensive view.

3.2 METHODS

3.2.1 Participants

Eighty-seven older adults were recruited. Among the eighty-seven, twelve participants did not complete the whole cognitive battery. Twelve other participants were rejected for various reasons, including four with vision problems, two non-Cantonese native speakers, two had neurological or psychological diseases, one was over 80 years old and met the exclusion criteria, one was near illiterate, and two had mild cognitive impairment (MCI). In the end, sixty-three participants were included in the analysis.

All of the sixty-three participants included in the analysis (26M, 37F) lived in Hong Kong for most of their lives, but not all were born in Hong Kong. The average age was 66.72 (*SD* = 4.09), and the average education level was 13.56 years (*SD* = 4.82). All participants were screened using the Montreal Cognitive Assessment – Hong Kong version (MoCA-HK) (Wong et al., 2015) and were classified as cognitively normal (*M* = 27.24, *SD* = 2.05). As females in this generation might have less education, a one-way ANOVA was run between the two genders and found no differences in age, education level and MoCA score (*p*s > .218). See Table 3.1.

	Total (*N* = 63)	**Male (*N* = 26)**	**Female (*N* = 37)**	**Gender difference (*p*)**
Age	66.72 (4.09)	67.35 (4.61)	66.28 (3.67)	.308
Education	13.56 (4.82)	14.46 (4.44)	12.93 (5.04)	.218
MoCA	27.24 (2.05)	27.35 (1.65)	27.16 (2.30)	.728

Table 3.1. Demographic information of the participants in Experiment 1. This table shows the participants' age, education years and MoCA score. Due to the possibility of females having lower education in this age group, a one-way ANOVA analysis of the gender difference was performed. The standard deviations are reported in brackets.

To investigate the effect of bilingualism, the participants were separated into monolingual and bilingual groups. As it was difficult, if not impossible, to find someone with zero contact with English in Hong Kong, a monolingual was defined as those who claimed they had never learned English (*N* = 5) or those reported to have acquired English but scored less than 5 in the Shipley Vocabulary test (Shipley, 1940) (*N* = 15). It should be noted that even in this case, the monolingual participants might still have some basic knowledge of English (e.g., alphabet, and basic vocabulary). Table 3.2 shows the language profile of the participants. All participants spoke Cantonese as their L1. All participants, both bilingual and monolingual, claimed Cantonese to be the more proficient and frequently used language than English.

	Monolingual (N = 20)	Bilingual (N = 43)	Group difference (p)	
Self-rated Cantonese ability	6.01 (0.75)	6.42 (1.57)	.269	
Self-rated English ability^	2.09 (1.14)	4.75 (1.02)	< .001	***
Frequency of using Cantonese	5.35 (1.01)	5.71 (1.11)	.220	
Frequency of using English^	1.46 (0.55)	3.50 (1.22)	< .001	***
AoA of English^	11.13 (8.80)	6.86 (2.79)	.006	**

Table 3.2. Language profile of the participants in Experiment 1. Participants rated themselves for their Cantonese and English proficiency and frequency of use on a Likert scale of 1 to 7, with 7 being most proficient or most used. Age of acquisition (AoA) of English was also provided if they had learnt it. ^ For self-rated English ability, frequency of using English and the AoA of English, 15 participants among the monolinguals provided the information and were listed in the table. However, they were counted as monolinguals because of the low proficiency as measured by the Shipley Vocabulary Test. * = <.05, ** = <.01, *** = <.001.

3.2.2 Task Design

Participants completed a set of cognitive tests that examined different cognitive domains. It included Golden's version of the Stroop task which measures inhibition ability (Golden & Freshwater, 1978; Stroop, 1935), Digit Span Forward which measures working memory (Woods et al., 2011), the Hong Kong List Learning Test which measures both short- and long-term memory (Chan & Kwok, 2006), the One-back task which tests attention, Picture Naming and Verbal Fluency which both measure language retrieval (Fong et al., 2020), and Raven's Standard Progressive Matrices which tests reasoning (Raven, 2003). The Language History Questionnaire (Li et al., 2019) was administered on the day when participants returned to get their cognitive test results. The questions included demographic information, age of acquisition, subjective rating of language ability and the frequency of using different languages in various scenarios. If the participants indicated that they had acquired English, then their English (L2) proficiency would be measured by (1) Lexical Test for Advanced Learners of English (LexTALE) (Lemhofer & Broersma, 2012) and (2) the Shipley Vocabulary Test (Shipley, 1940). The detail of each paradigm is described below. Questionnaires on Social-economic Status (SES) and lifestyle were also administered (see Appendix 9.2). In the following paragraphs, we will briefly describe each of the cognitive tests administered in this experiment.

Stroop task (Golden & Freshwater, 1978; Stroop, 1935)

Participants were presented with three tables, each comprising six columns of 20 stimuli each. The Word condition (W) consisted of Chinese characters for the colours “red”, “blue”, “yellow”, and “green” printed in white on a black background in random order. The Colour condition (C) consisted of coloured “XX XX” in the above four colours. The Colour-word condition (CW) had Chinese characters printed in a semantically incongruent colour, e.g., the word “yellow” printed in red. The participants were instructed to name the Chinese words in the W condition, and the colour of the C and CW conditions. The participants were given 45 seconds for each condition to name the word or the colour as quickly and accurately as possible. See Figure 3.1 for an example of each condition.

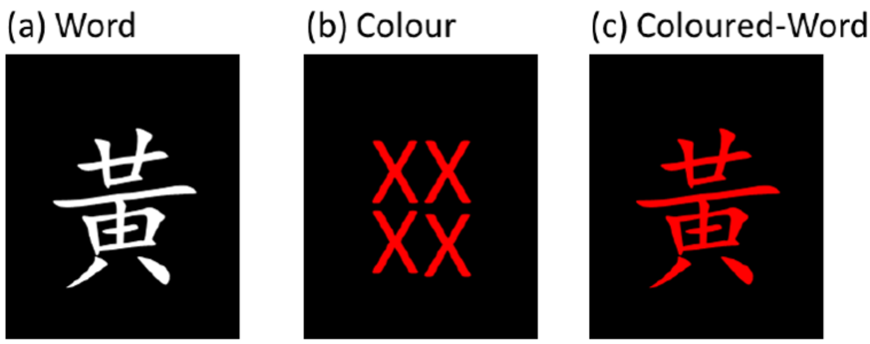

Figure 3.1. Example of the Stroop test. (a) Word condition, “yellow” written in white against the black background. Participants have to read the word. (b) Colour condition. Participants have to name the colour. (c) Colour-word condition, “yellow” written in red against the black background. Participants have to name the colour “red” instead of the word.

Digit Span Forward (Fong et al., 2022; Woods et al., 2011)

Participants heard a series of digits in random order, in which the series spanned from 4 to 14 digits. They were asked to repeat the numbers in the exact order of the recording immediately after hearing that trial. Each span consisted of three trials, and the participant would proceed to the next span only when they answered two out of three trials correctly. In the analysis, the maximum span referred to the longest sequence that the participant could recall correctly in at least two trials.

Hong Kong List Learning Test (HKLLT) (Chan & Kwok, 2006)

Participants heard a list of 16 disyllabic vocabularies presented in random order. The vocabularies were from four categories (countries, vegetables, relatives, furniture). Participants were given three chances to listen to the list and asked to repeat it immediately after listening (Trials 1 to 3). They were asked to repeat the list after 10 minutes (Trial 4) and 30 minutes (Trial 5) without listening again. They were reminded that they did not have to repeat the items in the exact order of listening. Participants did not know they would have the delayed-recall trials.

One-back

A sequence of numbers was presented on the screen. Participants were instructed to press the left button if the current number was different from the one before and press the right button if it was the same. After a short practice, a total of 60 trials (20 same and 40 different) were presented in the critical block. One participant's data was lost due to a technical problem. Therefore, only 62 participants' data was included in the analysis.

Tower of Hanoi

See Figure 3.2. Participants were given a wooden board with three poles. They were instructed to move the discs from the left to the right pole under two rules, (1) the larger disk cannot be put on top of the smaller ones, and (2) move only one disk at a time. Participants were given 20 minutes to complete the task. They began with three disks, and one more would be added after they successfully moved all of them to the right. This task was used as a non-verbal filler task between HKLLT-10 mins recall and 30-min recall and would not be analysed.

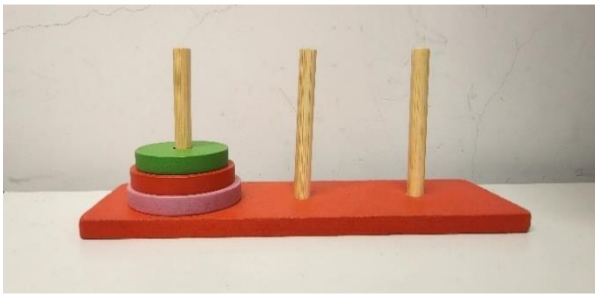

Figure 3.2. Tower of Hanoi. Please see the main text for the instruction on the task.

Picture Naming (Fong et al., 2020)

Participants were presented with 42 black-and-white line-drawings for 5 seconds each. They were asked to name it in Cantonese as soon as possible. The pictures were retrieved from Snodgrass and Vanderwart (1980). All pictures are usually named in disyllabic expression and were rated for their familiarity and clearness in depiction in a previous project of our laboratory (see Fong et al., 2020's Appendix S2). See Figure 3.3 for examples of the stimuli.

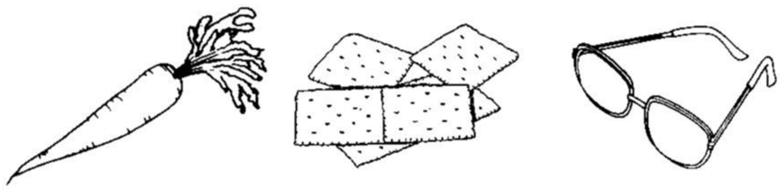

Figure 3.3. Example of the stimuli used in the Picture-naming test. Pictures were retrieved from Snodgrass & Vanderwart (1980). All pictures are usually named in disyllabic expressions (e.g., from left to right, 蘿蔔 /lo4 baak6/ carrot; 餅乾 /beng2 gon1/ (biscuit); 眼鏡/ngaan5 geng3/ (glasses)) and were rated for its familiarity and clearness in depiction.

Verbal Fluency (Fong et al., 2020)

A total of 13 semantic categories were tested in randomised order. It included eight concrete categories (mammal, non-mammal, fruit, kitchenware, tool, stationery, electrical appliance, toy) and five abstract categories (country, subway station, personal particular, occupation, and time unit). Participants were given 1 minute for each category and were required to name as many items belonging to the category as possible in Cantonese.

Raven's Standard Progressive Matrices (Raven, 2003)

Participants were presented with a picture with one piece missing in the lower right corner. They had to choose the correct piece from 6 or 8 options to complete the picture above. The original Raven's SPM consisted of 60 questions. Because of the time constraint, participants were presented with only the odd- or even-number questions. Participants were given 22.5 minutes (half of the original test) to finish the 30 questions.

Shipley (Shipley, 1940)

In the Shipley test, participants would have to choose a word with the same or the most similar meaning to the probe word out of four choices. They were instructed to try their best to choose only those they knew or had high confidence that it would be a correct answer and to refrain from wild guesses. There were 40 questions, from very common words (e.g., Talk – draw / eat / speak / sleep) to relatively rarer words (e.g., Pristine – vain / sound / first / level). There was no time limit for completing this task. The use of an English vocabulary test is because the focus of this study is on lexical level, therefore the L2 vocabulary size is our main interest.

Lexical Test for Advanced Learners of English (LexTALE) (Lemhofer & Broersma, 2012)

In the LexTALE task, participants had to judge whether a sequence of letters was a real English word or a pseudo-word. There was no time limit, and participants had to answer all 60 questions. The accuracy was calculated by the formula provided by the authors:

$$\mathrm{ACC} = \left(\frac{N\ correct\ real\ words}{40}\right) \times 100 + \left(\frac{N\ correct\ pseudowords}{40}\right) \times 100\ \div 2$$

However, the post-hoc analysis (Hui et al., 2020) found that because the task required participants to answer every question, those with lower English proficiency had to answer only by guessing. As the name suggested, the test was more suitable for advanced learners of English. It might not reflect the true proficiency of the participants in our case. Therefore, the task was excluded from the analysis in this dissertation.

Language History Questionnaire (Li et al., 2019)

The questionnaire was adapted and modified from Li et al. (2019). Participants filled in a questionnaire when they returned to get the report. The questions included demographic information (e.g., age, education, the place where they grew up), age of acquisition, self-rated proficiency, and frequency of usage (separated into reading, listening, writing and speaking) of every language/ dialect they knew. Self-rated proficiency was measured by a Likert scale of 1 to 7, with seven being the most proficient. For those who never acquired English, the self-rated English proficiency was counted as 1. The frequency of use was also measured by a Likert scale of 1 to 7, with seven being the most frequent. Likewise, those who never learnt English were counted as one on the scale for frequency of using English. A sample of the questionnaire (in Chinese only) could be found in Appendix 9.2.

SES and Lifestyle Questionnaire

This questionnaire includes information regarding occupation, financial status, marital status and social life. Health-related questions include self-rated health condition, smoking and drinking habits, sleeping habits, and frequency of doing leisure activities. A sample of the questionnaire (in Chinese only) could be found in Appendix 9.2.

3.3 RESULTS

3.3.1 Bilingual Advantage

To demonstrate the classic bilingual advantage effect, the results of all the behavioural tasks were first compared between the monolinguals and the bilinguals. In Hong Kong, English was taught as part of the compulsory curriculum in formal education, so people who attended school in Hong Kong would hardly be purely monolingual. However, their occupation might never require using English and eventually, they forget the language. A monolingual was defined as those who claimed they have never learned English, or those reported to have acquired English but scored less than 5 in the Shipley Vocabulary test.

The two groups did not differ in age ($F(1, 62) = .93$, $p = .339$, $\eta^2 = .02$). The monolinguals and bilinguals differed significantly in the education year ($F\ (1, 62) = 61.13$, $p < .001$, $\eta^2 = .50$). The two groups also showed the classic bilingual advantage in general cognition, as reflected by the higher MoCA score in the bilingual group ($F(1, 62) = 4.00$, $p = .050$, $\eta^2 = .06$). See Table 3.3.

	Monolingual (*N* = 20)	**Bilingual (*N* = 43)**	***P***	
Age	67.45 (4.60)	66.38 (3.38)	.339	
Education	8.60 (2.76)	15.87 (3.70)	< .001	***
MoCA-HK	26.50 (2.46)	27.58 (1.75)	.050	*

Table 3.3. Demographic information of the participants in Experiment 1. This table shows the mean and standard deviations (in brackets) of the age, education level and MoCA score of the participants in Experiment 1, and the group comparison between monolinguals and bilinguals. * = <.05, ** = <.01, *** = <.001.

	Monolingual (*N* = 20)	**Bilingual (*N* = 43)**	***p***	
Stroop – Word	83.45 (9.90)	88.49 (14.14)	.156	
Stroop – Colour	56.40 (11.62)	61.56 (11.30)	.100	
Stroop – Colour-word	25.30 (7.80)	30.49 (7.85)	.017	*
Digit Span (max. span)	7.50 (1.00)	8.28 (1.61)	.051	*
HKLLT – Immediate (Trial 3)	12.20 (1.74)	12.19 (2.41)	.982	
HKLLT – 10 mins	10.10 (2.57)	10.65 (2.81)	.460	
HKLLT – 30 mins	9.60 (2.93)	10.30 (3.10)	.398	
One-back – ACC (%)	95.67 (4.30)	96.55 (5.56)	.532	
One-back – RT (ms)	633.87 (120.74)	578.39 (84.76)	.042	*
Picture Naming – ACC (%)	92.98 (4.67)	94.35 (4.87)	.295	
Picture Naming – RT (ms)	1389.07 (199.24)	1479.97 (249.84)	.158	
Verbal Fluency	9.36 (1.52)	11.30 (2.20)	.001	**
Raven's SPM	20.45 (3.59)	22.19 (4.37)	.127	

Table 3.4. Behavioural results in Experiment 1. This table shows the mean and standard deviation (in brackets) of the cognitive tasks, and the group comparison between monolinguals and bilinguals. * = <.05, ** = <.01, *** = <.001.

Breaking down into different cognitive abilities, bilinguals did not show better cognition in every domain. Table 3.4 shows the mean, standard deviation and the group comparison between monolinguals and bilinguals for each cognitive task. The bilinguals produced significantly more colour-words in the Stroop test ($F(1,62) = 5.99$, $p = .017$, $\eta^2 = .09$) but not in the word or colour condition (ps > .100), indicating that they were better in inhibition but not only merely in articulation speed. The bilinguals were also found to have better working memory capacity than the monolinguals ($F(1, 62) = 3.96$, $p = .051$, $\eta^2 = .06$), as shown in the Digit Span. In the One-back task, monolinguals and bilinguals were similar in accuracy ($F(1, 62) = .39$, $p = .532$, $\eta^2 = 01$), but bilinguals were significantly faster in reaction time ($F(1, 62) = 4.31$, $p = .042$, $\eta^2 = .07$). Bilinguals produced more concepts in the Verbal Fluency test than their monolingual counterparts ($F(1, 62) = 12.73$, $p = .001$, $\eta^2 = .17$). No comparison was significant in other cognitive tasks.

As the two groups significantly differed in education, it was possible that the effect found was from education but not bilingualism. In Hong Kong, English is taught in school as a compulsory subject, those who had studied in formal education would therefore know English at least to a minimal level. The division of high and low education groups would therefore largely be the same as dividing into monolingual and bilingual groups. Instead, a two-tailed Pearson correlation analysis was conducted within the monolingual group ($N = 20$) to investigate the relationship of education and cognitive performance. Only one-back ACC ($r = .45$, $p = .046$) and Picture Naming RT ($r = .45$, $p = .045$) reached significance level. Results suggested that education contributes to cognitive advantage but not in all tasks. “Education” is therefore included as one of the variables in the following analysis, even though it was highly correlated with L2 proficiency level as measured in Shipley task ($r = .70$, $p < .001$).

3.3.2 Individual Differences

To understand what modulated the cognitive outcome, a linear regression model was built on each cognitive test that was significantly different between monolinguals and bilinguals, namely, Stroop CW, Digit Span, One-back RT and Verbal Fluency. For each model, the cognitive score being predicted would be the dependent variable. As the current analysis was interested in how demographic and language experience would affect cognitive ability, the independent variables included: age, education, gender (dummy coded as male = 1 and female = 2), MoCA, Shipley, frequency of using Cantonese, frequency of using English, self-rated Cantonese proficiency, self-rated English proficiency and AoA of English. LexTALE was not analysed because we previously found that participants could rely on pure luck to complete the task (Hui et al., 2020). Five monolinguals were excluded from the test because they did not have information on AoA of English or frequency of using it. The models were built with the stepwise method by SPSS version 29.

Test	**Predictors**	***B***	***SE***	***t***	***p***
Stroop CW	(Constant)	32.30	16.51	1.96	.056
	MoCA	1.48	0.46	3.21	.002
	Age	−0.70	0.23	−3.11	.003
	Shipley	0.23	0.09	2.59	.012
Digit Span	(Constant)	12.72	3.11	4.09	<.001
	Shipley	0.04	0.02	2.28	.027
	Age	−0.08	0.05	−1.71	.093
One-back RT	(Constant)	321.17	197.70	1.63	.11
	Gender (Male)	−61.25	24.64	−2.49	.02
Verbal Fluency	(Constant)	9.20	0.45	20.64	<.001
	Shipley	0.09	0.03	3.46	<.001
	Gender (Male)	1.13	0.51	2.20	.032

Table 3.5. Multiple regression analysis table of Experiment 1. Multiple regression analysis using the stepwise method to predict the score of each cognitive test that was significantly different between the monolinguals and bilinguals. Independent variables included age, education, gender, MoCA, Shipley, frequency of using Cantonese, frequency of using English, self-rated Cantonese proficiency, self-rated English proficiency and AoA of English. *B* = unstandardised coefficient.

Table 3.5 shows the multiple regression analysis table. For the Stroop CW, only Shipley and gender remained in the final model as significant predictors (F(3, 54) = 10.01, p < .001, adjusted R^2 = .32). Participants produced 1.48 more responses if they had 1 mark higher in MoCA (t = 3.21, p = .002), 0.23 more if they scored 1 more in Shipley (t = 2.59, p = .012), but 0.70 less if they were one year older (t = −3.11, p = .003). For Digit Span, the only significant predictor remained in the final model (F(2, 55) = 4.61, p = .014, adjusted R^2 = .11) was Shipley (t = 2.28, p = .027). Age was included in the model but was insignificant (t = −1.71, p = .093). As for one-back RT, only Gender was the significant predictor in the final model (F(2, 54) = 3.82, p = .028, adjusted R^2 = .09). Being male would be 61.25 ms faster than female (t = −2.49, p = .02). For Verbal Fluency, Shipley (t = 3.46, p < .001) and Gender (t = 2.20, p = .032) remained at the final model (F(2, 55) = 10.32, p < .001, adjusted R^2 = .25). One mark higher in Shipley would increase 0.10 more concept produced in the Verbal Fluency, and male produced 1.13 more concepts than females.

3.4 DISCUSSION

3.4.1 Bilingual Advantage Presence

The classic bilingual advantage was observed from the group comparison between monolinguals and bilinguals. MoCA is a widely used cognitive screening instrument that measures a variety of cognitive abilities in under 10 minutes, including visuospatial skills, language, attention, working memory, delayed memory recall and orientation. The cut-off score, derived from over two thousand participants, is used to determine the cognitive status of the participant taking into consideration of their age and education level. All participants in this experiment were considered cognitively normal based on the cut-off score at the 16th percentile of the standard in Hong Kong (Wong et al., 2015). However, the bilingual group (M = 27.58) scored significantly higher than the monolingual group (M = 26.50), reflecting a better general cognition. The result supported that bilingualism brought cognitive advantages to older adults.

The literature has suggested that bilinguals were better in executive functions (EF) compared to their monolingual counterparts (Bialystok et al., 2004; Bialystok et al., 2006; Bialystok et al., 2014). EF refers to a set of cognitive skills for achieving the goal, which most commonly includes inhibition, updating and shifting (Miyake et al., 2000). Some researchers also included working memory and attention as part of the EF. The current study investigated how bilingualism affects inhibition, working memory and attention with Stroop, Digit span and One-back, respectively. In these three tasks, bilinguals were found to perform better than monolinguals. In the Stroop task, bilinguals produced significantly more responses (M = 30.49) compared to monolinguals (M = 25.30) in the colour-word condition, but not in the word or colour conditions. It showed that the better performance in the colour-word condition was from inhibitory control, but not merely faster in articulation or colour perception. In addition, bilinguals could recall a longer sequence of random numbers (M = 8.28) than monolinguals (M = 7.50), reflecting a larger working memory capacity. As for attention, both monolingual (M = 95.67%) and bilingual groups (M = 96.55%) performed similarly well in accuracy, but bilinguals had shorter reaction time (M = 578.39 ms) than monolinguals (M = 633.87 ms). The result of our experiment supported bilingual advantage in the EF domain.

In contrast to the literature which usually found a disadvantage in bilinguals in verbal tasks (e.g., Portocarrero et al., 2007; Rosselli et al., 2000), the result from Verbal Fluency in our study showed that bilinguals were better than monolinguals. Bilingual participants produced an average of 11.30 exemplars in one category, which was significantly more than the monolinguals (M = 9.36). The discrepancy between the literature and our study could be due to our participants living in the L1-dominant community. As Sandoval et al. (2010) proposed, bilinguals were reportedly worse in Verbal Fluency for three reasons: (1) the constant inhibition of the interfering language took up cognitive resources, (2) bilinguals had less time to practice each of the two languages compared to monolinguals, and (3) some concepts might only be known in one of the languages. However, as our participants live in a community where Cantonese is the dominant language, the concepts are most likely to be acquired and used in L1 (see Table 3.2 for the participants' language profile). As the Verbal Fluency test in this current study was conducted in Cantonese, it posed a minimal challenge for the bilingual participants. The language situation was the opposite of studies like Rosselli et al. (2000), where participants lived in the L2 dominant society. Because of that, over half of their participants used English (L2) at work and Spanish (L1) at home, which was a more balanced usage of the two languages compared to the population in the current study. They found that even when the Verbal Fluency was conducted in Spanish (the participants' L1 and the more proficient language), the bilinguals still produced fewer concepts than the Spanish monolinguals. It was likely due to the second and third reasons of Sandoval et al. (2010), which the participants in our study were unlikely to be affected by.

In addition to language experience, the effect of education on cognition should not be overlooked (Ardila et al., 2000). As proposed by Mortimer and Graves (1993), low education level and low cognitive abilities were associated because (1) it was related to risk factors in adult life, e.g., lower SES, which then led to poor nutrition and fewer health care services; (2) low SES during early life which affected brain reserve; (3) effects from life-long mental stimulation, e.g., occupation and lifestyle. In our study, the bilinguals were significantly more educated than the monolinguals. It was because, in Hong Kong, English was part of the compulsory curriculum in formal education. In other words, people who were educated in Hong Kong would not be purely monolingual.

	Monolinguals (*N* = 20)	**Bilinguals (*N* = 43)**
Skill Level 1 (Elementary)	7 (35.00%)	2 (4.65%)
Skill Level 2 (Medium)	10 (50.00%)	18 (41.86%)
Skill Level 3 (High)	3 (15.00%)	23 (53.49%)

Table 3.6. Occupation skill level of the monolinguals and bilinguals. The number of monolingual and bilingual participants was separated into three occupational skill levels, as measured by the International Standard Classification of Occupations 2008 (ISCO-08).

In this age cohort, it was possible that the participants had to drop out of school due to the economic burden of the family and had only received a few years of formal education and hence had to work in lower-skilled jobs. In fact, the two groups of participants differed in their occupation levels, as measured by the International Standard Classification of Occupations 2008 (ISCO-08) (Ganzeboom, 2010); see Table 3.6. Bilingual participants were more likely to work at medium or high skill levels before retirement than monolingual participants. With more skilled work, it was expected that the income would be higher, and thus the social-economic status (SES) would also be different between the two language groups. SES was reported to be a potential factor that contributes to the bilingual advantage effect (Naeem et al., 2018). In the Scaffolding Theory of Aging and Cognition-Revised (Reuter-Lorenz & Park, 2014), education level, occupation, and SES were factors believed to contribute to the amount of cognitive reserve (Stern, 2012). People with more cognitive reserve could sustain their cognition even when the brain showed pathological changes.

Given that the monolinguals and bilinguals significantly differed in educational level, occupation and, therefore, possibly their SES, which were all factors believed to affect cognition, we will focus on the bilingual group in the next sub-section instead for a better picture of how language experience would modulate cognition.

3.4.2 Individual Differences and Cognition

The focus of the linear regression model was to understand how demographic information (age, education years, MoCA score) and language experience (proficiency, frequency of using the languages, AoA) would modulate the cognition of older adults. It did not include any independent variables from the other cognitive tests examined in the study, and therefore, only approximately $10 - 30\%$ of the total dependent variables were explained. As reviewed in Ch.2.3, hardly any cognitive test measures only one cognitive domain (Valian, 2015). It was expected that the ability measured in one test would also contribute to another test that was supposedly measuring a different cognitive ability. For instance, the Stroop CW condition aimed at measuring inhibition control ability, but the speed of articulation (measured by Stroop W) and colour perception (measured by Stroop C), or even just the physical eyesight, would undoubtedly contribute to the score. Therefore, the percentage of the dependent variable explained by the set of independent variables in the model was expected to be low. However, we believe it still provides a valuable insight into how demography and lifelong experience contribute to cognition.

The Stroop CW was predicted positively by MoCA and Shipley, and negatively by Age. In this task, participants have to read the font colour of the word instead of the more prepotent response - the word itself. It requires participants to suppress interference and is therefore thought to be measuring inhibitory control ability. The age-related decline in the Stroop task was well documented (Cohn et al., 1984; Troyer et al., 2006; West & Alain, 2000). In addition to age, those with higher MoCA scores were predicted to score higher in the Stroop CW condition. The changes reported in this task might be due to a combination of age-related general slowing and decreased inhibitory control. The decline in performance with age and general cognition might be explained by the Inhibition deficit hypothesis (Hasher, 2015), which suggested that older adults have lower inhibitory control and, therefore, easily interfered with by unrelated stimuli. The effect of Shipley is discussed in the next sub-chapter.

Digit span score was predicted positively by L2 proficiency (indicated by the Shipley task) and negatively by age. The digit span task required participants to memorize a series of random numbers and recall it immediately after each trial. Better performance in this task reflects higher working memory capacity. Working memory includes storing and processing information (Salthouse & Babcock, 1991). In the current experimental paradigm, participants were only required to recall it in sequence so the need for processing would be minimal. It is well-documented that when one is older, performance in digit span would is worsened (Bopp & Verhaeghen, 2005; Hester et al., 2004), which our result was consistent with this. In addition, the working memory task was predicted by L2 proficiency. A similar result was reported in the literature (Espi-Sanchis & Cockcroft, 2022), that more balanced bilingualism predicted an advantage in domain-specific working memory because of the higher efficiency in processing verbal content. However, it was also possible that the relationship between working memory and L2 proficiency was mutual, that those with higher working memory capacity would be able to learn an L2 better (Espi-Sanchis & Cockcroft, 2022). Interpretation of this effect must therefore be cautious.

In One-back RT, gender was the only significant predictor in the final model. Females were found to be slower than males, which was consistent with the literature using the visuospatial n-back (Cansino et al., 2013; Zarantonello et al., 2020). Similarly, Pelegrina et al. (2015) reported that young boys were faster than girls in a letter one-back task. Even though our task was a digit one-back task, the working memory component of the tasks was believed to be the same. Cansino et al. (2013) and Zarantonello et al. (2020) suggested that the gender difference was due to females having a strong decrement of testosterone after the menopausal period, which slowed them down in responding to tasks (Müller, 1994). In fact, it was observed that girls outperformed boys in younger children (6 – 10 years old), and the gender difference disappeared in the older group (11 – 13 years old) (Vuontela et al., 2003). In short, the faster reaction time in males might be due to the higher hormone level. However, this was only speculation as no data on hormone levels was collected in the study.

Gender was also a significant predictor for Verbal Fluency. Interestingly, in our regression analysis, the male was found to be an advantage factor over female, contrary to what was suggested in the meta-analysis on gender effect in verbal fluency tasks (Hirnstein et al., 2023; Mathuranath et al., 2003). A previous study has found that gender influences the semantic fluency of some topics (e.g., supermarkets, foods, and clothes) but not others (e.g., animals, transports) (Nogueira et al., 2016). In our study, 13 semantic categories were used to minimise the possibility of gender bias in terms of category choice. Yet, it was possible that some categories (e.g., tools, electrical appliances) might be stereotypically more favourable to males.

3.4.3 The Strength of the Languages

More importantly, it was found that language experiences were also predictors of better cognition. Besides MoCA score and age, which were discussed in the above session, the Stroop CW condition was at the same time significantly predicted by English proficiency, as measured by the Shipley Vocabulary Test. Our result in the Stroop CW condition supports bilingual advantage in inhibition. Shishkin and Ecke (2018) reported that the older immigrants who were more proficient in L1 showed interference control in the Stroop task as good as the younger immigrants who were more balanced. They proposed that it was the stability of language systems that contributed to interference control but not proficiency. However, the participants in our study were all non-immigrants living in the same community; in other words, they all had a relatively stable language system. If their assumption was correct, there should not be any difference between those with high and low proficiency.

The bilingual advantage literature often suggests that because of the constant need to inhibit the unwanted language (Green, 1998). Bilinguals were more experienced in utilizing the network that overlapped with general inhibition, and therefore they outperformed the monolinguals. As from the Adaptive Control Hypothesis (Green & Abutalebi, 2013), the control processes used in different interaction contexts varied, and the cognitive demand for using the languages greatly differed. However, the model was built assuming that the bilingual was proficient in both languages.

Meuter and Allport (1999) demonstrated that the strength of two languages was asymmetrical even in relatively balanced bilinguals. In that study, the bilinguals were asked to name the digits in one of the languages according to the cue. They found that the switch from the weaker language to the stronger one took longer than vice-versa. The asymmetrical cost of language switching was replicated by other researchers (Bultena et al., 2015; Verhoef et al., 2009). The asymmetrical cost was explained by the different strengths of the languages. The more proficient language, which was usually the L1, was stronger in strength than the less proficient languages. As both languages would be simultaneously activated, one had to inhibit the unwanted one in order to speak in the target language. It was harder to suppress the stronger language and more challenging to release it from suppression, resulting in a longer reaction time when switched from the weak L2 to the strong L1. Assuming the amount of effort is positively correlated with the amount of benefit in cognition, it could be hypothesized that the more frequent one had to suppress their stronger language, the more practice they would have which results in better cognition. In Hong Kong, most people use Cantonese as the language of daily conversation in the community, and English is seldom used beyond school and work. In other words, the frequency of using the weaker language was low. In order to enjoy the bilingual advantage, the strength of the L2 must be increased by advancing in its proficiency.

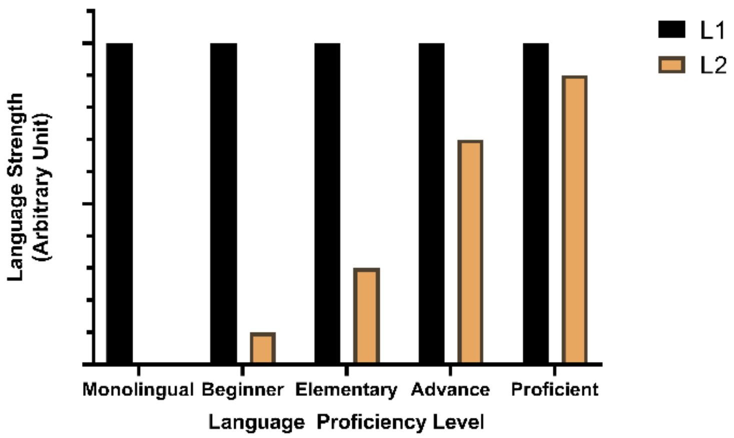

Figure 3.4. Illustration of language strength in L2 speakers with different proficiency. The figure assumes the speakers had the same level of L1 proficiency. The strength of the L2 increases when they become more proficient. Strength is presented in arbitrary units.

Figure 3.4 illustrates the hypothetical language strength of L2 speakers of different levels of proficiency. In this figure, the L1 proficiency level was assumed to be constant across different stages, and the difference between the two languages would be the amount of interference the co-activation of L2 would bring. If the L2 proficiency is low, it poses minimal interference when the speaker is talking in L1, and therefore the practice of inhibition would be the lowest. Along this line, Goral et al. (2015) found that balanced bilinguals did not benefit from bilingualism while dominant bilinguals showed the bilingual advantage in inhibition tasks. Other studies also reported that higher L2 proficiency in the L1-dominant population would improve inhibitory control (Boumeester et al., 2019; Xie & Pisano, 2019).

It was suggested that the asymmetric cost between L1 and L2 activation was found only in L2 learners but not in more proficient users (Costa & Santesteban, 2004). High-proficient bilinguals like interpreters (Woumans et al., 2015) were found to rely on a different linguistic network to process speech in a different language. For language learners, the lexicon of the L2 was not yet well-formed, and language-specific selection was not possible. When the proficiency increased, the lexical selection mechanism would be more sensitive to the activation levels of the words that were from the target language rather than from the unwanted language (Costa & Santesteban, 2004; Reynolds et al., 2016). The Dynamic Reconstructing Model (Pliatsikas, 2019) was along the same line, in which it suggested that the brain structure is reconstructed differently in three stages of L2 learning: the initial exposure, consolidation and peak efficiency. In the initial stage of learning L2, bilinguals were found to have an expansion in the cortical grey matter in order to adapt to the new challenge of rapid learning of new vocabularies. When the L2 proficiency increased, the brain structure in the cortical regions would renormalize to the stage closer to the baseline. The authors suggested that this was due to pruning, that the brain reorganizes and discards the unnecessarily expanded regions after the new challenge is partly resolved. At the peak of language proficiency, such as the level of interpreters, the differences would mainly occur in the subcortical regions and white matter tracts. In other words, the difference in brain between a beginner and a proficient L2 speaker was not in a linear relationship. The brain does not keep on expanding proportionally according to L2 proficiency. When the proficiency is high enough, the brain utilizes different regions to cope with the new challenges.

Nevertheless, our results found that higher L2 proficiency is associated with better inhibitory control. The discrepancy between our study and the literature was possibly because the L2 proficiency of the participants in the current experiment was not as high as that of interpreters. After a lifelong practice of inhibition, it is possible that they had formed a better and more efficient mechanism to control the two languages than the new learners. However, the proficiency level was at most in the consolidation stage as in Pliatsikas (2019) model. Consequently, they do not process an independent network for specific language processing. This benefited them in practising linguistic control with the same network and becoming better in general inhibition.

Interestingly, Verbal Fluency was predicted by the Shipley score too. The Verbal Fluency task was conducted in Cantonese, and no English was involved either inside the task or in the instruction. Logically, as a test that requires the retrieval of words from the Cantonese lexicon, it should be predicted by self-rated Chinese proficiency. In contrast, the model in our study suggested that higher English proficiency predicted better verbal fluency. Paap et al. (2019) also reported that the verbal fluency score was predicted by other-language proficiency, only it was found to be a disadvantage. One possibility of the differences we found might be due to the vocabulary size. It was suggested that when the vocabulary size of the testing language was controlled for, bilingual children were found to outperform monolingual children in the verbal fluency task conducted in that matched language (Escobar et al., 2018). In our study, monolinguals and bilinguals did not differ in self-rated Cantonese proficiency ($F(1, 61) = 1.54$, $p = .220$). On the other hand, being more proficient in the L2 enabled our participants to be exposed to more knowledge available from different sources. Foreign knowledge was more accessible to them, for example, watching Discovery Channel or National Geographic in English so they might know more animals. Therefore, they might have a larger vocabulary size comprised of the concepts learnt from both languages, similar to that reported by Pearson et al. (1993) for bilingual and monolingual children. However, because of the L1-dominant environment our participants are living in, they were likely interested in knowing the Cantonese terms of the newly learnt concepts. Therefore, the number of concepts available for the more proficient L2 speakers was larger and they could perform the verbal fluency task better.

3.5 CONCLUSION

Bilingual advantage is still under debate after decades of investigation. However, the models that tried to explain the reasons behind it were mainly based on balanced bilinguals, which only accounted for a very small portion of the global population. Within the bilinguals, their experience in languages was not homogenous either. Their differences in language experience might have different contributions to cognition. In this experiment, we recruited older adults from a dominantly L1 community to complete a set of cognitive tests. We found that even in the community where L1 was dominantly spoken, older adults could still benefit from bilingualism, specifically in cognitive abilities under executive functions. Among the bilinguals, multiple regression analysis found that L2 proficiency was the predictor for both the inhibition ability and verbal fluency. Bilingual advantage was possible because of the constant practice of suppressing the unwanted language. In order to benefit from bilingual advantage in the community that mostly uses L1, one had to increase the strength of L2 by acquiring higher proficiency, so as to create a greater challenge of suppression and a better practice of the control.

Chapter 4. Foreign Language Learning as Cognitive Training

This chapter reports an experiment using foreign language learning as cognitive training for older adults. All participants completed a cognitive battery before and after the intervention. Three groups of older adults were recruited. One of the groups attended a 6-week intensive English learning course as the intervention group, another attended a leathercraft course as the active control group, and the last group attended nothing as the no-contact control. This experiment aimed at answering Research Question 2: How do the individual differences lead to the presence or absence of bilingual advantage in cognition? Specifically, we investigate whether language learners in old age would also show benefits in cognition.

The design of the English course was reported in the 17th International Conference in Language and Social Psychology and the 2022 International Max Planck Research School (IMPRS) for Language Sciences Conference. The preliminary result was reported in the Bilingualism Matters Research Symposium 2022.

4.1 Introduction

4.1.1 The Transfer Effect of Cognitive Training

Cognitive reserve is the capacity of the brain to sustain pathological changes, that with the same level of pathological change, an individual with lower cognitive reserve might have developed into dementia (Whalley et al., 2004). Even though Cajal, the father of neuroscience, claimed that the brain was mostly fixed in adulthood in the early 20th century (Teter & Ashford, 2002), today, the neuroscience field generally agrees that the brain is a dynamic system that changes its structure and functions in response to the environment even in old age (Costandi, 2016). The brain could be as efficient as younger adults by utilising the available resources and developing processing strategies, for instance, by recruiting a different network to complete the task when the old network is no longer available (Stern, 2012). Chen et al. (2022) found that successful agers had a youth-like level of activation in regions associated with memory, together with the recruitment of additional regions in the prefrontal area in a memory encoding task. This result showed that the brain is capable of adjusting itself in order to work efficiently.

Lifelong intellectual activity is believed to enhance cognitive reserve. Previous studies have investigated the effectiveness of the non-pharmacological intervention on both healthy older adults (Jackson et al., 2012; Kwok et al., 2013) and pathological populations, including schizophrenia (Genevsky et al., 2010), MCI (Belleville, 2008; Hyer et al., 2016; Maffei et al., 2017) and mild to moderate dementia patients (Bahar-Fuchs et al., 2019). The intervention methods varied from physical exercises to cognitive tasks, or a combination of both (Bherer, 2015). One of the most well-known training programmes is The Finnish Geriatric Intervention Study to Prevent Cognitive Impairment and Disability (FINGER study) (Kivipelto et al., 2013), which involved over 1200 individuals with cognitive decline risk undergoing a two-year multidimensional programme. Participants in the training group received nutritional guidance, physical training, cognitive training and intensive healthy monitoring. The authors later reported that the multi-domain training programme was found to be beneficial to older adults who had dementia risk (Kivipelto et al., 2018).

Practising running 100 metres could undoubtedly enhance the performance in that particular track event, but it is also likely to improve the performance in the 200 metres sprint or even the speed in climbing stairs, an unrelated task that also relies on a good cardiovascular system. The improvement of the trained task ("criterion task") is not very surprising, but the fact that the training could induce a transfer effect is intriguing. The transfer effect was found to show in different tasks in the same domain as the training ("near transfer") or even to the untrained cognitive domain ("far transfer") (Jaeggi et al., 2011). The same might apply to cognitive training. For instance, Borella et al. (2013) used the Categorization Working Memory Span Task (CWMS), a verbal working memory task, as the training for older adults. The trained participants performed better than the non-trained controls in the criterion task, and also in the near transfer task (Digit Span) and the far transfer task (Stroop). Similarly, Jaeggi et al. (2014)

trained the participants with the n-back task, which examines working memory, and observed improvement in fluid intelligence. It was believed that the transfer was possible because of the shared neural mechanism between the trained task and the transfer tasks (Buschkuehl et al., 2012). For example, Dahlin et al. (2008) trained the participants with an updating task and observed improvement in the untrained 3-back task but not the Stroop task. They found that both the updating task they used in the training programme and the 3-back task shared similar activation pattern in the striatum, whereas the Stroop task did not. This shows that the shared neural mechanism was at least part of the reasons behind the transfer effect.

On the other hand, some researchers only found a transfer effect on tasks that were very similar to the trained task (Souders et al., 2017). They believed that the participants practised specific skills and strategies to accomplish the training task, and such skills were needed to complete similar tasks used in the testing phase. Some criticized studies that did not include a control group (Jaeggi et al., 2014) might not be showing the true training effect. The improvement observed in the training group might be due to the Hawthorne effect (Mayo, 1933/2016), in that the participants were aware that they were being studied and, therefore, modulated their behavioural performance. Participants might know that the experimenters wanted an improvement and, therefore, implicitly tried even harder during the post-test phase, thus, an "improvement" could be observed. Some critics even claimed that the transfer effect reported in the field was from inadequate control of the experiment or misinterpretation of the result (Lintern & Boot, 2021). In summary, the possibility of enhancing cognition through cognitive training was encouraging but debatable.

4.1.2 Language Learning as Cognitive Training

Bilingualism is reported to be one of the contributors to cognitive reserve and overall better cognition in older adults, but the results were based on lifelong bilinguals who had decades to practise linguistic inhibition (Bialystok, 2021). It was proposed by Antoniou et al. (2013) that learning a foreign language in old age would be a potentially effective cognitive training paradigm. Language learning is a complicated process requiring an extensive neural network to accomplish (Rodríguez-Fornells et al., 2009; Tyler et al., 2005). To name a few, it involves learning the phonology of the new language, a new set of vocabulary and grammatical rules. Fong et al. (2022) found that vocabulary learning success of older adults was predicted by anatomical measures of the left pars orbitalis and the left caudal middle frontal cortex, which are responsible for semantic and episodic memory functions. Regarding grammatical rules learning, Tyler et al. (2005) found that the left superior-temporal-frontal region was associated with the processing of regular verbs but less so in irregular verbs. These studies collectively indicated that language learning is accomplished through a large neural network.

It is especially difficult when learning a language written with a different script (e.g., Chinese written in Sinogram and English written in Latin letters; see Wang and Tsai (2011)) because, in addition to the other aspects of language, the learners would also have to memorise a whole different set of script and the mapping of the sound to it. Also, the language typology, for instance, the similarity of word order, might also contribute to learning success and, thus, the cognitive outcome. According to Antoniou and Wright (2017), learning a typologically different language would be more cognitively taxing. From previous literature, it was thought that more demanding activities would bring greater cognitive benefits (Park et al., 2014). On the other hand, learning a typologically similar language would be easier, and participants might be more fluent in it in the earlier stage of learning. In this case, the newly learnt language would be interfering with the L1 to a larger extent and thus require participants to spare more cognitive resources to suppress it during the parallel activation. The practice of suppression would, therefore, improve the inhibitory control of the participants. However, we believe it is unlikely to increase participants' proficiency in the L2 to this stage from a six-week elementary course. Therefore, we opted to conduct the intervention with a more distant language (English) than a more similar one (e.g., Mandarin).

Since the suggestion by Antoniou et al. (2013), several studies have investigated the efficacy of using foreign language learning as a kind of cognitive training. So far, the results have been unclear. After learning a foreign language for a relatively short period, an improvement in general cognition as measured by MoCA or MMSE was observed in some studies (Bubbico et al., 2019; Pfenninger & Polz, 2018). Wong et al. (2019) recruited older adults from Hong Kong to learn English, attend music appreciation sessions or play video games for six months. They found that foreign language learning improved the working memory while video game playing improved attention. However, the less cognitively taxing activity, music appreciation, did not significantly improve any tests. The result supported the hypothesis that the more demanding the activity was, the greater cognitive benefits would be observed.

However, similar to cognitive training using other types of intervention, foreign language learning does not always promise a positive result. For instance, Berggren et al. (2018) recruited a large sample of participants and found no difference between the language learning and the control group. Ware et al. (2017) developed a computerised English learning program for older French adults. Though the older adults gave positive feedback on the program, their cognition did not improve significantly. In general, it is still unknown how effective foreign language learning is as cognitive training for older adults.

4.1.3 Individual Differences in Training Success

Not even pharmaceutical intervention could promise the same reaction from everyone. Individual differences in various aspects might affect how successful the cognitive training would be. Many factors influence how individuals would receive cognitive training. First, the cognitive ability at the baseline might affect how much training gain one could receive. It was suggested that those with lower initial ability would benefit more from cognitive training (Karbach et al., 2017; Roheger et al., 2020). Whitlock et al. (2012) found that the initial ability score predicted improvements in attention and spatial orientation tasks after video game-based training, and that those with lower cognitive ability in the baseline showed greater improvement. A meta-analysis also reported that those with initially lower abilities would benefit the most from training (Traut et al., 2021). The findings suggested that cognitive reserve was flexible but not unlimited. The higher-performing participants might have less or even no room for improvement.

In terms of psychological differences, motivation keeps people up when facing the challenge ahead. In a working memory training paradigm, the children that reported the task being “too difficult” showed less training gain and less transfer effect (Jaeggi et al., 2011). In the adult study, it was reported that the self-reported engagement score and the training gain were positively correlated and that those who were more motivated in the task had higher gains from the training programme (Jaeggi et al., 2014). Participants who thought the training was too challenging or tedious might continue to join the study because of the monetary incentive or to keep the promise to the experimenter. However, they were not fully engaged in the training, and ultimately, no cognitive gain was observed. In short, motivation might contribute to the amount of training gain and thus the transfer gain in cognition.

One crucial difference between foreign language learning and other types of cognitive training was that the former was more self-directed than the latter. Take physical exercise as an example; though the older adults would certainly not be reaching the professional level of the sport after just a brief amount of training, their bodies would get exercised as long as they have attended the class. The same applies to cognitive training involving computerised games or mind-exercises such as crossword puzzles and Sudoku. However, language learning requires a certain degree of effort on the part of the participants in order to master even the most basic concepts. Unfortunately, not all people are successful in learning a foreign language even when they are highly motivated. Working memory decline was an observable phenomenon of ageing (Salthouse & Babcock, 1991), which posed additional difficulty for older adults in the learning process. It was possible that someone could not remember much from the class even when they had paid full attention to it. This leads to one question – is learning success a prerequisite to training success?

4.2 METHODS

4.2.1 Participants

Sixty-three community-dwelling older adults were recruited for the study. The older adults were all Salvation Army Chuk Yuen Elderly Centre members. Five recruited participants dropped out of the study because of family emergencies or health-related problems. Another five were rejected from the analysis for the following reasons: one was a Thai Chinese bilingual and, therefore, did not fit with our inclusion criterion of being a functionally monolingual, one had depression, one failed to follow instructions, and one participated only to accompany her husband, but she did not meet the inclusion criterion (age < 65). Fifty-four participants remained in the analysis. As the experiment was conducted during Covid-19, the elderly centre was semi-closed and did not provide walk-in services. The recruited members were the more active members willing to take the trouble to reserve services beforehand and join activities. In other words, these participants were very active in participating in elderly centre activities.

All participants were screened with Montreal Cognitive Assessment (MoCA) - Hong Kong version and were considered cognitively normal if they scored above the 16th percentile in their respective age and education level according to the norm by Wong et al. (2015). Moreover, they were asked to name the 26 basic vocabularies as the baseline measurement of their English ability (see Figure 4.1).

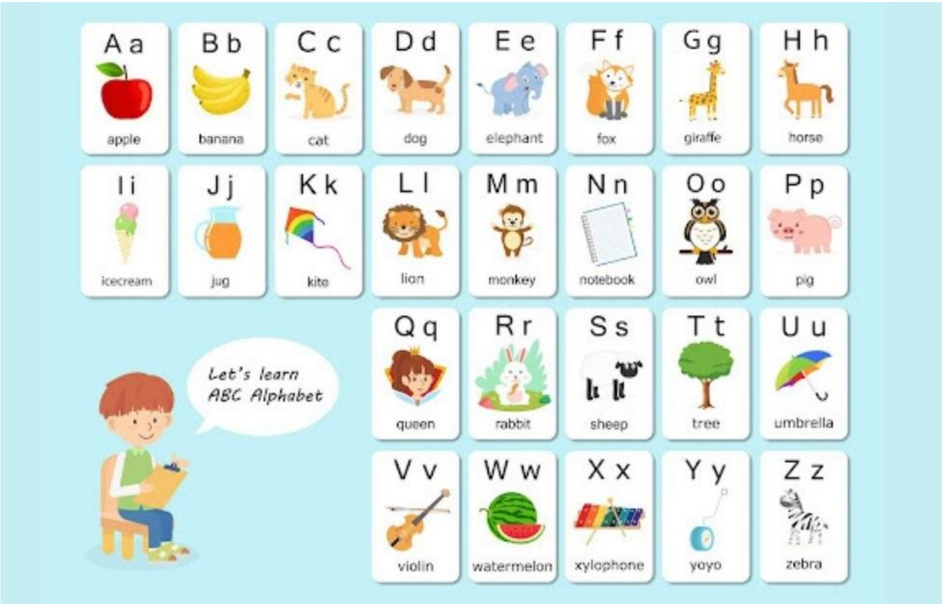

Figure 4.1. Measurement of initial English ability. Participants were asked to name the twenty-six basic vocabulary as a test of their initial English ability. Picture obtained from Shutterstock Figure ID 1498906745.

The remaining 54 older adults attended an English class (as the intervention group), a Leathercraft class (as the active control group) or attended nothing (as the passive control group) based on their preferences. See Table 4.1 for the demographic information of each group. Note that the gender is imbalanced because males were less active in joining activities in the elderly centre. Only one male participant was included in each group. The three groups did not differ in age ($F(2, 51) = 2.71$, $p = .076$), education years ($F(2, 51) = 1.06$, $p = .353$), MoCA score ($F(2, 51) = 0.19$, $p = .827$) or Initial English ability ($F(2, 51) = 0.73$, $p = .489$).

	N	**Age**	**Education (years)**	**MoCA (max = 30)**	**English (max = 26)**
English class	14 (13F, 1M)	69.45 (3.36)	6.29 (1.33)	25.07 (2.90)	13.00 (5.74)
Leathercraft class	17 (16F. 1M)	69.89 (3.22)	6.47 (3.95)	24.47 (3.00)	12.94 (8.33)
Passive control	23 (22F, 1M)	71.55 (2.45)	5.20 (2.88)	24.65 (2.44)	10.52 (7.51)

Table 4.1. Demographic information of the participants of Experiment 3. The number of subjects (*N*), age, education level, the MoCA score and the initial English ability of the participants of each group. Standard deviations are presented inside the brackets. F = Female, M = Male.

One participant in the Passive Control Group had a disability in the upper limbs, which prevented her from completing the Attention Network Test (ANT) because the task required button pressing. Her data on other tasks that were responded to verbally were included in the analysis.

4.2.2 Task Design

4.2.2.1 Cognitive Battery

All participants completed the cognitive battery twice, with six weeks in between. The English and Leathercraft class attended 1.5hr × 12 classes between the two testing timepoints, while the Control group received no intervention.

The cognitive battery included: (1) Animal Verbal Fluency, (2) Stroop task (Hui et al., 2020; Stroop, 1935), (3) Digit Span Forward, (4) Digit Span Backward, (5) Attention Network Test (Fan et al., 2002), (6) Picture Naming test (Fong et al., 2020), (7) Raven's Standard Progressive Matrices (Raven, 2003) and (8) O'Connor Tweezer Dexterity Test. For the details of Stroop, Digit Span Forward, Picture Naming and Raven’s SPM, please refer to Chapter 3.2.2 (page 29). The details of the remaining tests are described below.

Animal Fluency

Participants were given one minute to name as many animals as possible. The task was administered as part of the MoCA in the pre-test but as a standalone test in the post-test.

Digit Span Backward

Participants heard a series of numbers in random order, spanning from four digits to 12 digits. They were asked to repeat the numbers in the reverse order of the recording. For example, if the order was 3-5-8-1, then the participants should recall it as 1-8-5-3. Each span consisted of three trials and participants would proceed to the next span only when the subject answered two out of three trials correctly.

Attention Network Test (Fan et al., 2002)

See Figure 4.2 for an illustration. A 2 × 2 factorial design was employed, with CUE (no cue/ centre cue/ double cue/ spatial cue) and FLANKER (neutral/ congruent/ incongruent) as the two variables. In every trial, participants would see a fixation cross for a random duration of 400 to 1600 ms, and then one type of cue would appear for 100 ms. After that, only the fixation cross would be on the screen for another 400 ms. The stimuli then appear above or below the fixation cross for 1700 ms. Participants were required to press the left or right buttons (“A” and “L” on the keyboard, respectively) according to the direction that the central arrow was pointing. The central arrow was either flanked by arrows pointing at the same (congruent) or different (incongruent) directions or with plus signs (neutral) that did not point to any direction. A total of two blocks of 96 trials each was presented.

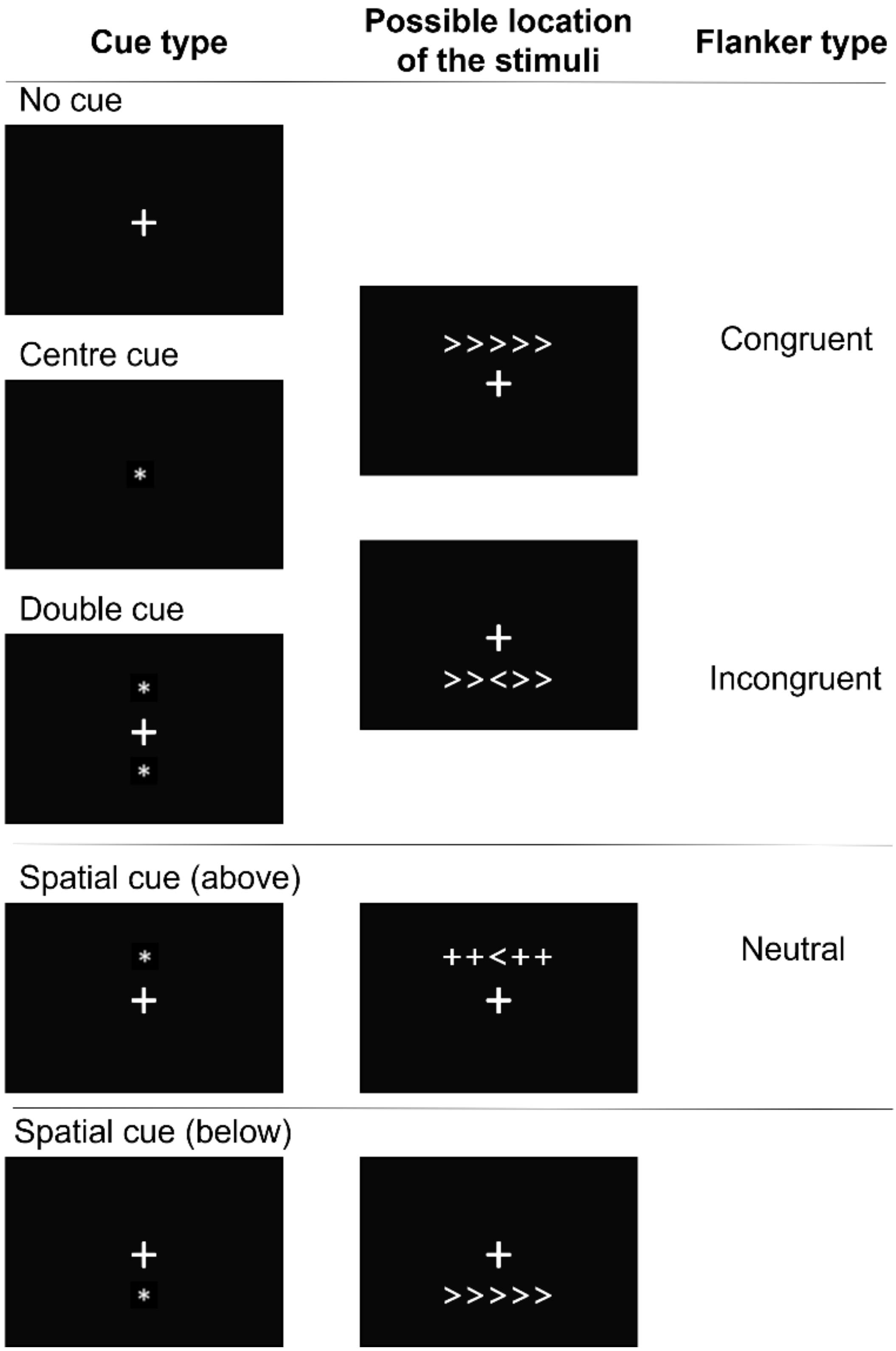

Figure 4.2. Attention Network Task (ANT). In this test, four types of cues will be shown briefly. After the cue, an array of five arrows will appear either on top of or below the fixation. Among the four, only the spatial cue provides information on where the stimuli will appear. Participants had to press the button indicating the direction of the central arrow. See main text for details.

In the experiment, only the spatial cue would provide information on the location of the upcoming target stimuli. For instance, if the spatial cue was on top of the fixation cross, then the arrows would appear on top. This allows the analysis of Orienting Effect. On the other hand, the double cue provided no spatial information but merely forewarned the participants to focus. The arrows could appear either on top or below the fixation. This allows the analysis of the Alerting Effect. Moreover, the Conflicting Effect could be measured by subtracting Congruent trials from Incongruent trials. See the following formula for the calculation of each effect:

$$Orienting\ Effect = RT\ of\ Centre\ cue\ - RT\ of\ Spatial\ cue$$

$$Alerting\ Effect\ =\ RT\ of\ No\ Cue - RT\ of\ Double\ Cue$$

$$Conflicting\ Effect\ =\ RT\ of\ Incongruent - RT\ of\ Congruent$$

One participant from the Control group was unable to complete this task as she suffered from an impairment in her upper limbs. Another three participants (one from each group) had scored below the chance level (2%, 7% and 40%) in the pre-test due to being too slow in responding; therefore, the e-prime script could not record their responses. Although two of them had performed within the average range in the post-test (99%, 95% and 31%, respectively), all of their pre- and post-test data were excluded from the analysis to avoid potential confounds.

<u>O'Connor Tweezer Dexterity Test</u>

A plastic board with 100 holes (10 × 10, each spaced 1.2 inches apart) was placed in front of the participants. Participants were instructed to move the pins using a tweezer from the storage compartment (located on top of the board) to insert them into the holes with their dominant hand. The time limit was three minutes. See Figure 4.3 for an illustration.

Figure 4.3. O'Connor Tweezer Dexterity Test. Participants were instructed to move the pins from the storage compartment of the board to the holes with a tweezer using their dominant hand.

4.2.2.2 English Class

Participants in the language learning group attended a 12-class elementary English lesson for six weeks. The last lesson was a revision section and an open-book exam. It was conducted in the classroom of the elderly centre, with which the older adults were familiar. Students were divided into three smaller groups, Class A, B and C, based on their preferences in time and date. The classes were taught by one instructor with the help of a teaching assistant (TA), both were native Cantonese speakers with good command of English. An instructor that speaks the same language as the older adults is more approachable and thus creates a more relaxing environment. A PowerPoint with audio-visual materials was used in teaching. Students were provided with an A4-sized coloured textbook and were encouraged to write notes. The full set of materials used in the English class can be obtained from Appendix 9.2.

Lesson	Theme	Lesson	Theme
1	Introduction of English	7	Asking for direction
2	Self-introduction	8	Emergency
3	Shopping 1	9	Simple present tense
4	Shopping 2	10	Simple past tense
5	Date and Time	11	Future tense
6	In the restaurant	12	Revision and exams

Table 4.2. Themes of each lesson in the English class. The table shows the theme of each chapter of the textbook used in the English class.

The textbook, homework and exam used in this study were designed by the experimenters based on the suggestions by Ramírez-Gómez (2019). All materials were printed with a font size of at least 14 pts on A4 paper for better visual accessibility (Ramírez-Gómez, 2019). Textbooks designed for young adults might not be attractive to older adults as they often included topics like job interviews and clubbing, which were of no practical use to them (Ramírez-Gómez, 2016). The content of the current textbook was tailor-made to older adults, which was useful in travelling or talking with domestic helpers at home. See Table 4.2 for the theme of each lesson. A two-page worksheet was distributed to students as homework after every class. The worksheet mainly replicated the in-class activity, and all answers could be found in the textbook (see Figure 4.4 for one example). For instance, in the class that taught location prepositions, students were provided with a picture and the words of "the dog is **on** the sofa" in the in-class activity. Students were provided with answers and explanations in the class. In the homework, the dog was changed to a clock and the sofa to a coffee table.

The decline in memory posed difficulty in learning, particularly in vocabulary spelling. It is especially difficult for people whose L1 is not an alphabetical language. Because of this, we did not require the older adults to spell the words or do any dictation. Instead, as described in Butzkamm (2003), "successful learners capitalise on the vast amount of linguistic skills and world knowledge they have accumulated via the mother tongue". We hoped to utilise the intact crystallised intelligence from the 60+ years of accumulated knowledge of the older adults in learning the L2.

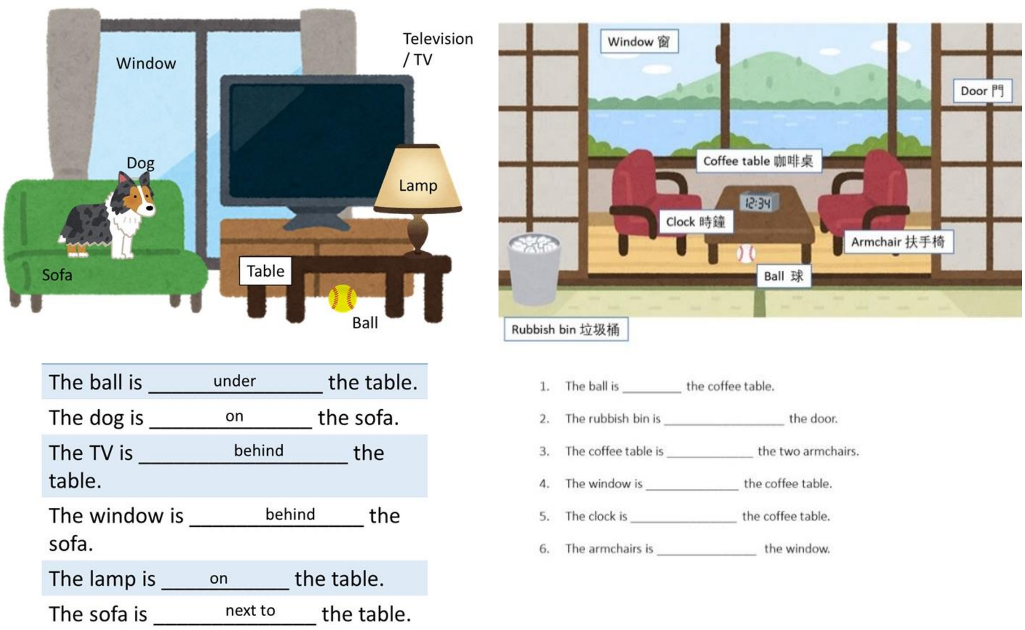

Figure 4.4. Example of classwork and homework. Left: a page in the textbook, used as an in-class exercise. Right: a page of the homework. The homework was designed as a replication of the classwork with minimal modification.

In the class, students were encouraged to notice and compare the similarities and differences between Chinese and English. For example, Cantonese has incorporated many words from English, and code-switching is very common. Students noticed the loan words (e.g., bus, taxi) and frequently code-switched items (e.g., "book": to reserve) and could memorise those vocabularies quickly. As for the differences, it helps increase the metalinguistic awareness of the students. In English, the "s" at the end of the noun indicates more than one item. Even though the Chinese language does not have a plural marker, students noticed and generalised it to other nouns. This learning strategy could also be applied to grammatical learning. For instance, the third-person singular of simple present tense requires an additional "s" at the end of the verb. Students understand that "eat" and "eats" share the same root, instead of memorising them as "I eat" and "He eats" as a whole phrase. They could also apply the same pattern to other verbs. However, the irregularity of English posed difficulty in learning. Similar to young students (Kuczaj II, 1977), the over-generalisation in verbs (e.g., go, went, *goed) and plural form (e.g., man, men, *mans) was observed.

Interaction between students was emphasised in language learning (Philp et al., 2013). However, under Covid-19 restrictions, students had to maintain social distance and sit far away from each other. Practising speaking between students was impossible in this sitting arrangement. Instead, students were asked to read aloud the dialogues one by one to the instructor. The presence of a TA was found to be helpful for older adults even in such a relatively small class as they often request assistance (van der Ploeg et al., 2022). Students were afraid to make mistakes and embarrass themselves in front of the class. They preferred to have their answers written down and checked by the instructor or the TA before reading them out loud during the class activities. The checking also helped in confirming that the students had jotted the notes correctly.

4.2.2.3 Leathercraft Class

The Leathercraft class was designed to be an active-control group. Participants attended a 12-class introductory leathercrafting course over six weeks, so they were provided with the same amount of social interaction as the intervention group. The first class introduced the procedures step-by-step. After the first class, participants were given a sample and a paper template of what to make in that class. They were encouraged to modify the template in any way they like (e.g., add a pocket, add a button, change the shape). Assistance would be provided when requested, but otherwise, the participants were relatively independent in the making process. The finished products included a key chain, a card case, a coin purse, a small purse and a wallet. As the participants in this group were also learning a new skill, it was expected that they would also show improvement in some cognitive tests.

4.3 RESULTS

Table 4.3 shows the behavioural results of the cognitive tests before and after the intervention. The three groups did not differ in any of the cognitive tests in the baseline (*p*s > .188).

	English		Leather		Control	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**
Verbal fluency	15.29 (4.84)	17.14 (4.50)	18.00 (3.61)	17.94 (4.56)	17.00 (4.21)	16.43 (3.75)
Stroop W	79.14 (10.50)	81.57 (9.28)	69.88 (14.97)	76.12 (15.97)	75.52 (16.77)	81.00 (15.65)
Stroop C	57.00 (10.70)	54.71 (11.11)	52.65 (13.10)	52.06 (11.33)	55.09 (14.66)	55.22 (14.19)
Stroop CW	22.57 (9.08)	25.00 (6.78)	22.88 (7.05)	24.59 (8.77)	23.30 (9.82)	25.52 (8.79)
Digit Span Forward	6.64 (1.69)	7.07 (1.38)	6.29 (1.21)	6.59 (1.37)	6.48 (1.31)	6.78 (1.20)
Digit Span Backward	4.00 (0.78)	4.29 (0.83)	3.82 (0.81)	4.06 (0.97)	3.96 (1.02)	4.17 (0.94)
Picture Naming ACC (%)	86.39 (9.72)	89.97 (10.02)	87.11 (11.94)	90.48 (10.31)	85.61 (7.34)	87.06 (7.14)
Picture Naming RT (ms)	1471.16 (249.65)	1418.73 (188.75)	1374.97 (251.87)	1357.76 (215.62)	1478.32 (235.21)	1455.02 (276.70)
ANT – Orienting^	5.07 (35.55)	20.47 (26.72)	6.61 (35.46)	17.38 (27.01)	18.04 (38.85)	23.30 (34.50)
ANT – Alerting^	15.39 (27.85)	29.40 (16.70)	17.92 (31.30)	15.84 (37.71)	17.27 (28.18)	29.60 (34.39)
ANT – Conflicting^	137.13 (57.72)	114.86 (38.75)	161.62 (47.73)	141.05 (45.52)	156.41 (69.88)	129.16 (59.11)
Raven's SPM	15.29 (5.93)	16.64 (5.15)	16.47 (6.45)	18.82 (3.36)	15.00 (5.54)	17.17 (4.73)
Dexterity Test	37.79 (10.93)	41.86 (15.45)	43.35 (8.94)	48.29 (11.51)	40.26 (10.59)	42.30 (11.18)

Table 4.3. Behavioural result of Experiment 3. The table shows the behavioural results of each cognitive test before the intervention from the three groups of participants. ^ The number of participants in the ANT task was 13, 16 and 21 for English, Leathercraft and Control, respectively. See the main text for explanations.

A repeated measures two-way ANOVA was performed for each cognitive test, with CLASS (English / Leather / Control) and TIME (Pre / Post) as the independent variables. No interaction was significant in any of the cognitive tests (*p*s > .449). The simple main effect of TIME was significant for Stroop W (F (1, 51) = 17.93, p < .001), Digit Span Forward (F (1, 51) = 5.36, p = .025), Digit Span Forward (F (1, 51) = 4.02, p = .050), Raven's SPM (F(1, 51) = 7.17, p = .010), Dexterity test (F(1, 51) = 7.25, p = .010), Picture Naming ACC (F(1, 51) = 17.40, p < .001), ANT Alerting (F(1,47) = 5.01, p = .030) and ANT Conflicting (F(1, 47) = 19.59, p < .001). Table 4.4 shows the difference score of pre- and post- test (Δ, post-test minus pre-test) for each group, and the p-value for the main effects and the interactions.

Δ	English	Leather	Control	CLASS (*p*)	TIME (*p*)		CLASS × TIME (*p*)
Verbal fluency	1.86	−0.06	−0.57	.343	.536		.316
Stroop W	2.43	6.24	5.48	.316	< .001	***	.389
Stroop C	−2.29	−0.59	0.13	.700	.267		.480
Stroop CW	2.43	1.71	2.22	.955	.037	*	.957
Digit Span Forward	0.43	0.29	0.30	.651	.025	*	.927
Digit Span Backward	0.29	0.24	0.22	.774	.050	*	.974
Picture Naming ACC (%)	3.57	3.36	1.45	.667	< .001	***	.324
Picture Naming RT (ms)	−52.42	−17.20	−23.30	.385	.130		.775
ANT – Orienting ^	15.41	10.77	5.26	.750	.135		.381
ANT – Alerting ^	14.01	−2.08	12.33	.315	.030	*	.937
ANT – Conflicting ^	−22.27	−20.57	−27.25	.433	<.001	***	.847
Raven's SPM	1.36	2.35	2.17	.486	.010	**	.857
Dexterity Test	4.07	4.94	2.04	.230	.010	**	.636

Table 4.4. Differences between pre- and post-test of Experiment 3. The differences between pre- and post-tests are shown here (Δ), together with the p-value of the two main effects (Class and Time) and the interaction. ^ The number of participants in the ANT task was 13, 16 and 21 for English, Leathercraft and Control, respectively. See main text for explanation. * = <.05, ** = <.01, *** = <.001.

To understand the efficacy of each intervention programme, a planned comparison was performed to test the differences between pre- and post-test within each group. In the English group, a significant effect of Time was observed in Picture Naming ACC (t(13) = 3.50, p = .004) and in ANT-Orienting (t(12) = −2.20, p = .048). In Leathercraft group, the effect was found in Stroop W (t(1, 16) = 3.92, p = .001), Picture Naming ACC (t(16) = 3.87, p = .001), ANT-Conflicting (t(15) = 2.59, p = .020), and in

Dexterity test ($t(16) = 3.76$, $p = .002$). In the passive Control, the Time effect was found in Stroop W ($t(22) = 2.76$, $p = .011$), Digit Span Forward ($t(22) = 2.08$, $p = .050$), Raven's SPM ($t(22) = 2.22$, $p = .037$) and ANT-Conflicting ($t(20) = 3.92$, $p = .001$). See Table 4.5.

	English			Leather			Control		
	t	*p*		*t*	*p*		*t*	*p*	
Verbal fluency	1.80	.095		−0.05	.958		−0.51	.616	
Stroop W	1.35	.202		3.92	.001	**	2.76	.011	*
Stroop C	−1.61	.131		−0.40	.694		0.10	.918	
Stroop CW	0.93	.372		1.30	.212		1.69	.105	
Digit Span Forward	1.03	.321		1.23	.236		2.08	.050	*
Digit Span Backward	1.47	.165		1.00	.332		1.16	.260	
Picture Naming ACC	3.50	.004	**	3.87	.001	**	1.16	.259	
Picture Naming RT	−1.73	.107		−0.48	.640		−0.71	.488	
ANT – Orienting ^	−2.20	.048	*	0.06	.952		−0.80	.432	
ANT – Alerting ^	−1.50	.160		−0.87	.397		−1.67	.111	
ANT – Conflicting ^	1.68	.120		2.59	.020	*	3.92	.001	**
Raven's SPM	0.77	.457		2.04	.058		2.22	.037	*
Dexterity Test	1.09	.296		3.76	.002	**	1.05	.307	

Table 4.5. Paired sample t-test of the Time effect of each group in Experiment 3. This table shows the paired sample *t*-test and the *p*-value of the Time effect within each group. ^ The number of participants in the ANT task was 13, 16 and 21 for English, Leathercraft and Control, respectively. See main text for explanation. * = <.05, ** = <.01, *** = <.001.

As for whether learning success is an essential step of training success, we investigate the relationship between learning outcome and cognitive outcome. Although some participants were observably less creative or skilled than the others in the Leathercraft class, there was no objective measurement of how successful an individual was in arts and crafts. On the other hand, participants had to finish homework and exam in the English class, which could objectively measure their learning success. As the homework was designed to be an extension of the in-class activities and answers could be found in the textbook, it was assumed that the motivated students would spend more effort working on it and hence score higher. The homework score could, therefore, be viewed as a measurement of motivation. In contrast, the exam, though in the form of an open book test, was conducted under time pressure. It could, therefore, measure the overall learning success. A two-tailed partial correlation analysis controlling for initial English ability was conducted to examine the relationship between motivation, learning success and the differences between pre- and post-scores in the cognitive tests. None of the correlations between Homework (motivation) and the cognitive tests was significant. In contrast, Exam (learning success) was significantly correlated with the difference score of Stroop CW (r = .65, p = .017) and Verbal Fluency (r = −.61, p = .028).

As an exploration on whether baseline cognitive abilities contribute to the success in learning the language, a two-tailed partial correlation analysis was also conducted between examination score and the baseline measurements in each cognitive test, controlling for initial English ability. Exam score was significantly correlated with Raven's SPM (r = .66, p = .011) and Picture Naming ACC (r = .70, p = .006). The effect of Raven's SPM was perhaps due to the emphasis on generalising grammatical rules and knowledge from L1 to English learning in the current course. Raven's SPM required participants to observe and generalise the patterns, which was essential in studying using the current course design. On the other hand, Picture Naming ACC required participants to recognise objects and access the mental lexicon rapidly (Abrahams et al., 2003), which was essential in learning new vocabularies.

4.4 DISCUSSION

4.4.1 Effectiveness of the Training

The planned paired sample t-test was conducted between the two time-points for each group to explore the effect of each intervention. As the Time effect was observed in different tasks for different groups, it suggests that the improvement was not simply a practice effect, that the participants had experience in doing the tasks in the pre-test and developed strategies for it in the post-test. In addition, the improvement of the Dexterity Test which was only observed in the Leathercraft group provided further evidence for this assumption. In the O'Connor Tweezer Dexterity Test, participants were asked to use a tweezer to move the pins into the holes on the board. It required fine motor control and good hand-eye coordination to accomplish the task (Brandy, 1995). The Leathercraft group was doing delicate hand-sewing during the intervention period, in which they had to pull the waxed threads with a needle through the pierced holes on the leather. The process was similar to the Dexterity test and hence the near transfer effect was observed.

4.4.1.1 Picture Naming

Picture Naming ACC was found to be improved in both the English and Leathercraft groups but not in the Control group. As mentioned in Chapter 2, it is unlikely that any cognitive test relies only on one cognitive ability to complete (Valian, 2015). Picture-naming is thought to include at least three sequential stages: object identification, naming activation and response generation (Johnson et al., 1996; Paivio et al., 1989). To name an item, one must first recognise its identity, and then multiple candidates of names would be activated. After choosing the correct item out of the activated candidates, the name would be finally verbally articulated. It is possible that the English and the Leathercraft groups were improving in different stages, and, therefore, both showed improvement in the outcome of the task.

A previous study found that bilinguals were slower than monolinguals in the naming task but not in the picture classification task, suggesting bilingualism affects the post-conceptual processing level (Gollan et al., 2005). It is believed that the slower speed in naming is due to the interference from the other language, that the bilingual would have to suppress the unwanted language before naming it in the desired one. The two languages of the bilingual do not share the same strength, and the weaker one would be easier to suppress. As our participants were still in the earliest stage of language acquisition, it was unlikely that they were experiencing a similar amount of interference from their newly learnt language as the lifelong bilinguals. Nonetheless, an improvement was observed in the task. Through learning and using a new set of vocabulary, the participants in the English learning group were indeed practising a process very close to "picture-naming" in class, only in a reversed way. In the class, participants were provided with lists of English vocabulary with either pictures or Chinese translations. When learning the new vocabularies, the participants created a link from the semantic concept to the newly built mental lexicon. According to the Revised Hierarchical Model (Kroll & Stewart, 1994; Potter et al., 1984; Weinreich, 1953), the low proficient L2 speakers organised their concepts in the structure that the L2 is first linked to its L1 before linking to the conceptual level. It is opposed to the structure that the highly proficient bilinguals have, that both L1 and L2 links directly to the concept. It is reasonable to believe our participants were still in the stage that the retrieval of concepts must go through the L1 first. To use the newly learnt English words in class or when doing homework, the participants must first activate the concept they would like to use, then retrieve the L2 words which were associated with its L1 equivalent. Although the improvement in RT was not statistically significant, it was also numerically better in the English group (52.42ms) than the Leathercraft (17.20ms) and the Control (23.30ms). Such practice in the retrieval of concepts and words might be the mechanism behind the improvement of Picture Naming in the English learning group.

However, this does not explain why the Leathercraft group also showed improvement in the Picture Naming task. In the Leathercraft group, the Stroop W was also improved but not in C or CW conditions, nor Picture Naming RT, suggesting that it was not from merely an increase in the speed of articulation. More likely, it was the recognition of the item that had been improved from the practice of crafting. Crafting is a complex process that requires the coordination eye, hand and mind (Seitamaa-Hakkarainen et al., 2016). As the picture-naming test used black-and-white line drawings, it also required the recognition of such pictures, which was found to be more difficult than recognising pictures with gradients or colour (Rossion & Pourtois, 2004). The Leathercraft course required participants to make a three-dimensional product from a piece of leather only by referring to a paper template and a sample of the product. This might contribute to a better perceptual skill and, therefore, improve the performance in picture-naming in the stage of recognising the items.

4.4.1.2 Attention Network Test

In terms of attention, Posner and Petersen (1990) proposed that there are three subsystems, (1) orienting to sensory information, (2) detecting signals for processing, and (3) maintaining an alert state. The Attention Network Test (ANT) integrated the three subsystems into one test and named each as Orienting, Alerting and Conflicting effect, respectively (Fan et al., 2002). In our study, three groups showed different improvement patterns in the ANT test. The English group significantly improved in the Orienting Effect, while both the Leathercraft and the Control groups showed improvement in the Conflicting Effect.

The Orienting Effect measures how quickly participants could direct their attention to the cued location, which is thought to be related to the disengagement of information (Fan et al., 2002). With a spatial cue giving explicit hints on where to look at in the succeeding stimuli, it is expected that all participants should be able to perform equally well. However, with only a centre cue provided, one would have to disengage their attention from all possible spaces that the stimuli would appear and orient to where the stimuli actually appeared. Previous studies had reported a bilingual advantage of disengagement of attention, and claimed that the bilinguals had a higher ability to ignore the irrelevant task that had passed, and focus on the task on-hand (Goldsmith & Morton, 2018; Grundy et al., 2017). In addition to the possibility that the new bilinguals started to show similar linguistic experiences as the lifelong bilinguals, the improvement of Orienting Effect might also be due to the intervention programme design. In the English class, participants would have to constantly pay attention to the instructor and the changes in the class activity. If one could not disengage their attention from the materials that the instructor was no longer referring to, they might risk missing the next topic. The class was relatively synchronised compared to the Leathercraft class, which every participant might be in a different stage of making their product. Therefore, the English group but not the Leathercraft group had demonstrated improvement in orienting.

Conflicting is thought to be related to the executive control of attention, which involves monitoring and solving conflicting information, and is related to the mental effort of processing (Fan et al., 2002). It includes detecting the presence of conflicts and allocating sufficient resources to solve them (Costa et al., 2008). For instance, in the neutral condition (e.g., ++>++), the interference (i.e., the plus signs) is easier to resolve compared to the incongruent condition's interference (e.g., <<><<, the arrows pointing to an opposite direction). In order to efficiently complete the task, participants should not devote all cognitive resources to easier conditions and risk having insufficient resources in the more challenging conditions. A previous study on children who participated in a multidimensional programme, including arts and crafts and motor activities found an improvement in executive function and visuospatial skills (Brock et al., 2018). This is possibly because crafting requires problem-solving in the process. Participants have to detect if anything goes wrong in hand and think of a way to remedy the errors. For instance, in the leathercraft process, participants have to be aware of whether they are sewing two pieces of leather on the wrong side. The attention devoted to monitoring the potential error in hand might be the reason behind the improvement in the ANT-Conflicting condition.

4.4.1.3 Others

Interestingly, the Control group was also found to show improvement in the ANT-Conflicting. Besides, improvements in Digit Span Forward and Raven's SPM were also found, in which the effect was not shared by the other two intervention groups. We believe that it is because the control might also have been participating in stimulating activities outside the study. As we mentioned at the beginning, Covid had hindered our ability in participant recruitment, and only those who were active in the elderly centre would participate in our study. Although enrolling in the control group showed that they were not interested in joining our two intervention classes, they might still be joining other activities organised by the elderly centre. In fact, 17 out of the 23 control participants had reported to us in the post-test session that they were joining a wide variety of classes, including Tai-Chi, physical exercises, Rummikub, singing, arts and crafts or even sign language learning. Whereas for the two intervention groups, the classes they attended could be considered a learning experience in addition to their other activities, the Control group was not expected to be engaged in any learning. It leads to a practical problem that concerns all cognitive training intervention experiments: the controls are not really controllable. Unless the control participants were living in, for example, a nursing home where their daily activities could be accurately recorded, there was no possible way to restrict the community-dwelling older adults from attending activities that could confound the study. The author believes that the direct comparison of the Control and the two intervention groups might not serve the expected purposes. Instead, a deeper look at each group might provide more meaningful insight into how the interventions might benefit cognition.

At the group level, neither the English learning group nor the Leathercraft group significantly differed from the passive Control group in the pre- and post-intervention differences. Due to the small sample size of each group, the result was not unexpected (see also Ware et al., 2017). Moreover, in our study, participants attended 18 hours of classes over six weeks, which was considerably fewer than most of the studies. For instance, Wong et al. (2019) provided a maximally 130 hours of computerised English learning courses over six months, and Herrera Naranjo et al. (2021) provided 40 hours over four weeks. However, as our course was conducted in traditional classroom style but not computerised self-learning, and our participants (65 – 75 years old) were older than Herrera Naranjo et al. (2021) study (40 – 60 years old), a prolonged or highly intensive course was not a feasible option. Nevertheless, there were other research groups with fewer participants and shorter intervention periods that found improvements after the intervention (e.g., Bak et al., 2016; Bubbico et al., 2019; Pfenninger & Polz, 2018), suggesting that these were not the sole obstacles that prevented the success of the intervention. It is possible that with more participants and longer intervention, the differences between groups would be statistically significant. As this study aimed to explore whether foreign language learning might contribute to cognition, the English group will be the focus of the below discussion.

4.4.2 Learning Success and Training Success

Cognitive training has been conducted via various means. Attempts have been made through physical training (Hsieh et al., 2018), working memory training (Borella et al., 2013), reasoning training like Sudoku and crossword puzzle (Jackson et al., 2012), learning of visual arts (Patterson & Perlstein, 2011), or a combination of physical and cognitive training (Gajewski & Falkenstein, 2012; Kivipelto et al., 2013). Since the suggestion by Antoniou et al. (2013), many have tried to use foreign language learning as a type of cognitive training because of its potential to utilise an extensive brain network during learning and hence provide sufficient intellectual stimulation for cognition to be improved. The success in cognitive training was believed to be due to the practice of using neural networks that overlapped with the transferred tasks.

On the other hand, researchers were well aware that not everyone reacted the same way to cognitive training. In fact, some studies believed that adjusting the task difficulty in the training was essential in designing an effective training programme (Küper et al., 2017; Ottersen & Grill, 2015). Some researchers emphasised the “desirable difficulty”, which provided the participants with enough but not overwhelming challenges (Bak et al., 2016; Bjork & Kroll, 2015). A suitable task difficulty might encourage the participants to be more motivated in participating in the training and hence receive better training results. Jaeggi et al. (2011) found that children who reported the training programme being too difficult performed worse because of a lack of motivation. These children had lower training gain in the post-test compared to those who reported the task difficulty being optimally challenging. It suggested that the motivation or the learning success in the training programme might be a factor that influences the transfer gain. However, to the best of our knowledge, few studies explicitly investigate the relationship between training success and the cognitive outcome.

It was well-accepted that older adults suffer from declining memory (Salthouse & Babcock, 1991). In fact, six out of fourteen participants in the English class had explicitly expressed difficulty remembering what was taught in the class and that, as quoted from one of the participants, “I forget everything when I get home”. Another participant described her learning as “I can do it during the class, but I cannot remember it afterwards”. In other words, even though some of them had tried hard in their learning progress, the new knowledge did not last long in their memory. Despite being motivated, learning success was not guaranteed. In the current study, the homework was designed as an extension of the classwork. For a more motivated student, such homework should not be a problem because they can always refer to the textbook and the classwork to find the correct answer. They could also ask their family members at home if they needed assistance. Therefore, the average score on homework was used as a measurement of motivation in learning. In the partial correlation analysis with their initial English ability controlled for, motivation did not correlate with any of the changes in cognitive tests. It confirmed our suggestion that being motivated alone was not enough in a training programme like language learning.

On the other hand, the examination score served as an indicator of learning success. The exam was open-book in nature with a time limit of one hour. Similar to homework, students could refer to the textbook and classwork at any time. However, with time pressure and no one to ask, the final score depended more on how much the students had learnt in the class. The examination score was positively correlated with the Δ

Stroop CW, with initial English ability controlled for. Previous studies suggested that the two languages in a bilingual do not share a similar strength, and that suppressing a stronger language requires more effort (Kroll & Stewart, 1994; Meuter & Allport, 1999). Theoretically, compared to the time point before learning the L2, the participants in this current experiment would have to spend more effort inhibiting their L2 when speaking in L1 (Hui et al., 2020). However, it was unlikely that the participants in this study would have experienced the same amount of interference from the L2 in their daily communication as the lifelong bilinguals because their L2 proficiency was still very low, and the processing of L1 would be affected only when L2 was sufficiently proficient (Van Hell & Tanner, 2012). Instead, the improvement in inhibition was more likely to have originated from L1 interference during L2 learning. In the class, those who were more proficient in the L2 were more active and willing to speak in L2 aloud. This gave them more practice inhibiting the strong L1 during the relatively immediate L2 production task. In comparison, the weaker learners were more reluctant to speak until the teacher or the TA had checked their written answers. Although reading the text aloud also required a certain amount of language inhibition (Parker Jones et al., 2012), it was expected that the effort of inhibition would be lower than that during an immediate production.

In addition, the examination score was found to be negatively correlated with Δ verbal fluency after controlling for initial English proficiency. In the verbal fluency task, participants were required to name as many animals as possible in one minute. Previous studies suggested that the increase in L2 proficiency would increase the interference from the L2 during an L1 production task (e.g., Portocarrero et al., 2007; see also Sandoval et al., 2010). Therefore, it was often observed that bilinguals performed worse than monolinguals in verbal fluency tasks. However, in the English class, no animal names were taught, except for “dog” and “cat” which students likely knew before the course. Therefore, theoretically, there should not be any interference from the newly acquired L2 when naming the animals in L1. We speculate that those with higher English proficiency were more likely to know vocabulary beyond the teaching syllabus. It was possible that through, for instance, spending time with their grandchildren, they might have picked up common animal vocabularies (e.g., “tiger”, “lion”, and “rabbit”). As all the participants lived in the same neighbourhood, it was assumed that they had a similar lifestyle. Those with worse English proficiency might have a similar level of exposure to these vocabularies, but they might not be able to pick them up as quickly as the more successful learners.

Moreover, no effect was observed in working memory as measured by Digit Span Forward and Digit Span Backward. This was opposite to what was expected by researchers who suggested using foreign language learning as cognitive training (Antoniou et al., 2013; Klimova & Pikhart, 2020), as it is thought that the learning of a new set of vocabulary and grammar rules would have trained the memory system. The lack of effect in improving memory in our study might be due to the design of the course. We did not require the participants to do dictation or even spell the newly acquired vocabulary. Instead, we only required them to try recognising the L2 word and associate the meaning with it. This was because we did not want to create too much burden in the elementary course and make the participants feel it was impossible to accomplish. If the course continued to a more advanced level with more emphasis on memorising the words, it is possible that memory could be improved.

In short, the learning success was positively correlated with inhibition control ability and negatively correlated with the language task. The finding suggested that even though the L2 exposure was brief and was only at a beginner level, those who were more successful in learning the L2 exhibited a change of cognitive abilities. Collectively, this points to a promising direction of using foreign language learning as an effective intervention for older adults.

4.5 CONCLUSION

Bilingualism is thought to be one of the protective factors for ageing, especially in inhibitory control ability. This was because of the constant practice of linguistic inhibition that transferred to general inhibitory control. However, previous studies often investigate the effect of lifelong bilinguals. Whether language learners who started in the later stage of life still benefited from bilingual advantage is unknown. This current experiment recruited older adults to learn English as a type of cognitive training. Compared to other types of cognitive training, foreign language learning required participants to be more proactive in participation that merely attending the class was not enough. Results found that learning success, as measured by the final examination score, was positively correlated with Stroop CW and negatively correlated with Verbal Fluency. This suggested that those more successful in language learning started to exhibit changes in cognition, similar to lifelong bilinguals. In conclusion, foreign language learning could be a promising intervention for cognitive reserve even if started at an old age.

Chapter 5. CODE-SWITCHING AND MENTAL LEXICON

This chapter introduces an eye-tracking experiment on the comprehension of code-switched sentences. Code-switching is a noticeable feature of Hong Kong Cantonese that people find it difficult not to code-switch during a casual conversation. As the cognitive effort in the production and comprehension of languages was believed to be the key factor that contributes to bilingual advantage, this experiment aims to investigate how code-switching is processed and how it affects the mental lexicon.

This experiment was published in Hui et al. (2022) and is summarised in the Methods and Results session to provide a more reader-friendly and comprehensive argument. I have permission from my co-authors and publisher to use the work in my dissertation. Copies of all copyright permissions are in Appendix 9.1.

5.1 INTRODUCTION

Code-switching and code-mixing refer to the use of two or more languages in a single utterance (Fairchild & Van Hell, 2017). Some researchers distinguish between the two by stating that the former refers only to inter-sentential switches and the latter to intra-sentential switches (Bokamba, 1989). Some used code-mixing exclusively for language learners during early bilingual development (Yow et al., 2016). Some treated the two terms as synonyms and used them interchangeably (Hasan & Akhand, 2015; Mabule, 2015). Myers-Scotton (1993/1997) defined code-switching as not only a switch of languages or dialects but also the changes in styles and registers. Poplack

(1980), on the other hand, named all extra-sentential (i.e., fixed phrases inserted in the sentence, e.g., "isn't it?"), inter-sentential and intra-sentential as three types of code-switching. Along with this view, this dissertation used "code-switching (hereafter "CS")" to refer to both inter-sentential, intra-sentential switching and the very short utterance (e.g., "Good", "OK") that could be a sentence itself.

In the Matrix Language Frame Model (Myers-Scotton, 1993/1997), the Matrix Language is the language that provides the abstract grammatical frame, for example, the morpheme order. The Embedded Language, on the other hand, is inserted within the matrix and usually "provides the content morphemes in the code-switched constituents" (Dussias, 2001). For instance, Example 1 shows a speech of a Hong Kong child speaking with his/her Indonesian maid, who speaks English and a little Cantonese. In this example, the Matrix language is English, and the Embedded language is Cantonese. On the other hand, Example 2 shows an excerpt from a Hong Kong local speaking with his/her friend on their memories in university time. Though the two languages used are the same as the one in Example 1, this sentence has Cantonese as the Matrix Language and English as the Embedded Language.

1. Example from Chan (2018)

Cousin A: [*English-Cantonese*] Daisy, cook the 腸仔(coeng4 zai2) for me!
Daisy, cook (heat) *the sausage* for me!

2. Example from Chan (2018)

Friend C: [*Cantonese-English*] 我地以前 print 好多野。
Ngo5 dei6 ji5 cin4 *print* hou2 do1 je5
We used to *print* so many stuffs.

The habit or attitude towards CS could be very different even for two neighbouring places that were geographically next to each other. For instance, residents on the Ottawa side of the river switch from French to English three times more than the residents on the Quebec side (Poplack, 1988). In Hong Kong, conversation among the locals is more common to have Cantonese as the Matrix Language and English as the Embedded Language than vice versa. Also, because the CS in Hong Kong is predominantly intra-sentential, the experiment reported in this chapter is, therefore, concerned only with Cantonese-English intrasentential CS.

5.1.1 Processing Code-switched Sentences

A bilingual can only use one language at any given time, but the unused language is never totally switched off. Using eye-tracking method, Spivey and Marian (1999) found that in Russian-English bilinguals, the irrelevant language was activated during an auditory task. The parallel activation of languages was later replicated in the Spanish-English bilinguals (Shook & Marian, 2019) and the Hindi-English (Mishra & Singh, 2014) bilinguals. Because the two languages are always activated together, a bilingual would have to inhibit the unwanted one in order to speak in the language relevant to the conversation.

The Adaptive Control Hypothesis (Green & Abutalebi, 2013) suggested that there are three bilingual interaction contexts, namely, the single language context, the dual-language context and the dense code-switching. The language production in each interaction context requires different degrees of control, eventually leading to different cognitive outcomes. Single language context refers to the use of one language in one environment and the other language in another environment. For instance, Language A is used exclusively at home and Language B at work. This interaction context does not typically involve language switching except when the bilingual moves to another environment. Dual language context refers to using both languages in the same environment, for example, switching to another language to speak to different people. Example 3 shows an example of a conversation between a Hong Kong salesperson and a Mandarin-speaking customer (Pan, 2000). Cantonese is the language most spoken in Hong Kong, so the salesperson initially addressed the customer in Cantonese. When the customer replied in Mandarin, the salesperson picked up the cue that the customer did not speak Cantonese and quickly switched the language. This was considered cognitively taxing because the speaker would have to inhibit the unwanted language (Cantonese) that is simultaneously activated and be constantly alerted to switch when an external cue (in this case, the customer's speech) appears. This interaction context is less common in conversation among Hong Kong locals, as the majority of the population speaks Cantonese as their mother tongue (*Proportion of Population Aged 5 and Over Able to Speak Selected Languages/ Dialects by Year*, 2017). This reflects how the environment might shape one's language behaviour, and thus potentially affect the cognitive consequence from the use of language.

3. Example from Pan (2000)

Salesperson: [*Cantonese*] 睇啲乜嘢啊？
Tai2 di1 mat1 je5 aa3?
What do you (want to) see?

Customer: [*Mandarin*] 我想看桌子。
Wǒ xiǎng kàn zhuōzi.
I want to have a look at the tables.

Salesperson: [*Mandarin*] 桌子？
Zhuōzi?
Table?

Dense code-switching is defined as switching between languages within a single sentence. One of the distinct features of Hong Kong-Cantonese that make it stand out from Cantonese of other regions (e.g., Guangzhou) is the frequent CS of Cantonese and English in daily communication (Pan, 2000). Example 4 shows an excerpt of an informal conversation between a student and an interviewer, in which the student describes an experience he had on campus (PolyU-Department of English, 2015). In this example, the speaker has inserted English words into the Cantonese sentence matrix. The production of this type of switching is believed to be not cognitively effortful because the speaker retrieves the most available language without any inhibition (Green & Abutalebi, 2013).

4. Example from PolyU-Department of English (2015)

Respondent: [*Cantonese*] 噉咪 call security，跟住 security 幫我哋開門。
Gam2 mai6, *call security*, gan1 zyu6 *security* bong1 ngo2 dei6 hoi1 mun4.
So, (we) *called the security* (guard). Then the *security* (guard) helped us to open the door.

Experimental studies often reported prolonged reaction time in cued switching tasks, in which the participants had to switch to another language when they saw a particular cue that precedes the trial (e.g., Costa & Santesteban, 2004; Meuter & Allport, 1999). This requires top-down control to inhibit the language and then activate the previously inhibited language. On the contrary, experiments that allow participants to freely use any of the languages to respond often reported no difference (de Bruin et al., 2020; Kleinman & Gollan, 2016) or even facilitation (Gollan & Ferreira, 2009) in switching the languages. The voluntary switching requires bottom-up control and is relatively effortless. In reality, the production of CS is more likely voluntary, that the speaker is not cued by external interference to do so. Bilingual CS is because, at that moment, the word or the phrase from the other language is the most retrievable compared to staying in the same language.

Whereas the voluntary production of CS is not effortful for the speakers, the comprehension of CS is believed to be cognitively demanding. Reading a code-switching sentence was reported to be more difficult than reading a unilingual sentence (Altarriba et al., 1996). A self-paced reading task reported that both alternation (i.e., a switch in the language in the middle of the sentence without switching back, e.g., "当黑暗降临时，所有 wolves howled at the moon loudly. (*When darkness fell, all wolves howled at the moon loudly*)") and dense CS (i.e., switching the languages back and forth, e.g., "当 darkness 降临时，所有 wolves 对着月亮大声嚎叫") required longer reading time than non-switch sentences (Jiang et al., 2022). As a listener or reader would not know when to expect a CS, once they encounter one during a conversation, they would have to switch to the other lexicon in order to comprehend the words. Consequently, the lexical switch delayed the comprehension of a CS sentence compared to a unilingual sentence (Adler et al., 2020; Valdés Kroff et al., 2018).

Moreover, the switching direction also contributes to how effortful the switching is. Switching from the stronger to the weaker language is reportedly more effortful. Wang (2015) reported that the Chinese-dominant bilinguals were faster when switching from English to Chinese, but a significant cost was observed when switching from Chinese to English. The stronger the language makes it harder to be inhibited, and, once it is inhibited, it is harder to reactivate (Meuter & Allport, 1999). Neurological evidence was provided to understand the dynamic management of the two languages during CS (Litcofsky & Van Hell, 2017). In their study, when switching from the weaker to the dominant language, an increase in the theta band was observed from the Time-Frequency Analysis. The authors suggested that it reflected the effort in releasing the dominant words from inhibition. On the other hand, the switching from the dominant to the weaker language elicited a larger Late Positive Component (LPC) and a power decrease in the lower beta. The authors interpreted the results as the monitoring of the new information and a sentence-level re-constructure. Another study also reported a main effect for CS in the LPC time window, suggesting sentence-level reanalysis (Valdés Kroff et al., 2020). When encountering a CS, the comprehender faces a conflict or a lack of information to parse the sentence resulting from the switch in language. A sentence-level restructuring and a reconfiguration of the language set is, therefore, needed to process the sentence fully. However, the processing cost is based on one assumption that CS, as words from another language, is stored in a separate mental lexicon. Therefore, the processing of CS requires the comprehender to switch from one lexicon to another.

5.1.2 Prefabs: The Habitual Code-switching

In some situations, code-switching (CS) is unexpected to the comprehender. For instance, when a non-balanced bilingual tries to convey an idea or name an object that he/she does not know the L2 equivalent, a CS might be used to fill in the missing information in the sentence. As the comprehender would never know what the producer could not say in the language they are currently using, the encounter of CS is unexpected. It, therefore, requires a longer processing time than if it is expressed unilingually. However, CS does not always appear unexpectedly. Bilingual societies often build up a "rule" of language usage, and the violation of such usage is considered difficult to process.

The habitual usage of CS could be as precise as the choice of the determiner. Such choice is often violating the textbook-language-rules, but it follows the norm generated by the users in the community. In a study with Spanish-English speakers, it was reported that during code-switching within a noun phrase, they tended to use the combination of a Spanish determiner with an English noun (94.5% of the recorded instances) than the other way round (Pfaff, 1979). Interestingly, the masculine determiner in Spanish ,"*el*", was used significantly more frequently than the feminine, "*la*", because the masculine determiner is acceptable to be followed by nouns that would be masculine or feminine in Spanish (e.g., *el* fork / *el* spoon; the Spanish of fork "*tenedor*" is masculine while spoon "*cuchara*" is feminine), while the feminine determiner could only be followed by feminine nouns (e.g., *la* spoon, but never *la* fork) (Beatty-Martínez & Dussias, 2017). The preference for using masculine determiner with both masculine and feminine (and neutral, in German case) nouns was also observed in French-German CS (Eichler et al., 2012). With such habit, listeners could have predicted a noun that would have been feminine in Spanish when they hear the determiner "*la*", and the violation of it would come as a surprise.

In Hong Kong, the Cantonese-English CS is a norm rather than an exception. Researchers have proposed many reasons for the language choice, including the emphasis on Western cultural influences (Chan, 2009), euphemism, specificity, punning, and the principle of economy (Li, 2000). In any case, the use of Cantonese-English CS is more common than the use of pure Cantonese in daily conversation. Li and Tse (2002) studied this phenomenon by recruiting students to be "purists" for a day by refraining from using English words. Most students reported it as almost impossible as some English words were unavoidable. Sung (2010) replicated the study by trying it himself. He described it as "It may not simply be practical or feasible for me to maintain linguistic 'purity' in everyday conversations with Hongkongers, as mixed code has become my habitual language use". Instead of the pairing of masculine and feminine determiners and nouns like in the Spanish-English cases, the habitual CS in Hong Kong is mostly at the word level. Some words are more likely to be expressed in English even when the sentence is otherwise purely Cantonese. A participant who tried to use Cantonese only for one day reported that "In many cases, I was accustomed to using English to express some terms instead of Cantonese, for example, *canteen*, *pizza*. After the day, I suddenly noticed that I seldom used Cantonese (飯堂 faan6 tong4, 薄餅 bok6 beng2) to say these words" (Li & Tse, 2002). Similarly, Sung (2010) listed some words that he found to be more commonly expressed in English than the Cantonese equivalent, including *lecture*, *semester*, *hall*, *gym*, *attendance* and *assignment*. Chan (2018) extended the study by using Cantonese, English or Mandarin only for each of the three days. His friends responded to him using pure Cantonese as "odd and thought that it hindered communication", which contradicts the literature claiming the comprehension of CS is more demanding than unilingual speech. It should be noted that the L1 equivalents of these words exist and are widely used in other Cantonese-speaking regions, so the difficulty was not from the lack of proper expression to convey the meaning.

A counter-example by Zhang (2012) demonstrated how people notice an unnatural CS. It was produced by a netizen from Mainland China. In the mainland, CS is mainly done by students who studied aboard only. The mixture of Mandarin and English sounds weird to the ears of the locals and they often make fun of it. In Example 5, the netizen replaced some words in English like in intrasentential CS (e.g., "think", "stiff", "big"). They also changed only part of the fixed-vocabulary (随心所欲, follow your

heart) and even invented a vocabulary by literal translation ("sea back", returnees, translated directly from 海歸) to exaggerate the effect.

5. Example from Zhang (2012)

Netizen: [*Mandarin-English*]

我 think 吧，咱們说 English 不能太 stiff 了。应该随 heart 所欲，胆子要 big，像那些 sea back 一样从容，这样才有效果，恩[嗯]！
wǒ *think* ba，zánmen shuō *English* bùnéng tài stiff le。Yīnggāi suí-*heart*-suǒyù，dǎnzi yào *big*，xiàng nàxiē *sea back* yīyàng cóngróng，zhèyàng cái yǒu xiàoguǒ，ǹg！
I *think*, we cannot be too *stiff* when we speak English. We should follow our *heart*, have *big* (more) guts, and take it easy like those "*sea back*" [who returned from abroad]. That's how to be effective. Right!

That habit of switching is specific to each community. Researchers have often overlooked the code-switching habit of the society and used some unnaturally switched stimuli in the experiment (see also Myers-Scotton, 2006). Because of this, artificially produced stimuli are likely to contain unfamiliar switches that are difficult to process (Valdés Kroff et al., 2018). The reaction time might, therefore, not reflect the processing of a language change but the encounter with unfamiliar phrases. The violation of the habitual use of the determiner would result in slower processing. For instance, the Spanish-English bilinguals were reported to fixate on the incongruent use of feminine determiner (*La* + masculine noun) longer than the congruent use, indicating the difficulty in processing the information (Valdés Kroff et al., 2018).

The Bilingual Interactive Activation model (BIA+, Dijkstra and van Heuven (2002)) proposed how language is comprehended by a bilingual. The model assumes non-selective access to an integrated lexicon. The input of a letter string would first activate the orthographical code and its neighbours in both languages. Therefore, theoretically, if an English-French bilingual sees the word "apple", words that are similar in orthography, e.g., the English words "appal" and "apply", and the French word "*appli*" would also be activated. The orthographical code then activates the associated phonological (/æpəl/) and semantic codes (the red round fruit). At this stage, the bilingual could retrieve the correct meaning of the letter string. If, as the model suggested, the mental lexicon of the two languages is integrated, then the input of L1 or L2 of the concept should not affect the retrieval of the meaning if the two languages had relatively similar proficiency, and, therefore, codeswitching would not impact the processing time. In contrast, if the lexicons are distinctively separated into two languages, then the encounter of a CS should have required a switch in the mental lexicon and, therefore, prolonged the processing time. However, with evidence from the CS habit in Hong Kong, Hui et al. (2022) proposed a third possibility: frequently code-switched words are prefabricated into the dominant-language lexicon, and the retrieval of it is relatively effortless.

The frequent use of CS in daily conversation alters the organisation of the mental lexicon. Languages are never constructed from scratch; instead, they are constructed from prefabs which dominate our lexicon (Bolinger, 1979; Wang, 1991). A prefab is a collection of components which frequently co-occur in speech and have a strong collocational bond. They are constructed from the language input (Bolander, 1989), and the repeated input from the speaker's experience is represented in memory as exemplars of varying strengths (Bybee & Torres Cacoullos, 2009). In other words, if CS is a habitual phenomenon within the community, then the CS word could become prefabs and merged into the dominant language, even if the word itself is originated from another language. There have been suggestions that words with conscious foreign origins have been incorporated into another language as a result of being switched between languages constantly (Lipski, 2005). In this case, the CS, though with a conscious language membership of being foreign, might be prefabricated into the L1 lexicon and be processed the same way as the L1 words. On the other hand, the L1 equivalent of such habitually CS items might be processed like foreign words.

5.1.3 Eye-tracking Method

Eye-tracking provides a valid means of collecting data during the comprehension process (Valdés Kroff et al., 2018). An example of a participant's fixations and saccades can be seen in Figure 5.1. The eye-tracking data include where the participants are looking ("fixation", represented by the circles in Figure 5.1), for how long they are looking at it (represented by the size of the circles), and also the movements between each fixation ("saccade", represented by the lines connecting each fixation point). These data allow researchers to understand the cognitive effort required for each sentence segment in great detail. We do not always read in one direction, but we sometimes go back to a specific part of the sentence and re-read it. In Figure 5.1, the number on each circle refers to the sequence of fixations. As the sentence is read from left to right, after fixating on the 5th point, the reader went a little bit backward ("regression"). After reading the whole sentence (the 9th point), the reader went back to the beginning of the sentence and re-read it. It is noticeable that the first fixation point (the pink circle marked as 1) is way above the range of the sentence. This is because the Q&A after each trial is located on the left upper corner of the screen. See Appendix 9.2 to download the animated version for better illustration. After the participant chooses the answer and presses the submit button on the screen, the Tobii system will display the subsequent trial immediately. As the critical AOI (see Figure 5.2) is in the middle of the sentence, which is located very close to the centre of the screen, the Q&A served as a fixation point to force participants to read from left to right instead of starting in the centre.

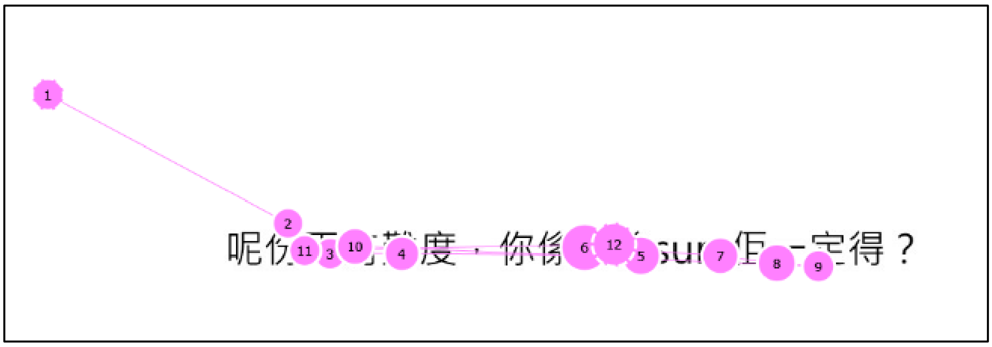

Figure 5.1. Illustration of fixations and saccades. The figure shows a sample of the eye-tracked data of one participant. Each pink circle represents a fixation point and the lines between the circles represent the saccades. The size of each circle represents the duration of fixation, which the longer the duration, the bigger the size. The number inside each circle is the sequence of the fixation. See Appendix 9.2 to download the animated version for better illustration.

Figure 5.2. Example of the stimuli and the AOI. An illustration of a sentence presented to the participants. The red rectangle indicated the location of the AOI. It is for illustrative purposes only that the participants would not see which area will be analysed during the experiment. The stimuli roughly translated to "Since I discovered I have an illness, I ***keep*** doing exercises."

Eye movement has been associated with cognitive and attentional demands (Huang et al., 2022). Following psycholinguistic traditions (Staub & Rayner, 2007), Hui et al. (2022) evaluated four eye-tracking measurements, including the first fixation duration, the total visit duration, the fixation count and the visit count. The first fixation is defined as the time a subject spends fixating inside the Area of Interest (AOI) for the first time before moving to the next fixation point outside of the AOI. It reflects the earlier stage in the processing of the word information, for example, lexical access (Cook & Wei, 2019). Total visit duration refers to the total amount of time the participants spent inside the AOI, including both the fixations and the saccades, and both the first encounter and the regressions. The longer duration indicates greater difficulty in comprehending the information (Cook & Wei, 2017). Fixation Count is the number of times one fixates inside the AOI, and is believed to indicate the processing difficulty (Cook & Wei, 2019). Visit Count is the number of times the eye movement enters the AOI, which reflects the overall processing difficulty.

5.2 METHODS

5.2.1 Participants

A total of 32 university students were recruited for this study (Hui et al., 2022). All students are locals of Hong Kong, who speak Cantonese as their mother tongue and have been educated in Hong Kong since kindergarten. This group is believed to represent the general young Hong Kong residents. One male participant, however, was rejected due to a low accuracy rate in the comprehension test (4 *SD* below the mean). The remaining 31 participants were included in the analysis (M_{age} = 21.30, *SD* = 1.88). Participants filled in the Language Background Questionnaire and the Shipley Vocabulary Test (see Chapter 3.2.2, page 31 for details) and all of them reported to be L1-dominant speakers and frequent code-switchers (*M* = 4.59, *SD* = 1.37; with 7 being *always code-switched*). See Table 5.1 for the language profile of the participants. Participants had a normal or corrected-to-normal vision and no self-reported history of learning/ reading disorder.

Language profile measurements	*M*	*SD*
Self-rated Cantonese proficiency (1 to 7)	5.73	0.95
Self-rated English proficiency (1 to 7)	4.33	0.99
Shipley Vocabulary Test (0 to 40)	18.10	5.75
Frequency of using Cantonese (1 to 7)	5.73	0.56
Frequency of using English (1 to 7)	3.92	0.83
Frequency of code-switching (1 to 7)	4.59	1.37
AoA of English	3.58	1.61

Table 5.1. Language profile of participants in Experiment 3. Participants completed a self-rated proficiency of Cantonese and English (from 1 to 7, 1 being least proficient), self-rated frequency of using Cantonese and English (from 1 to 7, 1 being least frequently used), frequency of code-switching (from 1 to 7, 7 being always code-switched) and the age of acquisition (AoA) of English. They also completed the Shipley Vocabulary Test to objectively examine their English proficiency.

5.2.2 Task Design

5.2.2.1 Stimulus Selection

A total of 255 sentences was created in the structure of “XXXXXX，XXXX [critical word] XXXX。”, in which the critical word was either the Chinese or English equivalent term. Part of the sentences was inspired by the code-switching corpus by Chan et al. (2005) and modified to the format used in this study. The sentences were rated for the language habit and reasonability by two batches of undergraduate students who were all born, raised and educated in Hong Kong. They rated the questionnaires online to fulfil the course requirement. Figure 5.3 shows the selection process for the stimulus used in the experiment.

The first batch of students (N = 42, M_{age} = 18.88, SD = 0.68) rated the probability of using the Chinese or the English expression inside the context. They were given eight choices: (1) *Must use Chinese,* (2) *Mostly use Chinese,* (3) *Prefer to use Chinese,* (4) *Half-half,* (5) *Prefer to use English,* (6) *Mostly use English,* and (7) *Must use English*. They were instructed to choose (8) *Neither* if they thought neither of the two options was natural. Sentences that were rated as (8) by more than one person were excluded. Stimuli with an average rating ≥ 6 were considered as Habitual-Unilingual, and those with ≤ 2 were Habitual-Codeswitched (hereafter "Habitual-CS"). The translation equivalent of the Habitual conditions would then be the Non-Habitual conditions.

The second batch of students (N = 56, M_{age} = 19.16, SD = 1.06) rated whether the sentences were reasonable. They were given seven choices: (1) *Very unreasonable*, (2) *Unreasonable*, (3) *Slightly unreasonable*, (4) *Neutral*, (5) *Slightly reasonable*, (6) *Reasonable*, and (7) *Very reasonable*. Thirty additional sentences were added for this rating. These additional sentences were designed to be illogical (e.g., 對眼越嚟越差，我諗要戴頭盔先睇到喇。/ My eyes are getting worse. I think I will have to wear a helmet to see). Participants who rated an average of ≥ 4 for these thirty sentences were considered as rating randomly, and all of their responses were discarded in the analysis.

Only the sentences that matched both the code-switching criteria and with an average of reasonability of higher than 5.5 were included in the study. This left 53 for Habitual-Unilingual, 40 for Habitual-Codeswitched and 25 for fillers. The experimenters then chose the best 40 among the first two conditions and the best 20 as fillers in the critical experiment. Table 5.2 shows the average rating result for the two Habitual conditions and the fillers. The two Habitual conditions differed significantly in Language Choice (p < .001), but the reasonable rating is comparable (p = .524).

	Habitual-Unilingual	**Habitual-CS**	**Filler**
Language Choice	6.54 (0.19)	1.65 (0.22)	3.78 (0.67)
Reasonable rating	5.88 (1.43)	5.93 (2.17)	6.05 (0.21)

Table 5.2. Rating results of the stimuli in the two Habitual conditions. Students rated the language choice of the critical words (1 being *Chinese* and 7 being *English*) and the reasonability of the sentences (1 being *very unreasonable* and 7 being *very reasonable*).

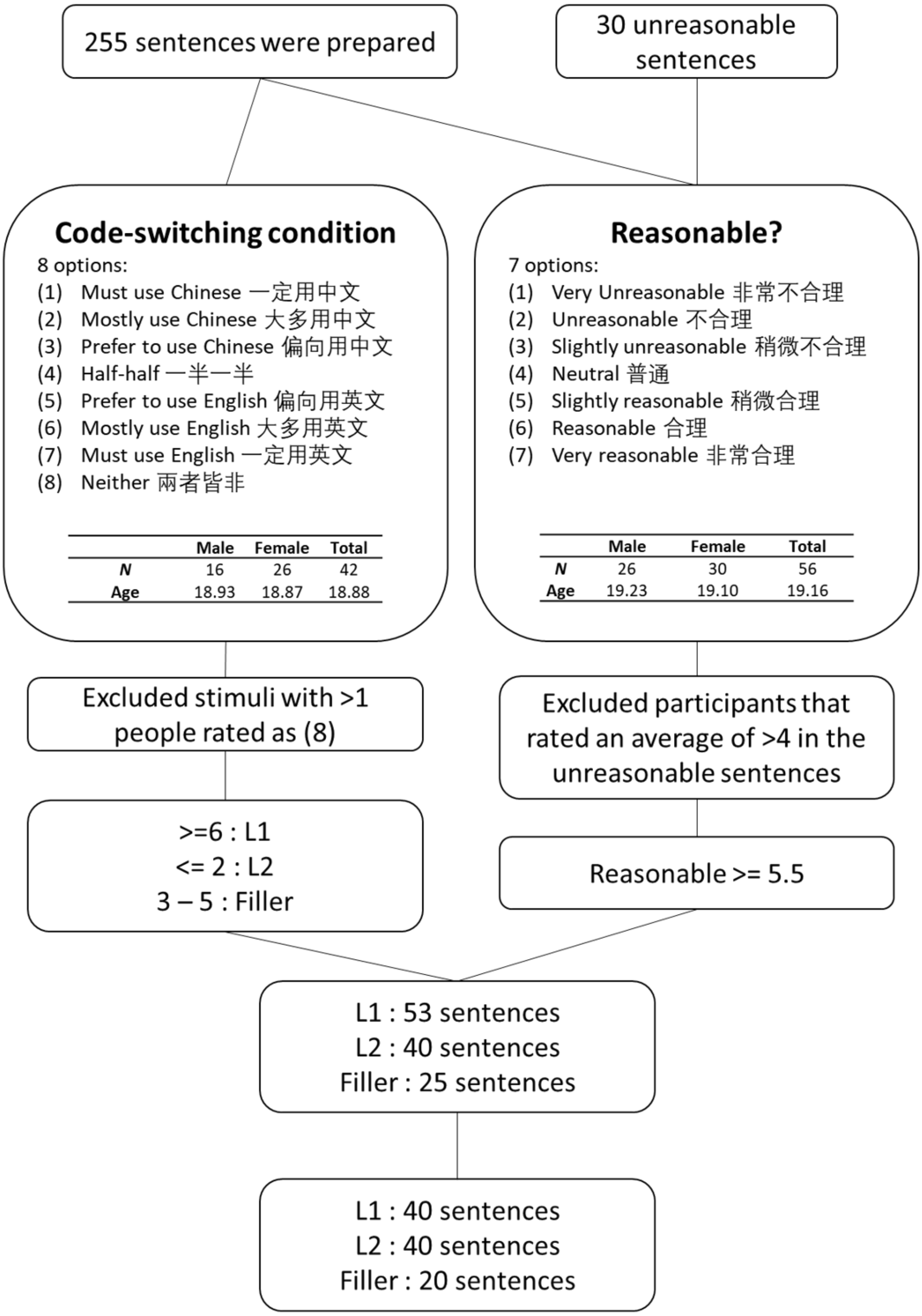

Figure 5.3. Stimulus selection process. An illustration on the selection process and criteria when selecting the stimulus for the critical experiment. See main text for description.

5.2.2.2 Critical Experiment

A two-by-two factorial design was adopted with two factors: (1) HABIT (Habitual/Non-habitual), whether the language used in presentation matched with the social norm and hence the expectancy of the listener; and (2) LANGUAGE (Unilingual/Code-Switched), the language presented in the trial. For instance, “皮膚” was rated as 6.60 in the language choice rating, and, therefore, the Chinese expression is considered as Habitual-Unilingual, and its English equivalent “skin” is considered as Non-Habitual-Codeswitched. In addition, the stimulus rated between 3 – 5, meaning either way is acceptable, were used as fillers in the study. A filler condition was included to mask the true intention of the study and was not analysed. See Table 5.3 for the examples in all conditions. The stimuli were divided into two lists so each participant would view only one language representation of the same concept (i.e., either *皮膚* or *skin*). To reduce the order effect, the presentation order of each list was pseudo-randomised into four versions. Participants would view one of the four versions only.

The eye-tracking experiment was conducted inside a soundproof booth with the desk-mounted Tobii Pro eye-tracker (Tobii-Pro-AB, 2014). Participants sat approximately 65 cm away from the screen without a chin-rest. Before the experiment, participants performed a standard calibration with nine dots. Participants were asked to stare at the moving red dot so the machine could be calibrated to track their eye movement. The experiment would only continue if the calibration of both eyes was satisfactory.

In the experiment, participants were instructed to read the sentence carefully and press the space bar after they believed they had fully understood the meaning. They would then answer a two-choice question related to the sentence with a mouse click. The Q&A was to ensure that the participants had read the sentences instead of just flashing through the trials. Participants went through a total of four blocks with 25 trials each, with self-paced resting time between the blocks. A practice of two trials was given to the participants before the critical trials.

Conditions	**Example**

Habitual-Unilingual	敷完呢款面膜，你會覺得***皮膚***即刻好咗。
Non-Habitual-CS	敷完呢款面膜，你會覺得 ***skin*** 即刻好咗。
	After using this mask, you will feel that your ***skin*** (condition) has improved instantly.
Habitual-CS	仲有嘢要討論，等我下晝 ***present*** 完再搵你。
Non-Habitual-Unilingual	仲有嘢要討論，等我下晝 ***匯報*** 完再搵你。
	(We) still have things to discuss. Let me find you after the ***presentation*** in the afternoon.
Filler-Unilingual	因為我鼻敏感，一定會有***紙巾***喺書包到。
Filler-CS	因為我鼻敏感，一定會有 ***tissue*** 喺書包到。
	I have nasal allergy, so (I) must have a pack of ***tissue*** in (my) backpack.

Table 5.3. Sentences examples in each condition. The AOI are in bold and italic for illustration only. No special formatting was presented during the experiment.

5.2.2.3 Language Profile

After the eye-tracking experiment, subjects completed a questionnaire on their language history and the Shipley test (Shipley, 1940) to assess their English proficiency. See Chapter 3.2.2 for description.

In addition to the self-rated proficiency and frequency of using the languages, participants were also asked to rate their frequency of code-switching. They were asked to rate how often they code-switch when talking to their parents, siblings, friends, classmates, colleagues and strangers (e.g., staff in shops) on a Likert scale of 1 to 7, with one being *never* and seven being *always*. They were allowed to leave it blank if they thought it did not apply to them, for example, if they did not have siblings or colleagues. The frequency of code-switching is calculated by averaging the score of the number of categories the participant had filled in.

5.3 RESULTS

Participants were asked to answer a question about the content of the sentence after each trial to ensure they had understood the sentence rather than simply skimming over it. The high accuracy (*M* = 99.10%, *SD* = 0.01) showed that the participants had understood the sentences before proceeding to the next trial. The accuracy rate did not differ between any of the conditions (*p*s > .168), indicating that neither the switch in language nor the habit of switching affected the understanding of the sentences.

Table 5.4 shows the summarised eye-tracking result of Hui et al. (2022). To follow the tradition of the psycholinguistics field (Staub & Rayner, 2007), four eye-tracking measurements were selected, including First Fixation Duration, which reflects the earlier processing stage, Fixation Count, which reflects ongoing processing, and both Total Visit Duration and Visit count that reflect the overall processing difficulty.

In the First Fixation Duration, we found a significant effect of Language, $F(1,30) = 18.63$, $p < .001$, $\eta_p^2 = .38$. Participants took longer to read unilingual sentences (*M* = 234.28 ms, *SD* = 35.62 ms) than CS sentences (*M* = 213.26 ms, *SD* = 26.30 ms). There was no Habit effect ($F(1,30) = 2.83$, $p = .103$, $\eta_p^2 = .09$) nor the interaction ($F(1,30) = 1.87$, $p = .182$, $\eta_p^2 = .06$).

An interaction between Language and Habit was found in the Total Visit Duration, $F(1,30) = 9.37$, $p = .005$, $\eta_p^2 = .24$. A simple effect analysis indicated that the duration differed significantly between the Habitual-Unilingual (*M* = 432.27 ms, *SD* = 154.70 ms) and Non-Habitual-Unilingual (*M* = 591.35 ms, *SD* = 205.57 ms) conditions, $t = -7.63$, $p < .001$. Moreover, participants spent longer reading the Non-Habitual-Unilingual condition (*M* = 591.35 ms, *SD* = 205.57 ms) than the Non-Habitual-CS condition, (*M* = 481.21 ms, *SD* = 229.69 ms), $t = 4.34$, $p < .001$. Notably, there was no significant difference between the Habitual-Unilingual and Habitual-CS conditions, $t = .51$, $p = .612$.

Metrics	Main effect	Post-hoc comparison	*F*	*p*		*t*	*p*	
First fixation duration	Interaction		1.87	.182				
	Habit		2.83	.103				
	Language	Uni > CS	18.63	<.001	***			
Total visit duration	Interaction		9.37	.005	**			
		H-Uni & NH-Uni				−7.63	<.001	***
		H-CS & NH-CS				−1.83	.078	
		H-Uni & H-CS				0.38	.709	
		NH-Uni & NH-CS				4.34	<.001	***
	Habit		26.89	<.001	***			
	Language		11.94	.002	**			
Fixation count	Interaction		10.13	.003	**			
		H-Uni & NH-Uni				−7.03	<.001	***
		H-CS & NH-CS				−1.77	.086	
		H-Uni & H-CS				−2.22	.034	*
		NH-Uni & NH-CS				2.03	.052	
	Habit		21.64	<.001	***			
	Language		0.06	.809				
Visit count	Interaction		9.49	.004	**			
		H-Uni & NH-Uni				−5.45	<.001	***
		H-CS & NH-CS				−1.65	.110	
		H-Uni & H-CS				−1.31	.199	
		NH-Uni & NH-CS				2.21	.035	*
	Habit		14.99	.001	**			
	Language		0.38	.540				

Table 5.4. Eye-tracking results of each measurement. The table provides the summarised statistical analysis of the four eye-tracking measurements of this study (Hui et al., 2022). H = Habitual, NH = Non-Habitual, Uni = Unilingual, CS = Code-switched. * = <.05, ** = <.01, *** = <.001.

An interaction between Language and Habit was observed in Fixation Count, $F(1,30) = 10.13$, $p = .003$, $\eta_p^2 = .25$. A simple effect analysis revealed that participants fixated more in the Non-Habitual-Unilingual condition ($M = 2.37$, $SD = 0.63$) than the Habitual-Unilingual condition ($M = 1.84$, $SD = 0.45$), $t = 7.03$, $p < .001$. Furthermore, they fixated significantly more times in the Habitual-CS condition ($M = 2.00$, $SD = 0.50$) than in the Habitual-Unilingual condition, $t = 2.22$, $p = .034$.

In Visit Count, there was an interaction between Language and Habit, $F(1,30) = 9.49$, $p = .004$, $\eta_p^2 = 1.24$. A post-hoc analysis showed that participants regressed more in Non-Habitual-Unilingual ($M = 1.93$, $SD = 0.49$) than Habitual-Unilingual conditions ($M = 1.64$, $SD = 0.36$), $t = 5.45$, $p < .001$. They also regressed more in the Habitual-Unilingual condition ($M = 1.64$, $SD = 0.36$) than the Habitual-CS condition ($M = 1.81$, $SD = 0.53$), $t = 2.21$, $p = .035$. No significant difference was found between the Habitual-Unilingual and Habitual-CS conditions, $t = 1.31$, $p = .199$.

5.4 DISCUSSION

The experiment reported in Hui et al. (2022) investigated how code-switching (CS) is stored and processed in the mental lexicon. Code-switching is a noticeable feature in Hong Kong language habits, and, as pointed out by the Adaptive Control Hypothesis (Green & Abutalebi, 2013), different language interactions require different levels of cognitive control. Previous studies suggested that the voluntary production of CS is effortless. In contrast, the comprehension of it would be difficult because (1) the comprehender would not know when to prepare for a CS, and (2) the change of language requires the comprehender to switch between language lexicons. However, the CS in Hong Kong is constrained at the word level and the community norm of when and when not to CS exists. The bilingual language input in daily life alters the mental lexicons and thus modulates how cognitively demanding it is to retrieve the concept.

5.4.1 Stages of Processing the Code-switching

Previous studies suggested that the processing of CS is effortful because of the need to switch between lexicons to retrieve the words (Adler et al., 2020; Valdés Kroff et al., 2018). This is based on the assumption that words are stored in different lexicons according to their language origin, therefore, a switch in languages requires a switch in the mental lexicon. The network science approach provided an insight into the overall picture of the semantic organisation that suggested otherwise. With data from two code-switching corpora (Mandarin-English and English-Spanish), Xu et al. (2021) constructed a semantic network and detected two groups of closely connected nodes (a "community" in network science terminology) for each of the language pairs. Each community was reported to be dominated by one language but with a small percentage of words from the other. For instance, the Mandarin-English community 1 consists of over 90% of L1 words and about 10% of L2 words, while the community 2 consists of approximately 90% of L2 words and 10% of L1 words. A similar result was observed for the Spanish-English language pair but to a lesser degree because the cognates were counted as "others" and did not belong to either language. The researchers concluded that the lexicons of the two languages are primarily separated, each having a small proportion of words from the other.

We suggest that bilingual prefabs are the "intrusion" from the other language in the community that Xu et al. (2021) reported. Our language experience shapes our mental lexicon and prefabs are formed (Wang, 1991). Grammaticalisation studies suggested that it only takes one or two repetitions to establish an agreement in the speech community that a certain phrase is a more preferred way to express a concept (Bybee & Napoleão de Souza, 2021; Hoffmann, 2004). While many studied prefabrication within a single language (e.g., Granger, 1998; Perera, 2001), we believe bilingual prefabs could also be formed after sufficient exposure to the bilingual word combination. In other words, we believe that the mental lexicon is not distinguished by the language nor completely integrated as a single lexicon. Instead, it is separated based on language usage. Because CS is a prominent language experience in Hong Kong, the more dominant lexicon is expected to have integrated with CS prefabs. Under the bilingual prefab interpretation, the habitual switches had integrated into the dominant lexicon as a prefab because of the frequent language input. The participants in our study, therefore, processed the sentences embedded with code-switched prefabs as if they were unilingual sentences despite a conscious language membership tag. There was no need for them to switch to the other lexicon and the semantic meaning was easily retrieved from the dominant lexicon.

According to the BIA+ model (Dijkstra & van Heuven, 2002), orthographical information is the first to be activated by the visual input. The BIA+ model emphasises that similar orthographic candidates will also be activated, regardless of the language. The First Fixation Duration is considered an indication of the early processing of words, including the highly automatic process of word recognition (Conklin et al., 2018; Peleg et al., 2020). Since the two languages in this experiment (Written Cantonese and English) do not share a common writing system, there should not be any orthographically similar words activated. Instead, the difference between the Sinogram and English Alphabet provides an early hint on the language membership, as reflected in the Language effect found in the First Fixation Duration. It showed that the language membership of the word was distinguished during the earlier processing stage.

After the retrieval of orthographical information, the associated semantic and phonological information was activated and the meaning could then be retrieved successfully (Dijkstra & van Heuven, 2002). Unlike how the sound of the Russian "*marku*" activates the English word "*marker*" in a listening task (Spivey & Marian, 1999), the different scripts in visual task inhibit phonological information of another language (Miwa et al., 2014). Therefore, the interference from the phonology of the other language should be minimal in this current experiment. The Fixation Count is believed to be indicating the ongoing process (Cook & Wei, 2017). The current experiment found a significant difference between the Habitual-Unilingual and Habitual-CS conditions, suggesting that there were differences in cognitive demands in processing in the ongoing stage. However, in terms of the overall processing effort, as indicated by Total Visit Duration and Visit Count (Cook & Wei, 2017), Habitual-Unilingual and Habitual-CS conditions showed no differences. A difference was, however, found between Habitual and Non-Habitual conditions. Results suggested that, although the language membership was identified in the earlier processing stage and there were differences during the ongoing processing, the difference arising from the Language effect was resolved at the end for the Habitual conditions.

Figure 5.4 shows the model we proposed to extend the BIA+ model to intrasentential CS processing (Hui et al., 2022). After the visual input of the words inside the AOI, the orthographical code is activated. The differences in scripts activated the orthographical code easily and the language membership was identified. Because the sentences' matrix language was Cantonese and they started with Cantonese, it is natural that the lexicon the readers activated at the beginning of the sentence reading would be the lexicon that is dominantly Cantonese with some bilingual prefabs integrated in ("Community 1", in Xu et al. (2021)'s term). For Habitual-Unilingual and Habitual-CS words, it could be retrieved from Community 1, therefore, the Total Visit Duration does not differ between these two conditions.

On the contrary, participants could not retrieve the meaning of the Non-Habitual words in the dominant lexicon. They have to inhibit it and activate the less dominant one to retrieve the meaning, causing a general slowdown in the comprehension of the Non-Habitual switches. The switch from the more dominant L1 to the weaker L2 caused a higher switching cost than vice versa because the suppression and reactivation of the more dominant language are more difficult. In agreement with this view, we observed that, in the Total Visit Duration, participants read the Non-Habitual-CS condition faster than those of the Non-Habitual-Unilingual condition.

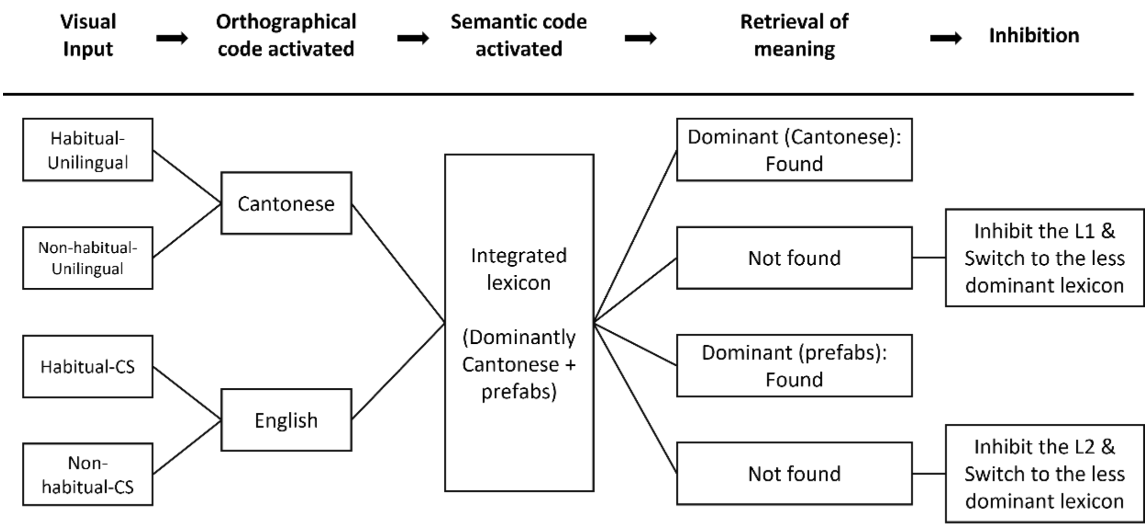

Figure 5.4. Code-switching processing stages.A theoretical model proposed to include CS comprehension inside the BIA+ model, with the extension on the processing of code-switching words. See main text for details. Figure obtained from Hui et al. (2022).

5.4.2 Code-switching and Cognitive Advantage: An Exploration

If the practice of switching languages improves cognition, and if the habitual code-switching (CS) in Hong Kong has become prefabs and is processed similarly to the L1, then there should not be any cognitive benefit derived from the frequent use of CS. To verify this hypothesis, the 43 bilingual older adults' data from Experiment 1 were analysed. See Chapter 3.2.1 (page 29) for their demographic information.

A two-tailed partial correlation was run between the frequency of CS and the Stroop Colour-Word condition (as the indicator of inhibitory ability), with Education year and Shipley score (as the indicator of English proficiency) controlled for. These two factors were partial out because L2 proficiency was found to be a significant predictor of Stroop Colour-Word and education was believed to be directly affecting cognition. The partial correlation was marginally insignificant (r = .29, p = .064). Results supported the hypothesis that, because CS in Hong Kong had become prefabs and integrated into the dominant lexicon, "code-switching" does not require a switch in the lexicons. Therefore, the frequent use of it does not induce a practice of switching; thus, no cognitive benefit was observed.

A study with Chinese-English bilinguals found that the frequent switchers showed higher efficiency in both verbal and non-verbal switching tasks (Han et al., 2022). The German-English study also found that bilinguals who code-switched more showed inhibitory advantages (Hofweber et al., 2016). We attribute the differences to the language usage habit between their studies and ours. Their participants lived in L2-dominant societies (English-speaking countries), where they were expected to use L2 outside their homes. The intra-sentential switching was restricted mainly to friends and family members who spoke the same language. Therefore, they would be experiencing single-language context and dual-language context interactions on a daily basis (Green & Abutalebi, 2013). On the other hand, our participants lived in an L1-dominant society, and code-switching is part of the dominant language. Under the bilingual prefabs interpretation reported in the above session, no switching of lexicons was needed to produce or comprehend the code-switching.

However, note that the average self-reported code-switching frequency was 3.49 (SD = 1.11), which was significantly less frequent than the younger adults reported in this experiment (M = 4.59, SD = 1.37, t = 3.79, p < .001). Results should be interpreted with caution as the statistical analysis was close to the boundary of significance, which might be due to the differences in the habit of using language between the two age groups. It should be noted that we do not intend to suggest that the finding in Hong Kong younger adults holds for all, not even for the same language pair in other regions (e.g., in Guangdong or in Cantonese-speaking Chinese American community). Instead, we emphasise how the formation of prefabs and, therefore, the lexicon, is influenced by language experience.

5.5 CONCLUSION

Previous studies believed that the comprehension of code-switching is cognitively demanding because the comprehender would have to switch between language lexicons to retrieve the meaning. However, the mental lexicons are shaped by language input. In Hong Kong, code-switching is a norm rather than an exception, and there is a constraint on which words to switch and which not by the community norm. Because code-switching is so common, it is prefabricated into the dominant lexicon. The retrieval of such words is, therefore, as effortless as retrieving L1 words, even though the language membership of the code-switching is clearly recognised. Because no switching of lexicons is needed, the frequency of code-switching would, therefore, not affect the general inhibitory skill. An exploratory analysis of older adults' code-switching habits and cognition supported this notion, showing that the frequency of code-switching does not affect inhibition ability.

Chapter 6. GENERAL DISCUSSION

This chapter will first summarise the results of the experiments in this dissertation. Then, the three important elements contributing to individual differences − environment, language and cognition, will be discussed in detail. We suggest that the key to bilingual advantage is the cognitive demand in using the languages, and that is not dependent on the language itself but the overall experience. Based upon the Revised Hierarchical Model (Kroll & Stewart, 1994) and the experiment results reported in this dissertation, an Experience-based Bilingual Mental Lexicon Model is proposed to explain the organisation and retrieval of concepts.

6.1 SUMMARY OF THE EXPERIMENTS

The bilingual advantage in cognition is an encouraging phenomenon in the ageing world. It is suggested that bilingualism contributes to the cognitive reserve, which delays Alzheimer's Disease onset and allows bilinguals to perform better in cognitive tasks than monolinguals (see Chapter 2 for full review). However, the hypothesis is not yet widely accepted and some researchers have not been able to replicate the bilingual advantage effect (e.g., Paap et al., 2015). Those that support bilingual advantage often suggest that the effect is brought about by the practice of inhibitory control during the daily conversation, as the bilinguals would have to inhibit the unwanted but simultaneously activated language when they speak (Bialystok et al., 2012). In this case, factors that affect the formation and organisation of the mental lexicon, and, therefore, the cognitive demand to retrieve concepts from it, are expected to contribute to the effect of bilingual advantage. This dissertation investigates how individual differences would affect the mental lexicon and thus affect the bilingual advantage, with a particular focus on the Hong Kong population. This dissertation aims to address three research questions: (1) Is there a bilingual advantage in cognition? (2) How do the individual differences lead to the presence or absence of bilingual advantage in cognition? and (3) What affects the organisation of the mental lexicon and the retrieval of concepts?

Experiment 1 answers the first two questions by recruiting older adults to complete a comprehensive set of cognitive tests. Comparing the monolinguals and bilinguals, we found that bilinguals scored higher in the MoCA test, indicating better general cognition. Within the bilinguals, we found that gender was the predictor of One-back RT, in which females responded slower than males in the task. Females were also found to perform better in the Stroop colour-word condition. Age, on the other hand, negatively predicted the score in the Digit Span task, suggesting that memory declines with age. In terms of linguistic variables, the L2 proficiency positively predicted the scores in the Stroop colour-word condition (inhibition ability), Digit Span (working memory) and Verbal Fluency (language retrieval). See Chapter 3, page 26 for details.

Experiment 2 was designed to provide an answer to whether learning a new language in old age, therefore becoming a new bilingual, would have an effect on cognition. A group of 14 older adults was recruited to attend a six-week elementary English course and their cognitive levels were measured before and after the course. Group comparison was not statistically significant possibly due to the small sample size. Comparing the pre- and post-test results, we found that the language learners showed improvement in Picture Naming ACC and Orienting score in the Attention Network Test, suggesting older adults benefit from learning a foreign language even for a brief period of time. Interestingly, we found that the exam score was positively correlated with the difference score of Stroop colour-word condition and negatively with the difference score of Verbal Fluency, after controlling for the baseline English ability. See Chapter 4, page 50 for details of the experiment. The results suggested that successful language learners show similar effects in inhibitory control, like the lifelong bilinguals in Experiment 1, as revealed in the Stroop test. However, the verbal fluency score had an opposite pattern. The differences between the two will be discussed in the coming sub-sections.

Moreover, we used the eye-tracking method in Experiment 3 to investigate research question 3 through one of the interesting phenomena of Cantonese: dense code-switching. After the visual input of a sentence, even though the language membership was identified at the beginning of the processing stage, only non-habitual code-switches required a switch in the lexicon and therefore prolonged the processing time. We suggest that the frequent input of code-switches from the community formed bilingual prefabs which integrated into the dominant lexicon. These words, even though being consciously identified as a foreign language, became part of the dominant language. Therefore, habitual switches do not require a change of the mental lexicon to retrieve the meaning. See Chapter 5, page 77 for details. The results pointed to an interesting hypothesis on how languages are stored in the mental lexicon of the bilinguals. The storage is not separated by language origin but by language experience.

From the results of the three experiments, we propose an alternative explanation of the organisation and retrieval of concepts from the bilingual mental lexicon. Based on the Revised Hierarchical Model (Kroll & Stewart, 1994), we postulate the Experience-based Bilingual Mental Lexicon Model to explain the dynamic of the language. The model has two additional features: (1) the mental lexicons are separated by experience but not language origin, and (2) the dominance is dynamic. Chapter 6.3 will provide a detailed explanation of this. We believe that the organisation of the mental lexicon affects how cognitively effortful it is for the bilingual to communicate. Thus, it affects the bilingual advantage effect observed.

6.2 INDIVIDUAL DIFFERENCES AND BILINGUAL ADVANTAGE

The bilingual advantage literature has not yet reached a conclusion on whether the benefit exists or is subject to a particular situation only (Paap et al., 2015). The literature often compares monolinguals and bilinguals as two homogenous groups. However, the definition of monolingual and bilingual is still undetermined in that different studies used different criteria (e.g., proficiency, AoA, linguistic distance) to define the two (Kirk et al., 2022). Moreover, bilingualism is not a categorical variable with two extreme ends (DeLuca et al., 2019; Luk & Bialystok, 2013). Nonetheless, it is common in the literature to assume a person is either a purely monolingual with zero knowledge of a second language, or a balanced bilingual with the same level of proficiency in both languages. Most people, however, are somewhere between the two ends. As suggested by Takahesu Tabori et al. (2018), the individual differences should be explored instead of treated as noise that confounds the study.

The individual differences arising from both the outer environment and linguistic properties are inter-related with cognition. Our environment shapes our languages, and the language modulates cognition. At the same time, the cognitive status affects the language performance. Moreover, our cognition is essential in helping us to cope with the environmental and the associated challenges (see Figure 6.1 for illustration). In the following subsections, we will discuss the interconnected relationships in detail with the experimental results from this dissertation.

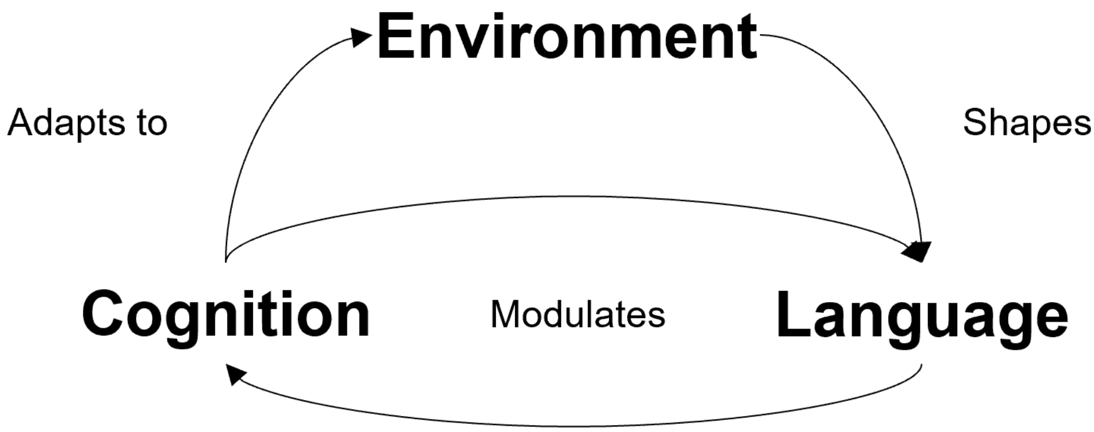

Figure 6.1. Schematic representation of the relationship between environment, language and cognition. Environment shapes the language, and language modulates the cognition. At the same time, cognition also modulates language performance and how we adapt to the environment. Please see the main text for a detailed description.

6.2.1 Environment Shapes Language

The input from the environment shapes our language. One does not build the language from scratch but constructs it with parts obtained from the language input. In first language acquisition, infants learn the language from their caregivers. In the most extreme scenario, language would not be able to develop without sufficient input from the outer environment. One of the most infamous feral child cases, Genie, showed that it would be almost impossible to have language output if one did not receive input. Genie was abused by her father, who forbade her family members to talk to her at all until she was rescued at age 13. Researchers reported that, without any linguistic stimulation for thirteen years, Genie could understand nearly nothing except for negative intonation, which her father used to her when she misbehaved (Curtiss, 1977; Curtiss et al., 1974). Her tragic case revealed the nature of language: without linguistic input, there would not be linguistic output. On the other hand, in childhood overhearers (i.e., a child that is taken care of by a caregiver who speaks another language) and international adoptees (i.e., a child who was adopted to a foreign country that spoke another language when they were very young) cases, they have a language that they heard in young age but have never acquired. Nevertheless, the brief exposure to that language enabled them to perform phonological tests better when they grew up (Au et al., 2002; Oh et al., 2010).

In addition to language input, the environment also affects how the community views a language, thus how they use the language. Poplack (1988) reported that the communities in Hull and Ottawa, which are two Canadian towns separated only by the Ottawa River, had very different views of their languages. Hull's communities were primarily Francophone, and the bilinguals thought English had an "instrumental value" only. On the other hand, Ottawa's bilinguals were mostly Anglophone and thought bilingualism had both affective and instrumental value. Their attitudes were reflected in their usage of language, in that the Ottawa communities code-switched about four times more from French to English and had more borrowings from English than the Hull communities. This difference in Hull-Ottawa is not a single occurrence but can be observed in many bilingual communities. For instance, Hong Kong and Shenzhen are only separated by the Shenzhen River, but, because of historical and political reasons, the language usage of the two cities greatly differs. Cantonese is the major language in Hong Kong, while Mandarin is the more commonly used language in Shenzhen. The environment, or the community that the speaker is currently in, determines the interaction context. For a native speaker of Cantonese, Hong Kong would be an L1-dominant environment, while Shenzhen would be an L2-dominant environment. The linguistic experience of that Cantonese speaker would be quite different in the two cities.

The language habit of the community contributes to the formation of the mental lexicon. One of the features of Hong Kong Cantonese that makes it stand out from other varieties of Cantonese is its dense Cantonese-English code-switching. It is common that a Cantonese sentence would have English words inserted inside. Such insertion is not because the Cantonese equivalent term does not exist but from the language habit of the community. When such switching spreads widely in the community, the use of

Cantonese words becomes unnatural or even attention-grabbing to the locals. In contrast, some concepts are expected to be spoken in Cantonese and never code-switched to English. In our study (see Chapter 5), we reported an eye-tracking experiment on reading Cantonese-English code-switching sentences. We found that the processing effort was similar for the Habitual-Unilingual and Habitual-Code-switched sentences. In other words, the comprehension of terms that followed the community habit were processed similarly, regardless of the language in which it was presented. Our results echoed an earlier study in Hong Kong, which reported that the comprehension of naturalistic code-switching is the same as reading a unilingual sentence (Chan et al., 1983). We suggested that this was because the language input of Hong Kong Cantonese was densely code-switched, and, therefore, the mental lexicon was built up with the bilingual prefabs (Hui et al., 2022). The retrieval process of the prefabs was the same as the retrieval of an L1 word from the dominant lexicon. On the other hand, even though some words are from the more dominant language (Cantonese), because of the habitual use of code-switching, those words were more cognitively demanding to comprehend.

The environment in which we live restricts the usage of our language. Communities develop their unique way of communication, for instance, language usage habit and code-switching. It determines the interaction contexts and affects how cognitively challenging it is to speak or comprehend the language under different circumstances.

6.2.2 Language Modulates Cognition

The habit of using the languages directly affects how cognitively demanding it is for a bilingual to communicate. The Adaptive Control Hypothesis suggested three possible interaction contexts that have varied cognitive demand (Green & Abutalebi, 2013). For instance, a single-language context requires less demand in controlling the language than a dual-language context because the bilinguals do not have to spare their attention to the external cue to switch the languages. To name a more concrete example, let us consider the case of a Cantonese native speaker again. If the speaker is living in Hong Kong, then s/he would be experiencing minimal cognitive demand in daily life because Cantonese is the major language of the community. The need to switch into another language (e.g., English, Mandarin) is limited to school, tertiary level occupation or with tourists. In other words, the speaker would be speaking in the most dominant language in most scenarios and have a minimal need to change the language. On the other hand, if the Cantonese native speaker is living in Shenzhen, the L1 is relatively constrained to Cantonese-speaking friend circles. As many people from other provinces moved to Shenzhen, Mandarin, which is the lingua franca of China, is more expected to be spoken in daily life. The Cantonese speaker is, therefore, using their less dominant language outside home. The amount of cognitive control is expected to be larger than the case in Hong Kong.

In this case, the cognitive demand one experiences in daily life contributes to the cognitive benefit. As reviewed in Chapter 2, a bilingual's two languages are always activated simultaneously (Marian & Spivey, 2003; Spivey & Marian, 1999) but at a different level of activation. Because of the overlapping regions in the processing of linguistic inhibition and general inhibition, it is believed that, through the practice of inhibiting the unwanted language, bilinguals also improve their general inhibitory control (Abutalebi et al., 2015). In this dissertation, we recruited monolingual and bilingual older adults to complete a comprehensive set of cognitive tests (see Chapter 3). We found that bilinguals scored higher in the Montreal Cognitive Assessment (MoCA) than monolinguals, which supports the bilingual advantage hypothesis. This is an especially encouraging finding because, as reviewed in the above paragraph, it is expected that Hong Kong bilinguals are experiencing minimal interference from their L2 because their dominant language (Cantonese) is the community language. In other words, monolinguals and bilinguals have similar language usage. What contributes to better cognition, if not because of the use of the second language? Using linear regression analysis, we found that inhibition, as measured by the Stroop Colour-word condition, was predicted by L2 proficiency.

Bilinguals do not usually have balanced proficiency in both languages (Meuter & Allport, 1999). Even for those relatively balanced bilinguals, the dominant and non-dominant languages are still not equal. Meuter and Allport (1999) compared a group of relatively balanced bilinguals with non-balanced bilinguals in a cued language-switching task. They found that more balanced bilinguals do not show an effect in changing of languages. On the other hand, those with greater proficiency differences showed significant differences in switching from L1 to L2 or vice-versa. This was because L2, as the less proficient language, had a weaker strength and, therefore, it was harder to suppress the stronger language. Once it was suppressed, however, it was harder to reactivate it. The asymmetric cost in language switching was replicated in several studies (Costa & Santesteban, 2004; Philipp et al., 2007). The bilinguals in Experiment 1 of the current dissertation were non-balanced bilinguals. As they are living in an L1-dominant society, the chance of practising the suppression of the stronger language (i.e., Cantonese) is limited. In order to enjoy the effect of bilingual advantage, they must improve their L2 proficiency so that they would experience sufficient interference during the L1 conversation (Hui et al., 2020).

Experiment 2 provided converging evidence (see Chapter 4). In the cognitive training study, a group of older adults attended an elementary English course for six weeks. In the last lesson, they completed an open-book exam to quantify their learning success. The examination score (i.e., L2 proficiency) was positively correlated with the Stroop colour-word condition (r = .65, p = .017), after controlling for baseline English ability. As mentioned in Chapter 4.4.2, we do not believe that a six-week elementary level of learning could provide the same amount of interference of the L2 as what the lifelong bilinguals have been experiencing. Instead, we suggested that it might be the inhibition of L1 during the class that provides the training of inhibition. However, the results suggested that even beginners would have started to cognitively benefit from the practice of inhibiting another language.

Collectively, our results showed that language modulates cognition. Specifically, being more proficient in an L2 improves older adults' inhibitory control ability. We propose that this is because of the asymmetric activation of the languages together with the influences from the environment. The L2 have to be sufficiently proficient for a bilingual living in the L1-dominant society to enjoy the bilingual advantage.

6.2.3 Cognition Modulates Language

Whereas language modulates cognition, cognition also modulates the performance of language. In the literature, language is often reported to be the cognitive ability least affected by age (Park & Reuter-Lorenz, 2009). However, it does not mean older adults have intact verbal ability. Age-related decline in language includes various aspects. In terms of production, older adults were found to have trouble with word findings and reduced the variability in sentence production (Kemper & Anagnopoulos, 1989). In terms of comprehension, it was found that older adults have decreased ability to make use of the semantic information in the context to guide processing (Federmeier & Kutas, 2005; Federmeier et al., 2010).

The Inhibition Deficit Hypothesis suggests that inhibitory control is the key element for many cognitive abilities, including working memory and language tasks (Hasher, 2015; Hasher & Zacks, 1988). Inhibition is needed to allocate resources to complete the tasks properly. If inhibition is declined, one would be easily affected by distractions from the surrounding environment or irrelevant cues. Using confirmatory factor analysis, Miyake and Friedman (2012) found that, after accounting for a common executive functions variance, there were no residuals for the inhibition latent variable. The authors suggested that inhibition is the basis of executive functions. Similarly, Kemper (2015) proposed that the decline in language was because of the declined inhibitory control of older adults. It made older adults more vulnerable to irrelevant information. For instance, if the target is "table", semantically related words (e.g., chair) and phonologically similar words (e.g., tablet) might be activated together. As inhibitory control ability declines, it affects older adults' word retrieval ability. Therefore, the "tip-of-the-tongue" phenomenon could often be observed in the ageing population. The Inhibition Deficit Hypothesis was tested with many language tasks, including the decline of performance of older adults in verbal fluency (Fong et al., 2021) and picture naming (Stasenko et al., 2021), and also in the word production and comprehension of aphasic patients (Biegler et al., 2008).

Similarly, literature often suggested bilinguals were found to be slower in verbal tasks compared with their monolingual counterparts. Studies found that compared with monolinguals, bilinguals named objects slower (Gollan et al., 2005) and produced fewer exemplars in the verbal fluency task (Gollan et al., 2002). Gollan et al. (2005) found that the difference between bilingual and monolinguals was in picture naming but not in picture classification, suggesting that the bilingualism effect lies in the post-concept retrieval stage. Bilinguals were affected by the process of inhibition, in that, besides competing concepts (e.g., table-chair), they would also have to inhibit another language (e.g., table-*mesa*) (Kroll et al., 2008). As convergence evidence, if a bilingual was allowed to use any of the languages to name the objects, there was no delay in naming observed because there was no need to inhibit the irrelevant language (Gollan & Ferreira, 2009).

As discussed in the above sub-section, bilingual's two languages have asymmetric strength according to the relative proficiency (Meuter & Allport, 1999). If the L2 proficiency is higher, then it would be stronger and harder to suppress. As the experiments in this dissertation were conducted in the stronger L1 (Cantonese), it is expected to be affected by the stronger L2. If this is true, then we should observe that the higher the L2 proficiency, the lower the verbal fluency score. Experiment 1, however, found an opposite pattern. Bilinguals were found to produce significantly more exemplars than the monolinguals ($F(1, 62) = 12.73$, $p = .001$). Among the bilinguals, linear regression analysis showed that the more proficient the L2, the more concepts they produced. As discussed in Chapter 3.4.3 (page 45), we suggested that because participants in our study were living in an L1-dominant society, it was likely that they would have acquired the L1 names for concepts they learnt through their L2. In other words, they would have more sources for learning concepts and thus acquired a larger vocabulary size than those with lower language ability. As verbal fluency score was influenced by vocabulary size (Friesen et al., 2015), bilinguals, specifically those with higher L2 proficiency, were found to perform better in this task.

However, Experiment 2 found an opposite result. In a group of older language learners, the correlation between the exam score and the difference score of verbal fluency was negative. It showed that those who were more successful in learning an L2 had a decline in verbal fluency after the English learning course. At first glance, the negative correlation seemed to suggest that the language learners were showing cognitive patterns similar to the bilinguals reported in the literature, that the verbal ability was negatively influenced by the newly acquired L2. Nevertheless, it is not convincing to suggest such a short period of learning would have similar interference effect as those of the lifelong bilinguals in the literature. Instead, using Antoniou and Wright (2017)'s terminology, we proposed in Chapter 4.4.2 that the decline in verbal fluency was the combination of the processing complexity effect and the interference inhibition effect. The processing complexity effect refers to the learning-induced cognitive demand. As regard the interference inhibition effect, instead of suggesting that the interference was from the newly-learnt L2, we propose that it was from the suppression of L1 during L2 learning.

Pliatsikas (2019) proposed the Dynamic Reconstructing Model, which might explain the differences between learners and lifelong bilinguals. In this experience-dependent model, language learning is separated into three stages: initial exposure, consolidation and peak efficiency. The first stage of language learning involves a wider range of neural resources, primarily the cortical grey matter in the parietal and temporal regions, since they are facing a new challenge. In the consolidation stage, the cortical grey matter renormalises to the level before learning because a more efficient mechanism is being developed. At the peak efficiency stage, the language users are such highly proficient bilinguals that additional experience in the language does not add much to the cognitive demand. The changes of cortical grey matter renormalise to the baseline level. In short, the model suggests that people face different levels of difficulty in the three stages of language learning, which, in turn, modulates different parts of the brain. We believe that the participants in the current project were in different stages of bilingualism. The new learners were at the initial stage, whereas the lifelong bilinguals were scattered between consolidation to peak efficiency stages. Therefore, opposite performance in the verbal fluency task was observed in the two experiments. In spite of this, since the cognitive training experiment had a small sample size, it is prudent to interpret the results with caution.

The modulation between cognition and language is mutual. In terms of bilingualism, being a bilingual is thought to improve the general inhibitory control because of the constant need of inhibiting the unwanted language. Our results supported this, as we found bilinguals outperforming monolinguals in tasks that required inhibitory control. On the other hand, the results in the current dissertation showed that, because of the difference in inhibitory control mechanism, whereas lifelong non-balanced bilinguals performed better in verbal fluency with increased L2 proficiency, the learners showed a decline.

6.2.4 Cognition Adapts to Environment

Cognition helps people to adapt to the new environment and challenges. In a boarder sense, cognition allows us to successfully orient in the surrounding environment. The Clinical Dementia Rating (CDR) Scale (Morris, 1991) suggested that starting from mild cognitive impairment, patients would have difficulty in geographic orientation. Patients would have trouble finding their ways even in familiar places like their own neighbourhood. A study reported that the incidence rate of dementia-related missing and its mortality rate per 100,000 person-year was 21.72 and 0.652 in Japan (Murata et al., 2020). The study found that the incidence rate in urban areas was higher than rural areas because of the ease of going out on foot, which is alarming to a metropolitan city like Hong Kong. Maintaining cognitive ability in older adults is a pressing issue. As discussed in the introduction, bilingualism is believed to be a contributing factor for the protection of cognition.

Moreover, good cognition is required for us to adapt to new challenges. In terms of language, the acquisition of an L2 might be one of the most difficult challenges. In this dissertation, we introduced a cognitive training using L2 learning as the intervention. We found that even in old age (65+), the cognitively normal older adults were still able to learn a new language (average exam score = 85.56, SD = 8.65). Furthermore, it was observed that participants with higher reasoning ability in the baseline had the trend of being more successful in learning (r (1,11) = .53, p = .06, two-tailed). This was because the teaching course was designed to utilise the relatively intact reasoning skill and the linguistic knowledge from L1 to aid learning, instead of relying on the declined working memory.

The results suggested that the older adults in this study were able to manage new challenges, and those who were more successful might be so through a compensatory mechanism. In neuroscience studies, it was observed that high-performing older adults activated bilateral brain regions when doing a memory task, whereas both low-performing older adults and younger adults only recruited the left prefrontal cortex (Cabeza, 2002; Cabeza et al., 2002). Successful agers were found to have youth-like activation in brain regions that the younger adults utilise in a memory task, together with additional recruitment in the prefrontal region (Chen et al., 2022). It showed that older adults who could reorganise the neurocognitive networks performed better, whereas those who continued using insufficient resources performed worse. This applies to the current studies. If memory is failing, one should compensate it with other available resources. Those who were able to look for alternative methods coped with challenges better.

6.2.5 Short Summary

To summarise the above sub-sections, environment, language and cognition influence each other. The outer environment, for instance, the language profile and habits of the community, would shape how one perceives and uses a language. The language input from the environment shapes the mental lexicon by introducing prefabs. Moreover, the language usage modulates cognition by inducing cognitive control and thus practising the inhibitory control. The cognitive ability, at the same time, modulates the performance of languages, as shown in verbal fluency tasks. Only with good cognition, could one efficiently cope with new challenges they faced in the environment. However, individuals varied in all three components. These factors affect how cognitively challenging the linguistic control would be, thus affecting who would enjoy bilingual advantage in cognition and when.

6.3 THE EXPERIENCE-BASED BILINGUAL MENTAL LEXICON MODEL

We postulated that the key to the bilingual advantage effect is the cognitive demand that arises from the environment, language and cognition of the bilingual. Specifically, the organisation and the retrieval from the bilingual mental lexicon contribute to the cognitive demand a bilingual experienced. In this section, we will discuss the bilingual lexicon with support from the literature and our experiments.

The Revised Hierarchical Model (RHM, Kroll & Stewart, 1994) was developed based on the earlier models, which suggested concept-mediation and the word-association models (Potter et al., 1984). The RHM suggested that both L1 and L2 word representations link directly to the concept, see Figure 2.2, page 11. However, there is an asymmetric strength in the two representations. The link between the L2 and the concept is weaker than the one between the L1 and the concept, because proficiency affects the strength. Moreover, bilinguals with lower L2 proficiency have to activate the concept via the L1, whereas people with higher L2 proficiency have developed a direct link from the L2 to the concept. However, over the years since RHM was first proposed, there have been suggestions that models that could capture the dynamic perspective of languages are needed (Schmid & Köpke, 2009).

The language input from the environment influences the organisation of the mental lexicon. From the results of Experiment 3, it was postulated that the lexicon is organised by experience but not by language origin. In the experiment, although bilinguals identified the language membership of the target words in the early comprehension stage, the overall cognitive effort to comprehend did not differ between habitual-unilingual and habitual-code-switched sentences. Instead, a prolonged processing cost was reported for the non-habitual usage of language regardless of the language presented. The authors suggested that the habitual code-switches were prefabricated into the dominant lexicon so that the retrieval of it did not require a switch to another language lexicon (Hui et al., 2022). In other words, within a lexicon, both words originated from the L1 and L2 are stored.

Based upon the RHM (Kroll & Stewart, 1994) and the experiment results in this dissertation, we proposed the Experience-based Bilingual Mental Lexicon Model. See Figure 6.2 for an illustration. There were two major features added to the model: (1) The lexicons are separated by language dominance, but not language origin, and (2) The dominance is dynamic.

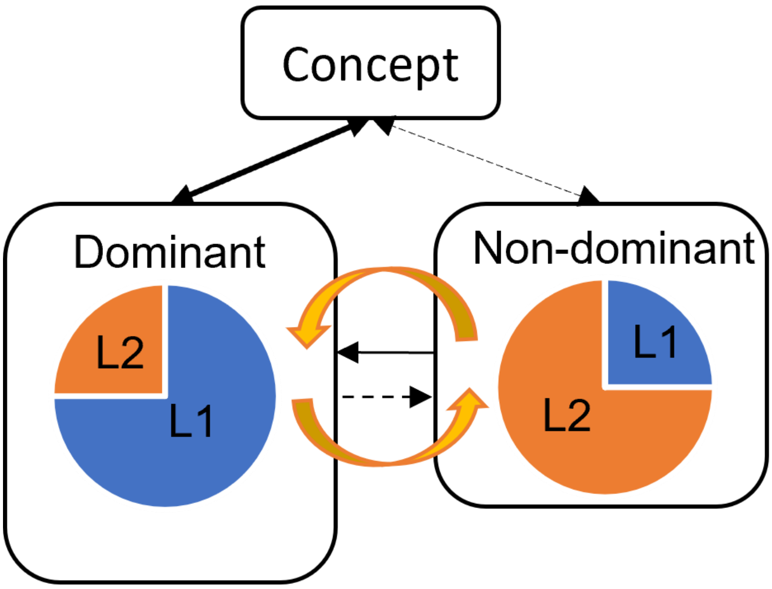

Figure 6.2. Experience-based Bilingual Mental Lexicon Model. The illustration of the proposed bilingual mental lexicon. The lexicons are separated into the dominant and non-dominant lexicons based on language experience, in which both words originated from the L1 and L2 are stored together. The proportion of L1 and L2 on the figure is for illustration only. The yellow arrows denoted that the dominance could be changed.

6.3.1 The Organisation

The lexical level is separated in terms of dominance instead of language origin. Similar to the RHM (Kroll & Stewart, 1994), we propose a shared lexicon in that the concept had direct links to both the dominant and non-dominant word representations but with asymmetric strengths. However, instead of separating the storage in the lexical level purely based on language origin, we named it the “Dominant” and “Non-dominant” lexicon. According to the original model, L1 is the stronger language and is strongly linked to the concept. In most cases, it is true that the words from L1 are the dominant representations. However, according to Sandoval et al. (2010), one of the reasons that the bilinguals showed worse verbal fluency performance than monolinguals was that some concepts might only be known in one of the languages. Whereas many assume that the concepts known in L1 would be more than in L2 because of the unbalanced proficiency, there are possibilities that the L1 term of a concept is the lesser known one. For instance, in Hong Kong, many secondary schools use English as the medium of instruction. Therefore, many mathematical and scientific terms might only be known by the students in English (e.g., “Pythagorean theorem”, “sine, cosine, tangent”, “hydrogen”) because these terms are rarely used outside the classroom. In this case, even though the term itself is undoubtedly not Chinese, it would be the dominant representation of the concept instead of the Chinese translation equivalent (“畢氏定理”、“正弦、餘弦、正切”、“氫”). Some students might acquire the Chinese equivalents due to curiosity, but since classes and exams only require the use of the English terms, it is expected that the Chinese equivalent would stay as the non-dominant representation due to lesser exposure to it. It shows that L1 does not necessarily have to be the most dominant word representation and, thus, the easiest to retrieve from the lexicon.

More importantly, the proposed model emphasises language dominance as being experience-based. The organisation is dynamic and changes according to language exposure. It is denoted with the yellow arrows in Figure 6.2. Using the Hong Kong students as an example, if the students switched to a school that uses Chinese as the medium of instruction, then the Chinese terms would gradually switch from non-dominant to the dominant representation. The L1 attrition phenomenon is widely observed in individuals who are learning and using an L2 frequently (Schmid & Köpke, 2009). An immigrant study reported that the L1 became less fluent in migrants after moving to the L2-speaking country for more than ten years, compared to the L1 monolinguals who stayed in the original country (Yilmaz & Schmid, 2012). On the other hand, bilingual migrants were reported to have better L1 and worsened L2 in old age compared to their performance in middle age, as many had retired and spent more time using their L1 at home (De Bot & Clyne, 1989; Keijzer et al., 2011). These immigrant studies supported the notion that language dominance is not static but changes with language experience.

Moreover, it should be noted that in the model, the Dominant lexicon is larger than the Non-dominant lexicon (represented by the different size of the two lexicons in the figure). This is because even for a relatively balanced bilingual, it is unlikely that one would have acquired the translation equivalent of every concept. For concepts acquired in a L2 but never the L1 (e.g., "sine" but never the Chinese "正弦"), it would be stored inside the Dominant Lexicon. Therefore, under no scenarios will the size of the Non-dominant lexicon be larger than the Dominant one.

6.3.2 The Retrieval

In terms of the retrieval of concepts, the proposed model shares the same view as the RHM (Kroll & Stewart, 1994) that there is an asymmetric activation in the Dominant and Non-dominant word representation with the concept. In retrieving the concept, the most critical part of the model would be the two links between the concept and the word representations. In the original model, it was suggested that increased L2 proficiency strengthens the link between the L2 and the concept. Although weaker, the L2 would still be activated simultaneously even if only the L1 was needed in a conversation (Marian & Spivey, 2003; Spivey & Marian, 1999).

Our model holds the same view that the weaker translation equivalent in the non-dominant lexicon would also be activated during a dominant language task. The conceptual link between the non-dominant language representation and the concept would become stronger when the language proficiency increased and, therefore, required more effort to inhibit it. On the other hand, bilinguals with lower L2 proficiency had a weaker link between the concept and the non-dominant representation.

Figure 6.3a and 6.3b shows an illustration of lifelong bilinguals with different L2 proficiency in a L1 verbal production task. The two groups differed only in the strength linking the concept to the non-dominant lexicon. Because the task was an L1, but not L2, production task, the bilinguals are only required to activate the dominant lexicon. Moreover, the sizes of the lexicons are not equal in the two groups. That is because the high L2 proficiency bilinguals are able to absorb knowledge from more sources and thus have a larger vocabulary size than the low L2 proficiency group. Even though the interference from the non-dominant lexicon is stronger, the high L2 proficiency group were still able to produce more concepts than the low L2 proficiency group. In our experiment (see Chapter 3 for details), we found that in lifelong bilinguals, L2 proficiency was a positive predictor of the Verbal Fluency task. Those who scored higher in the Shipley test were able to name more concepts in the task.

Since the practice of language inhibition contributes to the improvement in general inhibition control, bilinguals living in an L1-dominant environment would require a more proficient L2 to be sufficiently trained for the inhibition. Our experiment (see Chapter 3 for details) found that even L1-dominant speakers would enjoy a bilingual advantage in inhibitory control if their L2 was proficient (Hui et al., 2020), which provides evidence for this postulation

Consistent with the original model, we proposed that, for lifelong bilinguals, they would have developed a separate association between the concept and the two representations. On the contrary, the new learners would have an association between the less dominant to the dominant lexicon (see Figure 6.3c for comparison). As these L2 learners might not have developed an efficient network in controlling the newly acquired language, the link, although irrelevant to the task in hand, might also interfere with the task. In Experiment 2, for L2 learners, those who obtained higher score in the final exam were found to have a worse score in verbal fluency. Successful learners started to be interfered by the non-dominant lexicon and therefore, their performance was relatively declined in the task. In contrast, unsuccessful learners were not able to build up the non-dominant lexicon and were, therefore, unaffected.

For comparison, we also included the L1 monolinguals in Figure 6.3d. As they do not have the other lexicon as the interference, they would be the quickest in producing the concept.

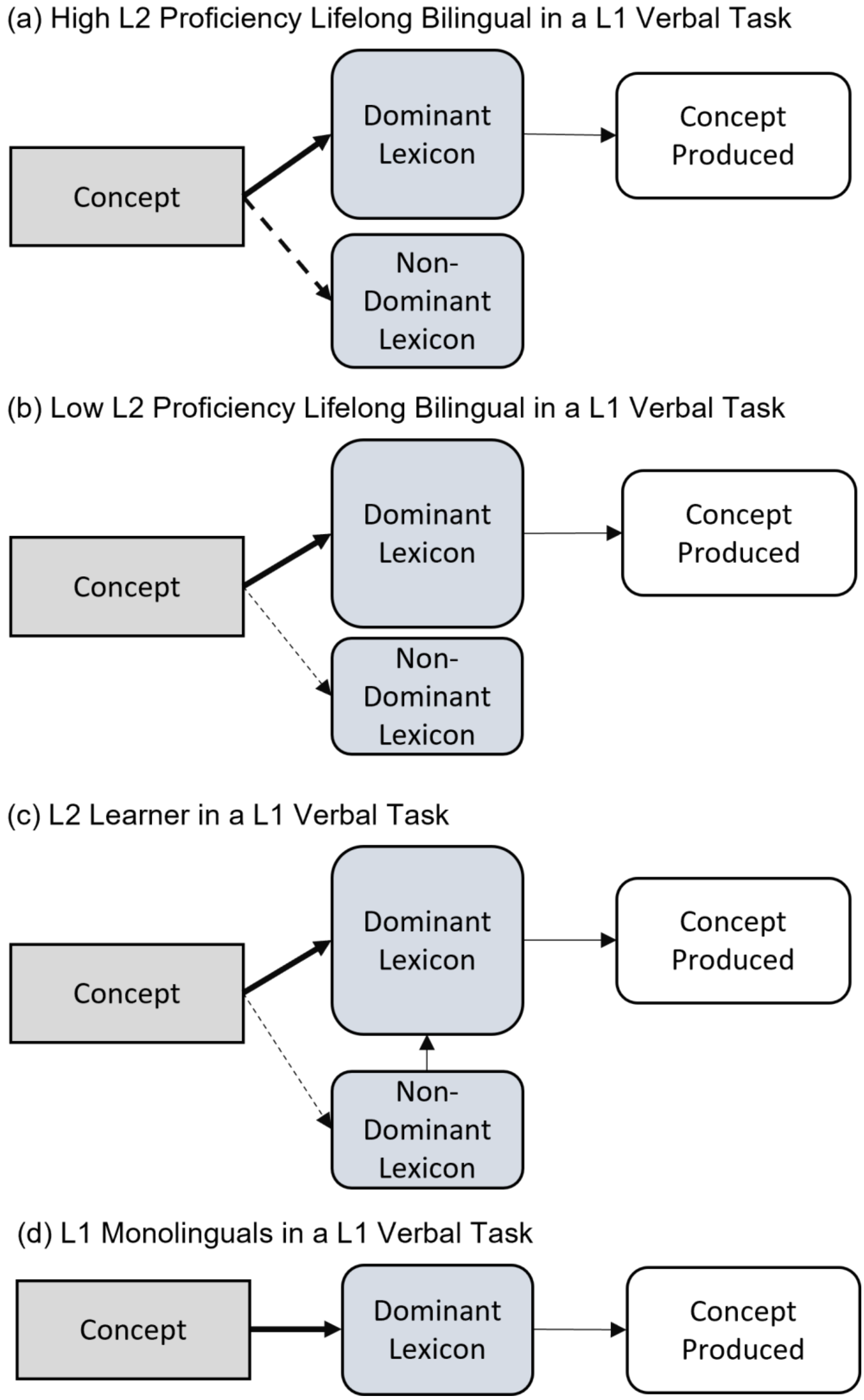

Figure 6.3. Bilinguals with different L2 proficiency under the Experience-based Bilingual Mental Lexicon Model. The figure demonstrates how bilinguals with different L2 proficiency levels retrieve a concept in L1 under the proposed model. (a) High proficient lifelong bilinguals, (b) Low proficient lifelong bilinguals, (c) L2 learners, and (d) monolinguals. See the main text for a detailed description. Thicker arrows represent a stronger strength. Thinner and dotted lines represent a weaker strength.

In addition, Figure 6.3d also represents the case of "code-switching" if no alternative representation is known by the speaker. For instance, if a person only knows the word "*printer*" in English but not the equivalent in any language, it would be stored in the dominant lexicon. There will be no competition from the other lexicon for this particular concept.

To verify the model, we also compared the lifelong monolinguals and bilinguals in Experiment 1 and the language learners in Experiment 2 for their performance in the Picture Naming (RT). Although the statistical analysis was not statistically significant (p = .31), monolinguals were the quickest in the task (M = 1389.07 ms, SD = 194.20 ms), language learners the second (M = 1418.73 ms, SD = 181.89 ms) and bilinguals were the slowest (M = 1479.97 ms, SD = 246.91 ms). Numerically, it suggested that the lifelong bilinguals might be experiencing higher interference from the non-dominant lexicon, whereas learners were experiencing lower and monolinguals no interference.

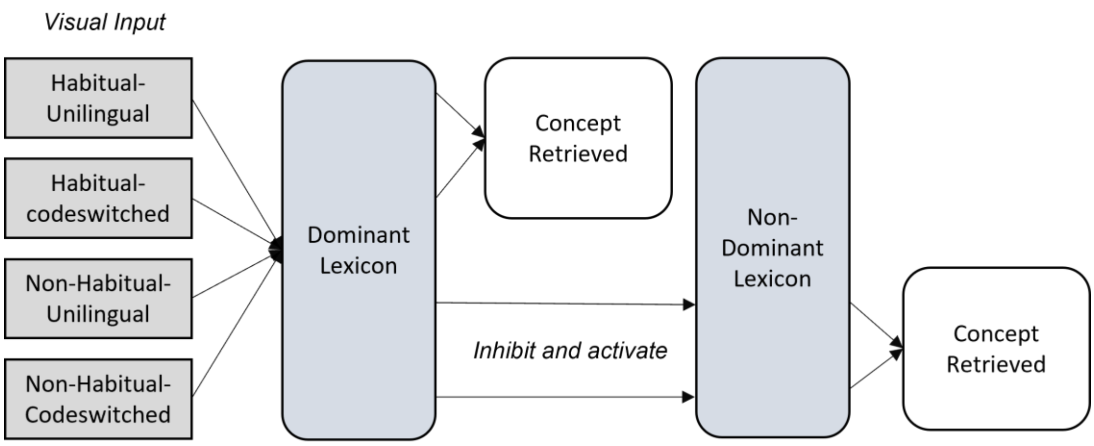

Figure 6.4. Code-switching sentences processing under the Experience-based Bilingual Mental Lexicon Model. The figure demonstrates the proposed model with the code-switching sentences data from Experiment 3. See the main text for a detailed description.

Although the RHM was proposed to be a language production model (Kroll et al., 2010) and the process of production and comprehension differs, the retrieval of concepts is still needed in language comprehension. Using the data from Experiment 3 (Hui et al., 2022), we demonstrated the processing of code-switching sentences under the Experience-based Bilingual Lexicon Model. See Figure 6.4. As the sentences had the matrix of Cantonese and started with Cantonese, it was natural that participants were activating their dominant lexicon when reading it. First Fixation Duration showed that the orthographical code was activated, and language membership was identified. However, as both Cantonese and English items were in the dominant lexicon, participants would not be cued to switch immediately. For the habitual unilingual and habitual code-switching, the words were in the dominant lexicon and were found easily. On the other hand, the non-habitual items were not inside the dominant lexicon and, therefore, the participants would have to inhibit it and activate the non-dominant lexicon. As inhibiting the L1 words was considered more difficult than L2 (Spivey & Marian, 1999), the Non-habitual Unilingual condition was processed slower than the Non-habitual CS condition.

It should be noted that the model is quite preliminary and based on the findings from this thesis only. Further investigation is needed to validate the model. We suggest future study to recruit different types of bilinguals (e.g., early vs late bilinguals, simultaneous vs sequential bilinguals), in different interaction settings (e.g., L1-dominant, L2-dominant and heritage speaker), using different verbal tasks (e.g., comprehension vs production).

6.4 CONCLUSION

This dissertation aims at answering what would contribute to bilingual advantage in cognition. From the three experiments, we explored the individual differences that might affect bilingual advantage, including personal differences (e.g., gender, age), language differences (e.g., L2 proficiency, AoA) and environment (e.g., code-switching habit of the community). We concluded that the environment and language experience would shape and modulate the cognition. In return, the cognitive status would modulate the language performance. Specifically, as we recruited participants who were living in an L1-dominant community, they would have to increase the L2 proficiency in order to increase the strength of the language. Thus, it would be more difficult to inhibit during an L1 conversation. The practice of inhibition would therefore be enough for the bilingual advantage effect. In other words, the key to bilingual advantage lies in the cognitive demand required to speak the languages in daily life.

Moreover, we modified the Revised Hierarchical Model (Kroll & Stewart, 1994) and proposed the Experience-based Bilingual Lexicon Model. Specifically, we emphasised that the language lexicon does not separate distinctively by the words' language membership, but by the language exposure and experience. To some bilinguals, the words from the L2 would be the more dominant representation of a concept. Therefore, the use of those L2 words would not be as cognitively challenging as the original model suggested. The modified version of the model would better capture the organisation and retrieval of concept of the bilingual mental lexicon.

Chapter 7. SIGNIFICANCE AND LIMITATION

This chapter highlights the significance of this dissertation, acknowledges its limitation, and points to a future direction to further the knowledge of bilingualism and cognition.

7.1 SIGNIFICANCE

"Monolingualism is the illiteracy of the 21st century (Roberts et al., 2018)". Although it sounds quite harsh, monolingualism undoubtedly will become more of an exception in the future due to globalisation. Many education systems in the world began teaching at least one foreign language during the compulsory education period (Pufahl et al., 2001), which means that, in the near future, it will be almost impossible to have someone who was schooled with zero knowledge of a foreign language. In Hong Kong, English is a compulsory subject starting from primary school. According to the 2018 Census, 89.6% and 90.7% of the population aged 6 to 65 reported being at least "not so good" in using spoken English and written English, respectively (*Use of Language in Hong Kong in 2018*, 2020). Both percentages have increased since the Census in 2012 and are estimated to be growing, see Figure 7.1 (*Use of Language in Hong Kong in 2012*, 2014; *Use of Language in Hong Kong in 2018*, 2020). It could be anticipated that, within a few decades, the whole population in Hong Kong would know at least the basics of English. In this case, we should look beyond the traditional comparison of monolinguals and bilinguals. Instead, we should move on to investigate the specific properties of bilingualism that might contribute to cognitive reserve.

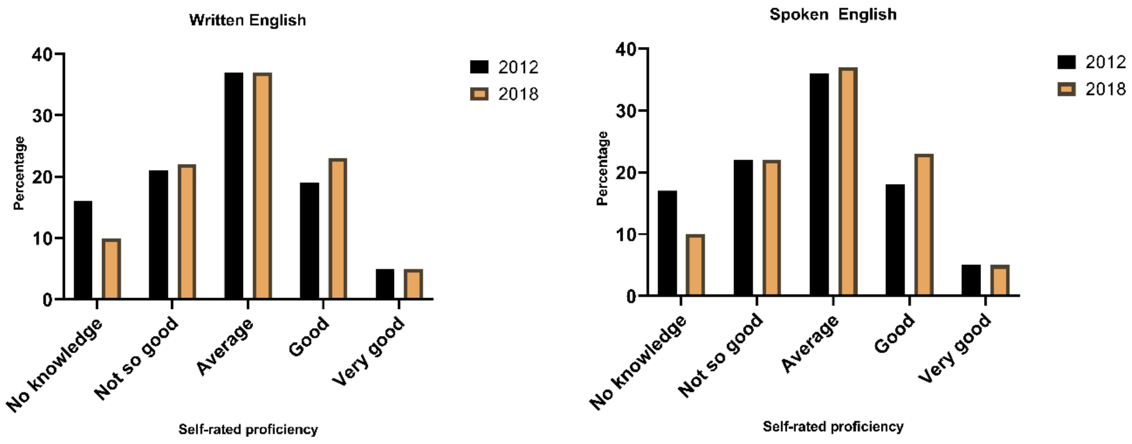

Figure 7.1. Changes in self-rated proficiency in 2012 and 2018. The figures show the self-rated proficiency in (left) written English and (right) spoken English of the Hong Kong population aged 6 to 65 in 2012 and 2018. Data were obtained from the Census Department (Use of Language in Hong Kong in 2012, 2014; Use of Language in Hong Kong in 2018, 2020).

To the best of our knowledge, this study is one of the few that investigate a wide range of factors that contribute to bilingual advantage, which include the environment (e.g., community norm, interaction contexts), linguistic properties (e.g., L2 proficiency, frequency of using languages, AoA) and individual variations (e.g., gender, age, occupation). We showed that language experience shapes the organisation of the bilingual lexicon, and, therefore, alters the cognitive demand during a conversation. As our participants were living in an L1-dominant society, only when the interference from the non-dominant language was large enough, would they be enjoying the bilingual advantage from the practice of inhibition. In other words, we suggest that the bilingual advantage effect largely depends on the interaction context.

Moreover, we proposed an Experience-based Bilingual Mental Lexicon Model that was modified from the Revised Hierarchical Model (Kroll & Stewart, 1994). We suggested that, instead of separating the lexicons purely by the language origin, the lexicon is organised by the language experience. Depending on the community the bilingual is living in, the interaction context, and the language experience of the bilinguals, the cognitive demand of retrieving an L2 might be less than the L1. Therefore, the L1 words might not be the dominant concept representation all the time. The world is more diverse than ever. Our modified model allows the dynamic changes of language dominance, which, in turn, affects the cognitive demand for the retrieval of concepts.

In terms of societal impact, this project reached out to the public directly by recruiting community-dwelling older adults to participate in the cognitive assessments. Most of the older adults reported a decline in memory when they arrived at the laboratory, but almost none could tell the difference between cognitive decline in normal ageing and pathological ageing. From the feedback of the older adults, many reported having a better understanding of ageing and cognition through participation of the research. Although the number of older adults we could reach was limited, we believe it is a good start for public engagement and education.

7.2 LIMITATIONS AND FUTURE DIRECTIONS

As with the rest of the world, this study was affected by COVID-19. The cognitive training experiment conducted between two waves of outbreaks was the most impacted experiment among the three. Older adults preferred to avoid the crowd, which added to the difficulty in recruiting participants, resulting in a small sample size in each group and unbalanced gender. Interpretation of the results in that experiment should, therefore, be treated with caution. Moreover, because of COVID-related restrictions, the lesson planning was not in the most ideal way. For instance, students' interaction was limited because they had to be seated far apart. Students could not see the mouth and lips movement of the instructor because of the face mask, which hindered the learning of pronunciation. Hopefully, future studies could be conducted in COVID-free time so that none of these restrictions would be present.

The experiments in this dissertation were limited to Hong Kong's population. In other words, only one type of interaction context was thoroughly investigated in the current project. Also, because English is taught in school as a compulsory subject, those who had received formal education would at least know a bit of English and were defined as "bilingual" in this study. As a result, there was no monolingual with matched education level for comparison. However, there were suggestions that "bilingual is not two monolinguals in person" in that bilinguals developed a special language control mechanism (Grosjean, 1989; Rothman et al., 2022), and the use of monolinguals as the control group for bilinguals was unnecessary or even inaccurate. We believe the inclusion of monolinguals as the starting point of the bilingualism spectrum is meaningful to understanding the full picture of bilingualism, but unfortunately, the recruitment of monolinguals was logistically impossible at the time of this study.

To further understand how the outer environment and the inner properties of bilingualism and individuals might affect cognition, we suggest recruiting participants with the same language pair but currently living in a different interaction context. In this dissertation, we recruited Cantonese-English bilinguals living in a Cantonese-dominant but frequently code-switched society. In the future, we could expand to Cantonese-dominant with fewer code-switching occurrences (e.g., Guangzhou), L2-dominant (e.g., international students in English-speaking countries), a heavily code-mixed society (e.g., Singapore, Malaysia), and English-dominant speakers (e.g., Cantonese-speaking Chinese American communities). A more comprehensive view of language and cognition could be achieved.

"Think globally, act locally": even if we have only investigated the situation in Hong Kong, we believe that our central idea of a dynamic language dominance lexicon could be generalised to other areas.

Chapter 8. REFERENCES

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Chapter 9. APPENDICES

9.1 AUTHORISATION LETTERS

The experiment reported in Chapter 5 was published in Hui et al. (2022) under Creative Common CC BY license. According to the publisher (MDPI), no permission is required for reusing any part of the article given that it is cited properly (See https://www.mdpi.com/openaccess). Permission from my two co-authors, Prof. William Shiyuan Wang and Dr. Manson Cheuk-Man Fong, were obtained for me to use the dataset in this thesis.

Dear Ms. Hui,

As a co-author of the paper below, I hereby give my consent to you to use its dataset in your PhD thesis.

Hui, N. Y., Fong, M. C. M., & Wang, W. S. Y. (2022). Bilingual prefabs: No switching cost was found for Hong Kong Cantonese-English code-switching. *Languages*, 7(3). https://doi.org/10.3390/languages7030198

Sincerely,

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9.2 MATERIALS USED IN EXPERIMENTS

The set of materials used in the experiments could be obtained from: https://osf.io/udac3/?view_only=7bde50b355f34eb89d7d6b6cc1846568

We only included those that were developed by us here. This includes:

(1) The questionnaires administered in Experiment 1, including the Language History Questionnaire and the Social-economic Status Questionnaire.

(2) The self-developed textbook, in-class exercises and the examination paper for Experiment 2. We thank いらすとや (https://www.irasutoya.com/) for providing the royalty-free images for developing the materials in Experiment 2.

(3) The set of stimuli used in the eye-tracking experiment and the rating results. Also, the demonstration of eye movement during sentence reading could be found.