Lexical selection in Mandarin-English bilingual speakers

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Writing this thesis has consumed all my energy and strength. During this battle, I received help and support from a lot of people. Without them, I would not even have been able to achieve this milestone.

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ABSTRACT

The ongoing debate in bilingualism research revolves the inhibition towards the non-target language and the required speed to switch to another language. This inhibition has been investigated through various switching-paradigm, whereby suggesting the importance of language proficiency and use. However, given the growing body of bilingual speakers from different background, it is crucial to tap into the magnitude of inhibition and its dynamic nature within different language contexts and exposure. In the current thesis, I examined how language context affects the need of inhibition and how flexibly can bilingual speakers adapt themselves to optimise their language switching efficiency.

In Study 1, Mandarin-English bilinguals completed language-switching tasks in different language contexts: (1) “L1-predominant” (most trials named in L1), (2) “L2-predominant” (most trials named in L2) and (3) “Mixed” (trials named half in L1 and half in L2). Based on our findings, I confirmed that switch cost asymmetry does not necessarily emerge during switching, and that the pattern of switch cost can also be modulated by the type of production process. In the production process with pictures named in either language (i.e., top-down processing), the degree of inhibition is dynamic and dependent on the predominant language.

In Study 2, I then tested whether this switch cost pattern (asymmetry in the L1-predominant not in L2-predominant) would also emerge in other production-based tasks (here, reading aloud) or whether it was constrained to picture naming. Mandarin Chinese-English bilinguals were asked to read aloud Chinese characters and English words. The procedure was otherwise identical, including the context manipulation, but pictures were replaced with words. In contrast to study 1, I did not observe the asymmetry in both contexts.

Study 3 tested whether the switch cost patterns (asymmetry in the L1-predominant, not in L2-predominant) would also emerge when participants could prepare for the target language (here, 250ms). Mandarin-English bilinguals saw a cue 250ms before the onset of the target pictures. The context manipulation remained the same. Here, I found different that magnitude of asymmetry was absent in both contexts.

Study 4 was set out to investigate the brain activity before speech onset. The results showed that switching to L2 requires greater cognitive demands than switching to L1. To this end, I provide direct evidence with dynamics of inhibition, and importantly the anticipatory ability of the bilingual brain. This suggests that future work should continue to explore the language production processes in bilingual speakers.

In summary, the results presented in this thesis demonstrated the flexibility of bilingual speakers when they switch languages. Furthermore, the effect of language context plays a role in bilingual language switching.

AUTHOR'S DECLARATION

This thesis is my own work and has not been submitted in substantially the same form for the award of a higher degree elsewhere. This thesis includes three papers, with one paper under review and two publishable papers. The following pages contain the authorship statements signed by the co-authors of each paper.

Authorship statement

The article "Top-down and bottom-up bilingual speech production: The effects of language context on inhibitory control" is under review in Bilingualism: Language and Cognition with authors Yun-Wei Lee, Patrick Rebuschat and Aina Casaponsa. Yun-Wei Lee was responsible for writing up the article, carrying out the research, conceptualization and design, and formal analysis. Patrick Rebuschat and Aina Casaponsa were responsible for supervision, conceptualization and design, guidance on formal analysis, and providing comments on the text.

Sign here	Date
Sign here	Date

Authorship statement

I, Yun-Wei Lee, have written the article and carried out the research behind it in collaboration with Patrick Rebuschat and Aina Casaponsa. I was responsible for writing up the article, carrying out the research, conceptualization and design, and formal analysis. Patrick Rebuschat and Aina Casaponsa were responsible for supervision, conceptualization and design, guidance on formal analysis, and providing comments on the text.

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CHAPTER 1. GENERAL INTRODUCTION

1.1 Background

Individuals who can speak more than one language have accounted more than half of the population in the world (Grosjean, 2021). Some of them grew up learning two languages from their parents, and some learned a foreign language in early/late teenage years at school, constituting a multi/bilingual language environment in real-life. Hence, speaking different languages occurs in a variety of scenarios, and the use of languages depends on the communicative goals (Grosjean, 2013. For example, one needs to speak Language A to one person but speak Language B later when encountering another person. This increasing body of individuals, so-called bilingual speakers are often sensitive to switch from one language to another for different purposes. This requires speakers to have an ability to process both languages immediately to be able to achieve the language goal. This language processing can often be observed in switching.

Bilingual speakers can switch between two different languages when they intend to (i.e., voluntary, non-cued) or when they are required to do so (i.e., involuntary, cued). Within the languages they speak, there are various components that determine the fluency of language processing, and these are (but not limited to) language proficiency/dominance, exposure, age of acquisition as well as frequency of language use. This ability seems flexible all the time, yet if we look into the diverse phenomenon of language processing, there is often the interference from the present environment. For instance, if L1 is the target language, while L2 is the non-target language, but both are activated in parallel (Bialystok, 2024; Costa et al., 1999; Kroll et al., 2014), language processing might become a hard task for bilingual speakers. Amazingly, bilingual speakers can ignore (or reduce) the interference, and still solve the hard task for the target language successfully, highlighting the flexibility and adaptability of the language processing network. The benefit of this phenomenon can be attributed to the underlying cognitive ability behind that interplay ones' language processing, namely language control or language selection (Abutalebi & Green, 2007, 2008; Abutalebi et al., 2008).

Language control is a mechanism that enables speakers to take control of their languages, knowing when to activate one language and de-activate (not fully) another language. The aforementioned "interference" will then emerge during the process of switching because when the target language changes, bilingual speakers will have to re-configure the language goal. Under the scope of language control, one aspect in which researchers have been investigating is how bilingual speakers reduce the interference from the non-target language, and how it affects the subsequent language performance. One of the most debated language control mechanisms is inhibitory control as some researchers supported its importance in bilingual language processing (Costa & Santesteban, 2004; Costa et al., 2006; De Bruin et al., 2018; Green, 1986, 1998; Green & Abutalebi, 2013; Green & Wei, 2014; Jackson et al., 2001; Meuter & Allport, 1999) whereas some did not (Blanco-Elorrieta & Pylkkänen, 2017, 2018; Blanco-Elorrieta & Caramazza, 2021, Finkbeiner et al., 2006). The debate mainly focuses on whether inhibition is required to reduce interference from the language not in use whereby selecting the target language (see Declerck & Koch, 2023 for a review). For instance, when a bilingual individual sees an apple, not only the lexical representation '*apple'* will be activated, but also its semantically related items (e.g., translation equivalents) in the other language (e.g., Mandarin Chinese). Hence, lexical representation from the non-target language leads to interference, which in turn are required to be inhibited to produce the target items. This phenomenon relies on the need of inhibition, and is a critical phase contributing to successful language processing. Interestingly, the magnitude of inhibition is not static across environments and experiments, instead, it is a diverse and changing mechanism that can be affected by different factors.

For example, previous studies have established that bilingual language processing is dependent on language proficiency and use (Abutalebi et al., 2013; Costa & Santesteban, 2004; Costa et al., 2006; Meuter & Allport, 1999, see Bonfieni et al., 2019 for age of acquisition). Particularly, the more dominant language increases the activation level, hence, it becomes easier to select the dominant language than the non-dominant one, and the former will receive greater magnitude of inhibition than the latter. Indeed, language proficiency is not the only factor as many more studies have investigated other factors by (1) manipulating the interval between a cue and target stimulus (Costa & Santesteban, 2004; Fink & Goldrick, 2015; Khateb et al., 2017; Ma et al., 2016; Mosca & Clahsen, 2016; Mosca et al., 2022; Stasenko et al., 2017; Verhoef et al., 2009), (2) asking bilingual speakers to switch either voluntarily or involuntarily (De Bruin et al., 2018; De Bruin & Xu, 2023, De Bruin & McGarridge, 2023; Gollan & Ferreira, 2009; Jevtović et al., 2020, Jiao et al., 2022, Philipp e al.. 2023; Zhu et al., 2022), (3) differentiating bilingual speakers with high/low cognitive flexibility (Liu et al., 2016), (4) using different types of language cues (Blanco-Elorrieta & Pylkkänen, 2017; Heikoop et al., 2016; Liu et al., 2019; Timmer et al., 2024), (5) manipulating production modality (e.g., Declerck et al., 2019; Finkbeiner et al., 2006; Macizo et al., 2012; Mosca & De Bot, 2017; Slevc et al., 2016; Martin et al., 2013; Reynolds et al., 2017; Zuo et al., 2022), (6) asking bilinguals to switch between two or three languages (Declerck & Philipp, 2018; Declerck et al., 2015; Guo et al., 2013; Philipp et al., 2007; Philipp & Koch, 2009), (7) recruiting another bilingual-like speakers: bidialectals (Declerck et al., 2021; Kirk et al., 2018; Kirk et al., 2022; Vorwerg et al., 2019), and (8) using code-switching (Adamou & Shen, 2019).

Of all the previous studies, it is apparent that employing different methods leads to the different outcomes of language processing. Still, one aspect that researchers tend not to pay attention to is the relation between activation and inhibition within a language context. Everyone (not just bilingual speakers) can be exposed to different language contexts where the use of L1 and L2 (even L3) differs (see Green, 2011; Green & Abutalebi, 2013; Grosjean, 2000, 2013; Wu & Thierry, 2010). One can not only be immersed in an L1 context (e.g., watching a movie), but also a L2 context (e.g., communicating with colleagues at work), and interestingly, this can affect how individuals process their languages. For instance, Degani et al. (2019) asked Arabic-Hebrew bilinguals to name different pictures entirely in L1 in an L2 exposure block (i.e., presenting L2 words constantly to the participants) and a non-linguistic exposure block (i.e., drawing). They reported higher error rates in L1 after L2 exposure than in the other context, showing there was cross-linguistic influence in L1 production. Branzi et al. (2014), asking Catalan-Spanish bilinguals to name pictures in L1 and L2 in separate blocks, found that L1 responses were overall delayed after participants named the pictures in L2 first (i.e., L2 after-effect, see also Misra et al., 2012 and Wodniecka et al., 2020). With respect to the previous studies, L1 and L2 overall performance was captured separately within two different contexts (i.e., pure L1 context and pure L2 context), but little is known regarding how L1/L2 switching performance can be affected. For example, in real life, a Mandarin-English bilingual who moves to an English-speaking country is required to switch between L1 and L2 in an L2-predominant context (i.e., Context L2). Would his/her switching performance be different comparing to another Mandarin-English bilingual who lives in a Mandarin-speaking (L1-predominant) country? Indeed, exposure can affect one's language performance, Interestingly, some studies (while not Mandarin-English bilinguals), have demonstrated the effect of being exposed to different contexts on L1/L2 switching (Olson, 2016; Timmer et al., 2019). They manipulated the ratios of L1 and L2 in two separate blocks (e.g., in L1-predominant context, 75% of picture were named in L1 and the rest in L2). It was found that switching performance (e.g., the magnitude of inhibition, overall performance of L1 and L2) was different, highlighting the effect of context on language control mechanism that modulates global activation level of a language and local performance of language switching. As aforementioned, studies based on language switching used a variety of methods to explore the differences across bilingual populations, yet the phenomenon of how a highly activated language affects a less activated language requires more investigations.

In addition to language context, several studies have also highlighted the fact that the brain is good at detecting, anticipating, and preparing for the upcoming language event (Gisladottir et al., 2018; Lupyan et al., 2020). Given the brain is adept at recognising an object and associating with its target language, the speed of this process can be shortened by presenting a language cue and pre-activating the relevant information beforehand (Costa et al., 2004; Khateb et al., 2017; Ma et al., 2016; Mosca & Clashen, 2016; Mosca et al., 2022; Wu & Thierry, 2017). For a bilingual individual, when pre-activating a language, say L1, the activation threshold of L1 can be lowered, hence, producing L1 becomes easier, and this also occurs to producing L2. In other words, comparing to being asked to switch immediately, being able to successfully anticipate and prepare for an upcoming language event can be less cognitively demanding. Studies have also shown an electroencephalographic (EEG) study, Wu and Thierry highlighted a deeper curve of contingent negative variation (CNV) when bilingual speakers produce their non-dominant L2, suggesting a greater magnitude of inhibition of the dominant L1. This further shows that there is a phase, within a few milliseconds, where the brain prepares to produce a language prior to articulation. To that end, in addition to the effect of language context, we question whether inhibition, in a switching environment, can be reduced or even eliminated when the target language is pre-activated.

The thesis adds to the literature by tapping into the dynamic language processing mechanism of bilingual speakers as a function of language context, with a focus on bilingual speech production. The language context in this thesis, is important as it modulates activation level, whereby affecting one's overall language performance and cognitive function. To date, the effects of language context on switching production have been relatively diverse, with different pattern of cost and latencies emerged (Olson, 2016; Timmer et al., 2019). For example, researchers who believed the more activated language in a context would lead to more delayed responses during switching (Olson, 2016), whereas others (Timmer et al., 2019) did not replicate such results in which the delayed responses did not always occur to the predominant language. This indeed highlights the flexibility of bilingual speakers, more importantly, the effects of language context on bilingual language switching. Nonetheless, what still needs to be investigated is the extent of how inhibitory control operates over the interferences within a language context, and how the brain adapt itself to different linguistic environment. Here, by manipulating the ratios of languages and allowing pre-activation of the target language, this thesis is set out to examine the relationship between inhibitory control and bilingual language switching in different language contexts with both behavioural and EEG studies.

Bilingual speakers can switch between sentences, intermix foreign words within a sentence (e.g., code-switching), or more easily, switch between words. One basic switching behaviour for bilingual speakers takes place when they name the same object in two different languages. This requires the process of switching between two lexicons (i.e., L1 and L2 lexicons). Because of parallel activation, the words (sometimes called lexical representations) from the irrelevant lexicon will have to be ignored. But how? The process regarding the selection of a lexical representation then becomes important.

1.2 Literature review

This section will first introduce the framework of bilingual lexical selection. Next, based on lexical selection, the cognitive mechanisms in which lexical selection is carried out will be introduced. Because of cognitive mechanisms, language switching can stimulate various behavioural results, and this is what the researchers are still investigate (debating) currently. Despite the different results across studies, one aspect we ought to consider is the flexibility of bilingual speakers' language processing network. To that end, the section will also introduce the hypothesis focusing on how cognitive mechanisms differ according to each language context, and this will be the core of the series of studies in the current thesis. Finally, the current thesis will introduce the relevant brain imaging studies in language switching and point out the aspect that still requires more investigations.

1.2.1 Bilingual lexical selection

Languages are produced when the brain retrieves different words (i.e., lexical representations) according to individuals' intention and communication goal. The production of a word begins when seeing an object (or a digit), whereby accessing relevant phonological and lexical representations and selecting the appropriate candidate, so-called lexical selection. When processing system gathers the information of each target lexical representations and them into articulation, such process is called lexical access (Caramazza, 1997; Finkbeiner et al., 2006; Levelt, 1993; 1999). For example, seeing a picture of an apple activates the lexical form of *apple* from the mental lexicon (i.e., a mental sets of words), where it stores all lexical representations in the brain and associate *apple* with its relevant linguistic features such as semantic information and phonological units, which helps an individual delivers the intended word in the corresponding language (Kroll & Ma, 2017). This process, also known as spreading activation, ensures linguistic features are linked to the object and achieves the goal of lexical selection and speech production (Dell & O'Seaghdha, 1992; Peterson & Savoy, 1998).

While all of us can access our lexicons every day because we need to communicate at some point, there is always a situation where bilingual speakers face more complicated language processing stage than monolinguals. Bilingual speakers' neural network tends to be more diverse than monolinguals, leading to some disadvantages (e.g., tip of the tongue and slower reaction times in the dominant language) in language processing (Gollan & Acenas, 2004; Gollan et al., 2005; Palomar-García et al., 2015). For bilingual speakers, they need to choose between two languages because one cannot produce two languages at the same time, and this sometimes is effortful given lexical representations of both languages are activated in parallel (De Bot, 1992, Kroll et al., 2014). That is, the parallel activation is inevitable, resulting in a variety of studies investigating the dynamic nature of bilingual speakers. In bilingual speech production, thus, researchers have proposed different accounts regarding the extent of how the process of lexical selection is achieved during the parallel activation of languages.

Over the past decades, researchers have proposed that bilingual lexical selection is language specific (Blanco-Elorrieta & Caramazza, 2021; Costa & Caramazza, 1999; La Heij, 2005; Roelofs, 1998), while some proposed that it is language non-specific (De Bot, 1992; Green, 1998). The main difference between the two accounts is whether suppression emerges when selecting the target lexical representations and whether one language can facilitate the other (Costa & Caramazza, 1999). The former hypothesis of language specific, the target word and language will be activated and selected at the beginning of speech production (i.e., preverbal stage) regardless of the magnitude of interference. Costa et al. (1999) employed a picture-word interference paradigm (i.e., presenting a target picture to be named alongside a distractor word) with Catalan-Spanish balanced bilinguals. The purpose was to investigate whether the picture could be successfully named in Catalan (i.e., bilinguals' L1) without interference from the distractor word. In one of their experiments, the picture-distractor word pairs were distributed in four conditions: (1) identical (e.g., Catalan-Catalan pair: picture *taula* – word *taula*), (2) translation equivalents (e.g., Catalan-Spanish pair: picture *taula* – word *mesa*), (3) same language (e.g., Catalan-Catalan pair: picture *taula* – word *pernil*) and (4) unrelated (Catalan-Spanish pair: picture *taula* – word *jamon*). The results showed facilitation in Catalan naming when the distractor word was either identical to the picture and was presented in the same language. Furthermore, the facilitation effect was also found in the second condition when the naming language of the picture and distractor words were translation equivalents. Costa and colleagues' assumption supported the notion that lexical selection should be language-specific given the parallel activation of translation equivalents facilitates responses, hence there should be no delay in neither one of the languages (Costa & Caramazza, 1999). However, in their other experiments, as they tested whether semantically related words (e.g., *taula* – *silla*) can affect lexical selection, they found semantic interference (i.e., slower responses) from L2 when naming the picture in L1 (see also Hermans et al., 1998). These results, to some extent, did not support the facilitation effect, but also raised a question regarding the way how bilingual speakers ignore the interference from the non-target language, given bilingual speakers face difficulty to produce the dominant L1 as aforementioned. Hence, some researchers further proposed a language non-specific hypothesis that requires the suppression of the interference.

The premise of language non-specific lexical selection stems from (1) two languages will be activated in parallel, and (2) the interference from the non-target language (Green, 1986, 1998; Norman & Shallice, 1986). In parallel activation, L1, the first language and L2, the second language, interfere with the target language and compete for production. Taking Mandarin-English bilinguals as an example, seeing an apple will activate the Chinese word

(蘋果) and an English word (apple) and their translation equivalents simultaneously. Imagine two boxers are competing, one will have to defeat the other to win the game. Similarly, within the scope of the non-specific selection, languages (on a cognitive level) tend to do this to each other, too. Hence, inhibition is needed to reduce the competition and lower the activation level of the non-target language, whereby selection the target language. However, there is a consequence when inhibition takes place, namely slower responses, contrasting the language-specific hypothesis. What makes the non-specific lexical selection more complicated for bilingual speakers is the process of target language selection. When there is competition, the cognitive demands to select the target language increase given (1) the language processing network will have to strategically reduce the competition and (2) select the target language to achieve the language goal. How does inhibition work through bilingual language processing? These previous studies were based on production in only one language, but bilingual speakers switch between languages very often, making processing more complicated. The magnitude or pattern of interference may vary according to different factors in which language-specific hypothesis cannot answer. Aforementioned studies (e.g., Gollan et al., 2004) revealed slower responses for bilingual speakers encounter when producing the dominant L1. Hence, tapping into the underlying reasons of these "slower responses" for bilingual speakers is the focus of the current thesis. While not fully rejecting the language-specific hypothesis, it is needed to unpack the dynamic nature of bilingual language processing.

In summary, there have been two different theories in bilingual lexical selection, with one that does not support the notion of inhibition (Costa & Caramazza, 1999), but the other one that emphasises on the importance of inhibition (Green, 1998). One thing we need to know is that the former was not based on switching. However, as more studies related to bilingual lexical selection have been conducted over the past decades, we have gained more understandings that there is a cross-linguistic interference from the non-target language when bilingual speakers retrieve lexical representations from target language. Costa et al. (2006), with a language switching study, reported that bilingual speakers (both less and highly proficient) need inhibition to suppress the non-target language. In addition, even when switching is not required, such as Branzi et al. (2014), bilingual speakers still took more time to retrieve their dominant L1 when the stimuli were first named in L2. This then points out the role of inhibition during bilingual lexical selection. How does inhibition work and how is this mechanism applied to reduce cross-language interference via the bilingual cognition? I will explain this in the next section.

1.2.2 Bilingual language control mechanisms

Bilingual language processing is a process that is mediated by a general system called executive control (EC) system. Previous studies have reported that bilingual speakers can perform better than monolingual speakers, highlighting the advantage of speaking two (or more) languages (Bialystok, 2024, but see Paap et al., 2013). One phenomenon is that bilingual speakers are good at switching because their cognitive abilities are more flexible than monolinguals', whereby help them in different environments (i.e., bilingual advantage, Bialystok & Martin, 2004; Dong & Liu, 2016; Prior, 2010, see Van den Noort et al., 2019 for a systematic review). To be able to switch, bilingual speakers need to have enhanced attentional system and the ability to quickly disengage from the current task and switch to another task. Similarly, in language switching, bilingual speakers often need to switch from Language A to Language B, and this process involves several stages enabling the speakers to successfully get to Language B. How do they do this?

When achieving a language goal achieved, EC will then apply the necessary cognitive abilities during the process. In EC, there are quite a lot of cognitive abilities that bilingual speakers are required to have, as difficulties will occur if either one of them is impaired. For example, patients with deficits in a brain region (i.e., basal ganglia) where it takes control of the processing of multiple languages will show more difficulties than the healthy ones (e.g., Parkinson's disease, Cattaneo et al., 2020; Cattaneo et al., 2015, Mild Cognitive Impairment, Calabria et al., 2025). As a result, bilingual speakers must have a strong cognitive ability that helps them take control of their languages and to decide when to select the correct responses, and this ability is called language control. To achieve successful language control, there is an attentional system that distributes necessary mechanisms (Bialystok, 1999). Within the attentional system, several important mechanisms there are conflict monitoring, interference suppression, goal maintenance, task (dis)engagement (Green & Abutalebi, 2013). The attentional system monitors the conflict or irrelevant information that may hinder language processing. When there is an interference, the attentional system will then apply suppression to the it so that bilingual speakers can achieve and maintain the language goal. For instance, when a bilingual speaker is speaking in L2 but suddenly needs to switch to L1, there is a conflict because L1 and L2 are different languages and L1 will interfere with L2 production. As a result, interference suppression here is needed to reduce the conflict to help the bilingual speaker disengage from "producing L1" to engage in "producing L2. Then the language goal of L1 will have to be maintained so that the language goal (i.e., producing L1) can be achieved. All mechanisms are in a collaborative relationship between each other. Nevertheless, interference suppression is particularly important in language control because it can contribute to the "slower responses" of the previously suppressed language, which is why this mechanism is widely investigated across various studies. There is one influential hypothesis supporting interference suppression – Inhibitory Control Model (ICM, Green, 1998).

Inhibitory control includes both processes of selection and inhibition (Bialystok & Craik, 2022). This is a theoretical framework suggesting that during the process of lexical selection, inhibition emerges to reduce interference from the non-target language (Green, 1998, 1986). Inhibition is not only required in language processing, but also our daily tasks, with a larger proportion of prefrontal cortex involved during the inhibitory process (Munakata et al., 2011). For example, when we are concentrating on one task, we need to constantly inhibit the thoughts of doing other tasks, so as when we speak one language. According to Green, inhibition is needed when selecting the target language. As aforementioned, inhibition is operated by an attentional system (in Green's hypothesis, it was called Supervisory Attentional System, SAS) in the lexico-semantic level (i.e., the place where lexical representations are selected and associated with its sematic information), which constantly monitors communication goal and execute cognitive functions. Within SAS, there are language task schemas associating with each language (e.g., producing L1 is L1 language task schema, and same for producing L2), and each language task schema contains lexical forms and representations, which leads to the final selection. In the bilingual mind, switching to another language indicates changing the language task schema, hence SAS needs to constantly check if the current speech production plan is correct for the target language. This often happens when the current task demand of a trial is incongruent with a subsequent trial such as switching (i.e., conflict monitoring). For instance, in real-life, when a bilingual speaker is producing L2 but he/she suddenly realises that it is required to switch to L1, the behaviour of switching from L2 to L1 triggers SAS to increase the activation of L1 and relevant lexical representations, whereby inhibiting the L2 lexical representations.

The magnitude of inhibition, according to Green, depends on bilingual speakers' language proficiency and use, and these bilingual speakers can typically be categorised as "unbalanced bilinguals" and "balanced bilinguals". For unbalanced bilinguals, the mother tongue, also known as the dominant language, L1, receives more activation, making L1 a more proficient language than L2, a foreign non-dominant language. This leads to L1 being inhibited more than L2 when L1 is not in use. On the contrary, L2, the less proficient and foreign language, does not require much inhibition given its lower activation level than L1. For balanced bilinguals (i.e., those who grow up in a bilingual community and speak both languages very frequently), the magnitude of inhibition is the same as their L1 and L2 are equally proficient (e,g., Costa & Santesteban, 2004; Timofeeva et al., 2023). While inhibition is a crucial mechanism in language control, switching between languages still comes with a cost with different amount of inhibition.

This cost is elicited by the time when bilingual speakers need to overcome the magnitude of inhibition, and has first been reported in a study (Meuter & Allport, 1999). In Meuter and Allport's study, they asked a group of dominant L1 bilingual speakers who spoke different second languages to name digits using a language switching task. It was found that switching from L2 to L1 became more costly than vice versa, supporting the hypothesis of ICM. The reason is that, during L2 production (i.e., when L2 becomes the target language), L1 needs to be strongly inhibited as it is the more activated and dominant language than the other. As a result, when L1 becomes the target language again (i.e., switching from L2 to L1), bilingual speakers require more effort to receive activation again as L1 inhibition is strong. In contrast, the magnitude of cost tends to be smaller when switching from L1 to L2 given overcoming the inhibition of the less proficient non-dominant language should not be as costly. The asymmetrical pattern of switch cost (i.e., called switch cost asymmetry or asymmetrical switch cost), in terms of language proficiency and use, has become evidence indicating the different magnitude of inhibition during switching. In other words, with respect to Green's model, Meuter and Allport further added that inhibition is associated with the relative activation of a language, such that the size of the asymmetry becomes smaller when languages receive similar activation, as in balanced bilinguals.

The difference in language proficiency and use that contributes to different patterns of switch cost and inhibition have been reported. For example, in a series of studies focusing on unbalanced and balanced bilinguals, Costa and Santetseban (2004) investigated the switch cost difference between the two groups by using the same language switching paradigm in Meuter and Allport (1999) (except replacing digits with picture). They found that unbalanced bilinguals showed asymmetrical switch cost but the balanced ones showed symmetrical switch cost (see also Campbell et al., 2005). The reason, according to Costa and Santesteban, was because of the unbalanced activation levels of the two languages, such that the magnitude of inhibition becomes different in switching. Another reason was that unbalanced bilinguals are not used to switch languages as balanced bilinguals, causing a greater dependency on inhibition. On the contrary, balanced bilinguals (e.g., those who grew up in Basque country), given their language background which allows them to switch and be exposed to two languages very often on a daily basis, do not depend on inhibition as much as unbalanced bilinguals. Therefore, the activation levels of L1 and L2 should be the equal, whereby benefiting balanced bilinguals to switch easily with less need of inhibition. As an alternative account, Costa and Santesteban suggested that unbalanced and balanced bilinguals' employ different lexical selection strategies to switch. Particularly, unbalanced bilinguals need to depend on inhibitory control to reduce interference (i.e., language non-specific), but for balanced bilinguals, switching production shows lack of inhibitory control (i.e., language specific). Nonetheless, this assumption seems to be inconsistent in another study when Costa et al. (2006) asked balanced bilinguals to switch between different language pairs (e.g., L1-L2, L1-L3, L1-newly acquired language) (see Christoffels et al., 2007, 2016). While they found symmetrical switch cost again when balanced bilingual speakers switch between L2 and L3 (i.e., a weaker language), asymmetrical switch cost, still emerged when switching between L1 and a newly acquired language. The finding shows that despite balanced bilinguals are exposed to two languages every day, their lexical selection in switching does not make them entirely rely on an activation-only mechanism.

To date, the language control mechanism that based on inhibitory control is still highly debated given bilingual speakers' variability and switch cost tends to be different all the time. Some studies have questioned the notion of why bilingual speakers need an inhibitory control to activate the target language and inhibit the non-target one (see Declerck & Koch, 2023 for a review). In recent years, Blanco-Elorrieta & Caramazza (2021) challenged ICM, arguing that bilingual switching should be cost-free without inhibitory control, under either one of the conditions: (1) target language should always be activated, and (2) when target naming stimuli are univalent, with respect to Finkbeiner et al. (2006). First, they claimed that the underlying reason behind switch cost is by forcing bilinguals to switch. For example, many language-switching related studies require bilingual speakers to switch according to a language cue signalling the target language (i.e., cued-switching paradigm). The type of cue can be colours, shapes, or faces. Participants are instructed to follow the cue to switch, meaning the switching process is involuntarily, leading to the switch cost (see Blanco-Elorrieta & Pylkkänen, 2017). In fact, there are other studies using voluntary-switching paradigm and still found switch cost in bilingual speakers (e.g., De Bruin et al., 2018; De Bruin & Xu, 2023; Liu et al., 2019), hence this does not fit well into their notion of cost-free switching performance.

Second, stimulus valence is a relatively interesting aspect that requires more investigations. According to Finkbeiner and colleagues, they argued that inhibition was not necessarily caused by the competition between languages, and in fact, was caused by the multiple activated lexical representations that need to be selected. For instance, when seeing an object (e.g., an apple), Mandarin-English bilinguals will activate words for this object in both languages, and these are called bivalent stimuli. With the activation of translation equivalent by seeing an object, language control mechanism takes time to respond, but this was not found in another switching paradigm in Finkbeiner et al. (2006) who asked bilinguals to name objects were only associated with one language, the univalent stimuli. In Finkbeiner and colleagues' study, they used bivalent and univalent stimuli and asked bilinguals to switch between L1 and L2. The results showed that found that there was no switch cost when the trials involved univalent stimuli, suggesting that when a stimulus is associated with only one language, switch cost should not be observed. As for bivalent stimuli, however, there was greater L1 switch cost, in line with Meuter and Allport (1999). These findings indicated that switch cost was potentially elicited by bivalent stimuli, which, from Finkbeiner and colleagues' perspectives, challenges the inhibitory control theory because inhibition does not exist. The reason is, when selection between languages is not needed, there should be no competition that increases cognitive demands, whereby eliminating switch cost, and Blanco-Elorrieta and Caramazza's supported this assumption. Nevertheless, this account was further tested in some other studies, with bilinguals reading words aloud, by using the real univalent stimuli (i.e., words/letters).

If we explore the two accounts (i.e., voluntary switching and stimulus valence) from another perspective, absence of switch cost is not because inhibition does not exist nor there is no competition between languages. To begin with, we ought to know that when bilingual speakers are allowed to voluntarily switch between languages (especially in code-switching), switch cost does not necessarily have to be present. For balanced bilingual speakers or interpreters, switching between languages is a task they do way more often than unbalanced bilinguals or L2 learners. In fact, they are used to switching, hence very little inhibition is needed. For those speakers who do this all the time, there is a switching benefit, meaning bilingual speakers can be benefited when they switch than when they stay in one language (De Bruin et al., 2018; Gollan & Ferreira, 2009, see also Green, 1998). This benefit often refers to faster responses. As a result, using two languages becomes an advantage in which switch cost is not always observed. Still, this does not indicate that the underlying mechanism is inhibition-free because in a context where language switching is expected, language control mechanism needs to avoid any form of interference so that bilingual speakers will not produce the wrong language.

Additionally, regarding stimulus valence, many more previous studies have shown that cross-language competition emerges even bilingual speakers read words aloud and that parallel activation of both languages will still lead to some extent of cognitive demands. To begin with, the production modality of reading aloud is different from that of naming pictures/digits. The former is a bottom-up processing involving reading univalent stimuli (e.g., words) and the latter involves a top-down processing involving bivalent stimuli (e.g., pictures). Univalent stimuli are unique cue of a language, which in turn largely activates the target language for articulation, comparing to pictures/digits. The bottom-up processing sequence starts from phonological encoding, semantic encoding, then the stage of articulation. Hence, different words (e.g., Mandarin characters versus English words) will promote the encoding process (see also Dijkstra & Van Heuven, 2002). In several previous studies focusing on language switching in bottom-up modality, switch cost was found in all studies, with either asymmetrical or symmetrical pattern (e.g., Declerck et al., 2019; Macizo et al., 2012; Martin et al., 2013; Slevc et al., 2016; Reynolds et al., 2016; Zuo et al., 2022). But why switch cost still emerged even when processing is easier in a bottom-up fashion? Declerck et al. (2019), with a study comparing switch cost in comprehension (e.g., decide whether a number is even or odd, in both German and English) and production (e.g., reading words aloud), assumed that it is the parallel activation behind that always trigger switch cost. Comprehension leads to a more efficient processing speed, while production involves a more complex processing system that the parallel activation will lead to some extent of interference from the non-target language. This means that the non-target language will still be activated (e.g., reading an English word will co-activate its translation equivalent), which will elicit inhibition and switch cost. This does not mean that language control always applies a great amount of inhibition to deal with the interference because sometimes the target language can highly activate itself, whereby reducing the need of inhibition. Here, it shows that the inhibitory process is a dynamic, revealing it is not an all-or-nothing mechanism (Abutalebi & Green, 2008; Green & Abutalebi, 2013).

Up to here, the previous studies have demonstrated that language switching comes with a cost, and this is often caused by the “local inhibition”, meaning the mechanism that deals with a sudden switch from one language to the other. However, this is not the only evidence in language switching demonstrating the presence of inhibition. In fact, bilingual speakers are found to be globally inhibiting their dominant language in order to boost the activation of the non-dominant language. The next section will explain the phenomenon of global inhibition of the dominant language.

1.2.3 Global inhibition in bilingual speech production

We may think that L1 processing should be faster than L2 processing given the higher proficiency of L1, but this is not always the case in language switching (see also Mosca & De Bot, 2017). Another phenomenon that cannot be fully explained within the scope of a competition-free (or cost-free) processing (e.g., Blanco-Elorrieta & Caramazza, 2021) is the "global slowing of the dominant language". This can be found in many (but not all) bilingual production-based studies (see Bobb & Wodniecka, 2013; Goldrick & Gollan, 2023; Guo et al., 2011; Van Assche et al., 2013), which is why the main assumption researchers proposed to date is inhibition. For example, in Van Assche and colleagues' study, they employed a verbal fluency task where two groups of bilingual speakers were instructed to name as many words (either L1 or L2) as possible. Their results showed that bilingual speakers had more difficulties retrieving words in L1 after retrieving words from L2, suggesting that there was global L1 inhibition when producing L2. This global inhibition, in language switching studies, has also been observed, with slower L1 responses than that of L2. Here, I will further explain this finding in bilingual language processing. There is a difference between global inhibition and local inhibition as the former considers the overall performance of a language whilst the latter considers the immediate switching performance of a language (i.e., switch cost). The global inhibition (sometimes called global control, proactive control or reversed language dominance) is often applied to the more proficient dominant language, and this in bilingual speakers, should be L1 (see Declerck et al., 2020).

Over the years, some researchers have shown the effect of global inhibition on the dominant language performance. For example, Branzi et al. (2014) asked Catalan-Spanish bilinguals to name pictures in L1 and L2 in separate blocks without switching. Half of the participants started from naming the pictures in L1 and the other half started from L2. Their findings demonstrated that when bilingual speakers started naming the pictures in L2, L1 performance of the same set of pictures would be hindered, leading to overall delayed L1 performance (i.e., L2 after-effects, see also Ivanova et al., 2022; Wodniecka et al., 2020). In addition, using switching paradigm, some other researchers have also observed this trend in bilingual speakers (Costa & Santesteban, 2004; Costa et al., 2006; Goldrick & Gollan, 2023; Martin et al., 2013; Stasenko et al., 2021, but see Verhoef et al., 2009). Global inhibition has led to a variety of results. For example, in bilingual language processing, it is expected that the overall performance of the dominant language should be faster than the other given its higher proficiency and activation level than the non-dominant language. The non-dominant language, on the other hand, does not inherently receive the more activation than the dominant one, hence its overall performance should be slower than the dominant language. Interestingly, this phenomenon, occurs in bilingual comprehension studies such as lexical decision or word recognition, with no production tasks involved (Dijkstra & Van Heuven, 2002; Mosca & De Bot, 2017). In speech production, faster overall L1 performance can sometimes be found when bilingual speakers are not required to switch, but this is not the case when they are required to do so. One potential reason is that bilingual speakers need to balance the activation for both L1 and L2, hence L1 will have to be globally inhibited benefitting L2 (Christoffels et al., 2007; Timmer et al., 2019).

To date, however, we are still not sure why this global inhibition to L1 emerges given the even more inconsistent findings across previous studies comparing to findings of switch cost. If the L1/L2 activation needs to be balanced to optimise the switching performance, then global L1 should be found in most studies. Recently, Declerck et al. (2020) proposed an interesting assumption regarding which type of bilingual speakers often show globally delayed L1 performance, and these are balanced bilinguals. Comparing to unbalanced bilinguals, balanced bilinguals tend to “over-shoot” (or “over-apply”, see Gollan & Ferreira, 2009) inhibition to the dominant language when they switch. Particularly, activation levels of L1 and L2 do not differ much for balanced bilinguals because they activate both languages very often on a daily basis. Given the small difference between the activation of the two languages, balanced bilinguals often apply too much inhibition towards L1 to benefit L2, leading to slower globally delayed performance. Nevertheless, for unbalanced bilinguals, the activation levels of L1 and L2 largely differ (e.g., high L1 and low L2) as the former is more activated than the latter, hence they rely more on local control which often leads to asymmetrical switch cost. Hence, the previous studies regarding global inhibition here show the dynamic nature in language control. The pattern of inhibition can be largely modulated, and from these findings, it is difficult to deny the presence of inhibition as even balanced bilinguals cannot always merely rely on activation despite they use both languages frequently. With respect to Declerck et al. (2020), language control in switching involves the global inhibition of L1. However, the reason behind this mechanism requires more investigations given (1) bilingual speakers share a variety of language experience and (2) switch cost should not be the only consequence in language switching. To date, researchers have revealed the baseline phenomenon in switching, namely language competition between the two languages (contrasting Blanco-Elorrieta & Caramazza, 2021) and the consequences when switching takes place (both switch cost and overall delayed response).

In the current section, previous studies have demonstrated the potential effect of language proficiency and use and how switching can lead to delayed responses. While proficiency is an important account (since bilingual speakers with very low L2 proficiency will have very limited ability to switch), what requires more investigations is the way how bilingual speakers adapt themselves in different switching context. In most language switching studies, the results would always highlight the fact that bilingual speakers are good at switching languages flexibly. But how flexible are they? Hence, the next section will unpack the theory behind the flexibility and adaptability of bilingual speakers in different language contexts.

1.2.4 The adaptive control mechanisms of bilingual speakers

Bilingual speakers can adapt the cognitive abilities to achieve different linguistic or non-linguistic tasks as the environment shapes their minds and executive function (see Bialystok, 2024). When it comes to the flexibility of bilingual speakers, a variety of language behaviour has been reported. One aspect is how bilingual speakers adapt themselves when they are required to switch. To that end, extending from Green (1998), Green and Abutalebi (2013) proposed Adaptive Control Hypothesis (ACH) focusing on not only the use of cognitive abilities within bilingual speakers, but also the different contexts modulating the corresponding mechanisms. The ACH includes three types of language contexts: single-language context, dual language context, and dense code-switching context. The single-language context requires only one language, hence no switching is involved. This occurs to bilingual speakers who use their L1 at work and L2 with their families, but this is different from dual-language context. Dual-language context refers to the use of two languages within one context. This language processing in this context emphasizes more on the language cue. For example, a bilingual speaker speaks L1 to a person but switch to L2 for another person. The dual-language context allows participants to switch language but this “switching” is different from dense code-switching context. In dense-code-switching context, bilingual speakers often intermix L1/L2 words within a sentence (e.g., I went to 公園 (the park) today), while dual-language context expects them to produce one language at a time without intermixing. According to ACH, there are eight control processes involved in the three contexts: goal maintenance, interference control, salient cue detection, selective response inhibition, task disengagement/engagement, opportunistic planning. The magnitude of the control processes differs in the three contexts and each control process has its role in language processing (see Table 1.1 below, adapted from Green & Abutalebi, 2013).

Table 1.1. Eight control processes and the corresponding role in ACH (Green & Abutalebi, 2013)

Control process	Corresponding role	Single-language	Dual-language	Dense code-switching
Goal maintenance	Maintain and achieve the language goal	+	+ +	=
Interference control	Detect and suppress the interference	+	+ +	=
Salient cue detection	Identify the cue for the target language and decide whether switching is necessary	=	+	=
Selective response inhibition	Stop the response in one language when switching is needed	=	+	=
Task disengagement	Disengage the speaker from speaking one language	=	+	=
Task engagement	Navigate the speaker to process the new target language	=	+	=

Opportunistic planning	Help the speaker intermix L1/L2 words within one utterance	=	=	+

Each symbol in the table represents the use and magnitude of the control processes: “+” means when the control process is active in that context, “+ +” means the increasing magnitude of the control, and “=” means when the control remains inactive.

Of all the control processes, according to Green and Abutalebi (2013), interference control is one of the main mechanisms. The interference control refers to conflict monitoring and interference suppression, and these two components are indeed required in language switching. Here the ACH complements the ICM using inhibition as the foundation. In ICM, Green (1998) highlighted the importance of L1/L2 language proficiency and use such that on one hand, bilingual speakers with lower proficiency requires greater inhibition to suppress the activation of the dominant language, leading to asymmetrical switch cost. On the other hand, bilingual speakers with high proficiency apply inhibition equally to both languages, showing symmetrical switch cost. Moving forward, ACH situates on the adaptable cognitive mechanisms of bilingual speakers, which provides a broader interpretation to bilingual language processing. For example, ACH considers inhibition to be more crucial in single-language and dual-language contexts, but not dense code-switching. The reason is that, as aforementioned, bilingual speakers who code-switch a lot, the magnitude of inhibition decreases significantly because they switch very often and inhibiting one language and the other does not make code-switching efficient. However, for single-language and dual-language context, inhibition is needed more given switching is not as freely and frequently as in code-switching. Thus, inhibiting the non-target language to avoid interference helps promote the language performance. One might wonder why in single-language context still requires inhibition to be active. Imagine an L2 learners (dominant in L1) need to speak L2 to their colleagues, L1 will constantly interfere with L2 production, leading to L1 inhibition to avoid the interference. Still, the magnitude of inhibition is the greatest in the dual-language context, and is the most complex language context bilingual speakers can encounter. In other words, the dual-language context resembles the language-switching studies and is a context where the most cognitive controls are required, leading to the most cognitive demanding context. Therefore, the cognitive ability to solve interference in dual-language context increase given the frequency of processing two languages (see also Wu & Thierry, 2013 comparing conflict monitoring in single-language and dual-language context).

As aforementioned, dual-language context resembles the paradigm in most language-switching studies. Because of the methods, the language control and cognitive demands of bilingual speakers are different across studies. Nevertheless, researchers have not focused much on the nature of bilingual language control within different ratio of L1 and L2 in separate dual-language context. In fact, mostly they investigated either (1) the difference between single-language and dual-language context with 50% L1 – 50% L2 (e.g., Christoffels et al., 2007; Costa & Santesteban, 2004; Declerck et al., 2019; Gollan & Feirreira, 2009; Ma et al., 2016; Timofeeva et al., 2023) or (2) difference between two single language contexts (e.g., Branzi et al., 2014; Misra et al., 2012; Wodniecka et al., 2020; Van Assche et al., 2013). Since bilingual language control mechanisms are highly adaptable, it is necessary to further explore how they perform within different dual-language contexts. Interestingly, Timmer et al. (2019) conducted a cued-switching study based on this issue with Dutch-English bilinguals. They manipulated the ratio of L1 and L2 in two dual-language context. Namely, in one context, the participants were instructed to name 75% of the pictures in L1 (i.e., context L1) and the same ratio for L2 in the other context (i.e., context L2). Their results showed that the pattern of switch cost was symmetrical for context L1 and reversed asymmetrical switch cost (i.e., greater L2 switch cost) for context L2. Furthermore, they found global L1 slowing in context L1 only. This demonstrated the adaptability of bilingual speakers within each dual-language context and importantly, the dynamic nature of bilingual language control. Elaborating more on Timmer and colleagues' results, even unbalanced bilinguals (though highly proficient in L1 and L2 but not similar to balanced bilinguals) could show symmetrical switch cost as well as global inhibition to L1. This then raises a question towards Declerck et al. (2020) regarding the effect of language proficiency (e.g., unbalanaced bilinguals versus balanced bilinguals) on the tendency of global inhibition to the dominant language. As a result, the ratio of L1 and L2 in each dual-language contexts shed light on the different switching performance of bilingual speakers. Does this indicate unbalanced bilinguals also "over-shoot" inhibition to the dominant language (as in Declerck and colleagues' assumption) or alternatively, does this simply indicate the effect of each dual-language context on switching, whereby modulating language activation and inhibition (as in Christoffels et al., 2007)? The current thesis, thus, will further investigate the effect of different dual-language context on bilingual switching performance.

In summary, language switching studies in the past have adopted the dual-language context as in Green and Abutalebi (2013). However, only a few studies were conducted to explore the difference ratios of L1 and L2 and the underlying mechanism. In ACH, it is apparent that bilingual language processing involves a variety of control processes depending on the context one is exposed to. This then motivated the current thesis to tap into the effect of language contexts on switching performance. So far, while inhibition is required to reduce interference upon encountering a switch, some studies have pointed out that a switch can be prepared, whereby reducing the magnitude of inhibition. In the next section, I will discuss the preparation of bilingual language processing.

1.2.5 The preparation of bilingual speech onset

Previous studies related to language switching often focused on how bilingual language control deal with an immediate switch. Therefore, switch cost and global L1 slowing reflect the effort when bilinguals overcome inhibition and benefiting the non-dominant language, respectively. These previous studies indicated the fact that bilingual language control is flexible, but what requires more investigations is how the control processes are prepared before speech onset. In language processing, individuals (both monolingual and bilingual speakers) are able to predict an upcoming event by seeing a cue in advanced, whereby influencing their performance (Gisladottir et al., 2018; Jończyk et al., 2019; Rohenkohl & Nobre, 2011). According to ACH (Green & Abutalebi, 2013), the control process of salient cue detection in dual-language context here plays the role of detecting a language cue and signal the processing system for the target language. In a language switching scenario, for instance, the language cue can be either a person's face, a country's flag, or a geometric shape. When an English person walks in, the target language will then be activated by this person's face, whereby signalling the corresponding controls such that English (and the controls responsible to form an English language goal) can be prepared and produced. Hence, the ability to be able to detect a cue is important because any form of failure will lead to inaccurate speech production. This highlights the fact that bilingual speakers' language processing system can prepare for an upcoming speech, and in language switching studies, this indeed has been tested (Costa & Santesteban, 2004; Philipp et al., 2007; Ma et al., 2016; Mosca & Clahsen, 2016; Mosca et al., 2022).

The paradigm testing bilingual speakers' predictability to a language event is called pre-cuing (or cue-to-stimulus interval), but here I call this "pre-activation". To being with, the paradigm is manipulated by presenting a language cue a few milliseconds before a target picture to be named. Therefore, when presenting a cue beforehand, the target language will be pre-activated, hence this is a pre-activation stage before speech onset. According to the previous studies, this pre-activation stage affects the magnitude of inhibition and pattern of switch cost (Costa & Santesteban, 2004; Fink & Goldrick, 2015; Khateb et al., 2017; Ma et al., 2016; Monsell & Mizon, 2006; Mosca & Clahsen, 2016; Mosca et al., 2022; Verhoef et al., 2009, 2010). Some common phenomena in language switching when pre-activation takes place is (1) switch cost reduction and (2) switch cost pattern transition (i.e., from asymmetrical switch cost to symmetrical switch cost). Comparing to simultaneous language-picture presentation, this method is indeed interesting because it teases apart the pre-activation stage of the target language and production of the target language, which enables language control to largely reduce interference from the non-target language. In real-life, when a bilingual person is going to an event where most attendees are L2 native speakers, he/she will have to inhibit L1 and pre-activate L2 beforehand, leading to facilitation of L2 performance. Similarly, when switching between L1 and L2 by pre-activating the target language, switch cost pattern may become different and modulate the language outcome.

In a study investigating unbalanced and balanced bilinguals, Costa and Santesteban (2004) used two paradigms: presenting a language cue alongside a target picture as well as presenting a cue 500 and 800 milliseconds before a target picture. Comparing to simultaneous cue-picture presentation, they found that presenting a target language cue before a picture can reduce the magnitude of switch cost (i.e., switch cost reduction). Switch cost became smaller but remained asymmetrical for unbalanced bilinguals but symmetrical for balanced bilinguals. Note that this was also why Costa and Santesteban suggested the effect language proficiency on bilingual speech production (i.e., unbalance bilinguals always showed asymmetrical switch cost, balanced bilinguals always showed symmetrical switch cost) (see also in Ma et al., 2016 as they found asymmetrical switch cost in their Mandarin-English bilingual speakers). Nevertheless, as aforementioned, language proficiency cannot be considered the only factor contributing to different switch cost patterns, which in later studies, unbalanced bilinguals showed symmetrical switch cost at a longer pre-activation time (e.g., Khateb et al., 2017; Verhoef et al., 2009, but not in Ma et al., 2016 where they found reduced asymmetrical switch costs across all pre-activation intervals). In a recent study, it was reported that pre-activation can eliminate switch cost, meaning language switching can be cost-free for bilingual speakers (Mosca & Clahsen, 2016; Mosca et al., 2022).

With respect to a study, Mosca and Clahsen (2016) and Mosca et al. (2022) took a step further by, again, using different short intervals for pre-activation. The former was the first study reporting switch cost elimination within 800 milliseconds of pre-activation. The latter study, with even shorter interval between a language cue and a picture, switch cost again completely disappeared within 250 milliseconds of pre-activation. In contrast to most previous pre-activation studies, Mosca and colleagues proposed an interesting finding, whereby challenging the classic theory of inhibitory control. This indicates language switching can potentially be a cost-free production, and importantly the competition between L1 and L2 can disappear within such a short interval. One aspect we ought to examine is whether pre-activation is powerful enough that it can cope with the "hard problem" in which both languages compete for selection (Finkbeiner et al., 2006). If 250 milliseconds was enough to eliminate language competition whereby causing an lexical selection, then this would mostly solve this hard problem when bilinguals switch languages. For instance, imagine seeing an English native speaker coming and a bilingual person needs to immediately switch to the same language. The behaviour of "seeing" an L2 native speaker coming and the time to wait for this person arrives in front of a bilingual person is certainly longer than 250 milliseconds. According to Mosca and colleagues' findings, thus, switching between L1 and L2 would become very easy for bilinguals.

With respect various studies using pre-activation, the magnitude of inhibition can be modulated across studies. Particularly, some bilingual speakers adopted greater inhibition while others did not. Hence, switch cost can sometime be reduced or eliminated. If pre-activation can promote the process of switching, then this means that the underlying mechanism can be prepared before speech onset. To date, the effect of pre-activation on bilingual language control has been reported in previous behavioural studies. The literature in language switching, however, is still missing evidence regarding how the brain prepares for the inhibitory process before speech onset (i.e., before switching). The next section will introduce the relevant studies using brain imaging approaches.

1.2.6 The cognitive mechanism of the bilingual brain

In addition to behavioural studies, the association between bilingual language processing and inhibitory control has been investigated through EEG (e.g., Branzi et al., 2014; Chauncey et al., 2011; Declerck et al., 2021; Jackson et al., 2001; Christoffel et al., 2007; Kang et al., 2021; Kroll et al., 2008; Martin et al., 2013; Misra et al., 2012; Li et al., 2017; Liu et al., 2018; Liu et al., 2024; Liu et al., 2019; Timmer et al., 2017; Timmer et al., 2019; Timmer et al., 2021; Verhoef et al., 2009, Wodniecka et al., 2020, see Cespón & Carreiras, 2020 for a review), fMRI (e.g., De Bruin et al., 2014; Guo et al., 2011, Li et al., 2013; Reverberi et al., 2015; ; Zhang et al., 2015; Zhang et al., 2024; see Luk et al., 2012 for a meta-analysis), and MEG (e.g., Blanco-Elorrieta & Pylkkänen, 2015, 2016; Timofeeva et al., 2023; Zhu et al., 2022). There are several regions that are associated with the cognitive mechanisms. For example, the prefrontal cortex and anterior cingulate cortex are two important brain regions in language processing, and the executive functions both regions are responsible for are selection/inhibition and conflict monitoring (Abutalebi et al., 2012). Other cognitive abilities such as working memory and goal maintenance belong to the parietal cortex (see Abutalebi & Green, 2007, 2008). De Bruin et al. (2014) linked the right inferior frontal gyrus and pre-supplementary motor area with inhibitory control. In a study with a group of Dutch-English-German trilingual speakers (dominant in Dutch) and a cued-switching paradigm involving, they found that these two brain regions were more activated when the participants switch to their non-dominant language, suggesting greater inhibition was triggered to suppress the dominant language.

Different from fMRI, EEG studies has become a popular way to explore the brain activity at a time point. Most of them focus on the post-stimulus language processing. Over the years, indeed, EEG studies have supported the inhibitory process of the brain, with event-related potentials (ERPs) and oscillatory evidence (Rossi et al., 2023). A classic ERP component in bilingual language processing (i.e., N400, a post-stimulus negative amplitude that peaks around 400ms) has been traditionally associated with difficulty in semantic processing. More recently, N400 has been interpreted as indexing incongruity with lexico-semantic expectations during language processing. For example, when switching takes place, a greater magnitude of N400 can be found because switching from one language to the other develops cognitive demands, hence leading to greater N400 (Kang et al., 2021). Furthermore, some ERP waveforms in N200 (i.e., negative amplitude that appears around 200ms) have been reported to show switch cost. Jackson et al. (2001) found a stronger N200 effect when bilinguals switch to L2 than to L1. This then indicated that L1 was strongly inhibited for L2 production, causing greater L1 switch cost. However, findings regarding N200 have been diverse. For instance, Christoffels et al. (2007) did not report the same finding as N200 effect for non-switch trials in their study, hence N200 did not relate to switch cost. Some other studies, such as Martin et al. (2013), showed that N200 pattern was largely dependent on bilinguals' age of acquisition (i.e., early bilinguals showed no difference in N200 waveforms when switching between L1 and L2 as well as L1 and L3), but still, they did not observe the association between N200 and switch cost. In addition to N200 effect with switch cost, some researchers also investigated Late Positive Component (LPC, a post-stimulus positive amplitude that peaks around 400-600ms) to reveal cognitive demands during switching (e.g., Martin et al., 2013; Liu et al., 2016; Timmer et al. 2019). For example, Martin and colleagues observed that there was greater LPC effect in switch than non-switch trials, meaning the former should be more cognitive demanding than the latter (see also Jackson et al., 2001). As suggested by Martin and colleagues, studies should also focus on how LPC associates with switching and overall language performance. To that end, Timmer et al. (2019) conducted a study based on language context and reported stronger LPC in L2 production than in L1 production in L1-predominant context but not in L2-predominant context. As aforementioned, Timmer and colleagues found bilinguals largely relied on global L1 inhibition in L1-predominant but not in L2-predominant. This finding explained the phenomenon when bilinguals produced L2, L1 needed to be strongly and globally inhibited.

Researchers have also explored the “rhythm” of the brain – oscillations. Oscillations are measured using a time-frequency analysis (TFA) to tap into how the brain behaves over a time period. In domain-general cognition, researchers have focused on oscillatory signatures such as alpha (8-13 Hz) and theta power (4-7Hz), whereby linking these two components to inhibition and general cognitive control (Jensen et al., 2010, Klimesch et al., 2007). In particular, Bice et al. (2020) used a resting-state approach to investigate bilingual and monolingual speakers, with a variety of language experiences (e.g., age of acquisition, L1/L2 proficiency). They reported that bilingual speakers showed higher alpha power than monolingual speakers, with a greater influence related to language proficiency and L1/L2 use. This then further reflects the inhibitory control ability of the bilingual speakers, meaning the higher L2 proficiency, the higher alpha power. Theta power has been associated with a more general cognitive ability in interference and conflict monitoring. For example, in a

Go/No Go task (i.e., a task in which participants need to respond when they are cued to do so, but suddenly need to stop when they see a stimulus that does not require any responses), Nigbur et al. (2011) revealed a more activated theta power when participants encountered a "No" task after constantly giving responses. Furthermore, Nigbur and colleagues observed a similar magnitude of theta power in a flanker task (i.e., a task that participants need to decide whether a string of arrows are all presented in the congruent or incongruent direction). Their results showed that greater theta power emerged in the incongruent condition. This approach has been less used in bilingual language switching and cognitive control, which researchers encourage that it is time to move on to explore the brain to grasp thorough picture of neural mechanism behind language control (Rossi et al., 2023). To date, there are two studies looking into oscillations during switching (Liu et al., 2017 using EEG, Timofeeva et al., 2023 using MEG). Liu and colleagues' study was the first one investigating theta power in less-proficient Mandarin-English bilinguals. They tested their participants' inhibitory ability with a Simon task, and further divided them into two groups (i.e., one with lower inhibitory ability and the other one with higher inhibitory ability). Using a cued-switching study, Liu and colleagues found that the participants in the first group showed higher theta power than the other when switching from L1 to L2. In addition, they showed symmetrical switch cost, whereas the other participants (i.e., low inhibitory ability) showed asymmetrical switch cost. Their study suggested that participants with higher inhibitory ability were able to balance the effort to switch between L1 and L2, meaning these bilingual speakers have higher cognitive flexibility to apply inhibition (as shown in the theta band).

So far, we understand that inhibitory control emerges when there is a conflict between languages, and bilingual speakers need to rely on this mechanism more than monolingual speakers. Luk (2012) also indicated that a language cue can proactively activate the target in the pre-SMA area. However, little is known is how, in a switching environment, the bilingual brain prepares for either L1 or L2 production with the help of inhibitory control. As the aforementioned behavioural studies indicated, there is switch cost reduction when the target language is pre-activated, meaning inhibitory control can be pre-applied before speech onset. That is, if pre-activation can help the brain proactively predict and reduce cognitive demands, this will then indicate that inhibition is elicited before producing the target language for less costly switching. Hence, when bilingual speakers produce either L1 or L2, the magnitude of inhibition upon seeing a language cue requires more investigations. The question we ought to focus on is: “How does the brain predicts, and how does the pre-activation process differ between L1 and L2 switch/non-switch production?”

Contingent negative variation (CNV) is a negative amplitude showing the anticipatory stage of the target stimulus and more broadly, the motor preparation of the brain (Walter et al.,1964). This is an ERP component that has been investigated in previous switching-related studies showing the proactive anticipatory ability of individuals and the effort to prepare for and promote the performance of an upcoming task. This can be done by cueing participants to prepare for a target stimulus to facilitate the target response. For example, CNV activity has been found to be reduced for older adults compared to younger adults (Gajewski et al., 2010). Gajewski and colleagues asked a group of younger and a group of older adults to switch between digit categorisation tasks (e.g., identify (1) whether a digit is odd or even, (2) whether a digit is greater than 5). The results showed that older adults showed longer reaction times for the target trial and less CNV activity than younger adults, highlighting younger adults’ flexible proactive control mechanism. The relationship between CNV and proactive control mechanism has been investigated in previous studies from a domain-general perspective (e.g., see Cudo et al., 2018, Lu et al., 2025, Schröder et al., 2024, and Shen et al., 2018 using AX-CPT). As the brain can proactively react to an upcoming task to reduce the effort for a target stimulus, how does the brain proactively elicit language control mechanisms?

The inhibitory mechanism can be proactively applied to the non-target language when switching is required, and this indicates the task engagement/disengagement of languages. For example, in a language switching study, Verhoef et al. (2010) presented a language cue 750ms before the target stimulus. Their findings showed that in the pre-stimulus stage, there was a late anterior negativity (around 350ms – 500ms) when an upcoming stimulus involves an L2 naming trial comparing to an L1 naming trial, especially when the current naming language was L1. The greater negativity was elicited when the bilingual participants know they needed to switch away from L1 to engage in L2, leading to greater effort of preparation for L2 production. The same results were also reported in Blanco-Elorrieta et al. (2018) where the researchers found disengaging from L1 to engage in L2 requires greater activation of certain brain areas in an MEG study. While the previous studies did not specifically label the "greater effort for L2 preparation" to CNV, the time window where the negativity appeared could possibly be a CNV activity, and this was reported and confirmed in a later study by Wu and Thierry (2017). According to Wu and Thierry, the preparation of L2 production requires more effort than L1 production. Given the inherently higher activation of the dominant L1, the effort to prepare for L2 production increases (i.e., strong inhibition towards L1). Wu and Thierry's findings highlighted the proactive control mechanism during language production. Linking their results to the above mentioned two studies, the pre-stimulus brain activity can reflect the proactive control processes of production. Hence, it is necessary to carry out a further study to explore the relationship between proactive language control and the frequency of language use in a given context.

In a study, Wu and Thierry (2017) was the first to demonstrate the pre-activation stage (i.e., pre-stimulus) of L1/L2 production, using contingent negative variation (CNV) as the target ERP component. CNV is a negative amplitude indicating the anticipation stage of the brain before a response is made. That is, this ERP component shows how the brain anticipates an upcoming target stimulus (i.e., pre-stimulus activity, Hoxha et al., 2023). Wu and Thierry's study is the first study showing inhibition before L1/L2 speech production. In their study, bilingual participants were asked to name different pictures according to a language cue presented before a target stimulus. The language cues were presented 1000ms prior to the target picture, and this method was same as previous studies using pre-activation intervals (Mosca & Clahsen, 2016; Mosca et al., 2022). Note that this study was different from language switching studies as they did not ask their participants to switch. This was done by interleaving the L1 and L2 naming trials with several non-naming trials where participants did not have to make any responses. While Wu and Thierry's study did not focus on language switching, the results were particularly interesting. When bilinguals saw an L2 cue and knew they needed to name the picture in L2, there was deep CNV waveform than seeing an L1 cue. This finding, supporting Green (1998), suggested that when bilinguals needed to name an upcoming picture in L2, the brain would have to elicit strong inhibition towards L1. This finding was in line with the classic theory of inhibitory control, whereby verifying the presence of inhibition even when bilinguals were not switching between languages. Their results were also in line with Luk et al. (2012) indicating that presenting a cue in advance can help the brain execute necessary language control proactively. Unfortunately, EEG evidence in language switching studies (both with production-based and comprehension-based tasks) have not yet answered the pre-activation stage of the target language in a way of how inhibitory control process is being prepared before speech onset. For example, switching from L2 to L1 is more cognitively demanding than vice versa, but if this magnitude of effort can be reduced by pre-activation, the cognitive mechanism of the brain might also exhibit similar results. Moreover, within different dual-language contexts, little is known of how the brain adapts to optimise the efficiency of language control. With respect to Timmer et al. (2019), the literature should take a step forward to unpack how language context shapes the function of the brain. Timmer and colleagues have established an example of how the brain performs differently in an L1-predominant context and L2-predominant context.

While ERP provides detailed information of time-locked about brain responses, it can sometimes miss the ongoing, sustained dynamics engaged in language processing, and this is where oscillatory activity becomes useful. In brain oscillations, alpha frequency band has been associated with inhibition of irrelevant information. Theta frequency band has been linked to the engagement of cognitive control processes (e.g., conflict monitoring). These two frequency bands can particularly index the process of language processing during switching (Timofeeva et al., 2023). For example, bilingual speakers need to suppress the irrelevant non-target language, and this requires inhibitory control to be at play. At the same time, they also need to constantly detect conflict/competition between languages, which requires increasing conflict monitoring during switching. Both alpha and theta can potentially complement the ERP components such as post-stimulus N200 and pre-stimulus CNV, whereby highlighting the engagement and dynamics of language control processes (within a time window) when switching between L1 and L2. To that end, in this thesis, I aim to further investigate whether the CNV pattern can be modulated by L1 and L2 switch/non-switch production and overall L1/L2 performance.

1.3 Summary

In summary, previous studies have investigated bilingual language processing in a variety of ways, with an emphasis on bilingual speakers' cognitive abilities. One impressive ability is interference control, where inhibition takes place and suppress the irrelevant information. To explore the suppression of interference, language switching task is often used to measure the speed switching between L1 and L2. In the past, researchers (e.g., Costa et al., 2004; Meuter & Allport, 1999) observed asymmetrical switch cost and revealed the effect of language proficiency and use on language processing, but as the number of studies increase over the years, more factors contributing to switch cost asymmetry have been reported. Most language switching studies only employed one type of dual-language context (i.e., 50% L1 – 50% L2), but it is apparent that this should not be the only type of language context if we intend to unpack the dynamic of bilingual language processing. To that end, what is still missing in the literature is how bilingual speakers perform in dual-language context, especially when the L1/L2 ratios and use tend to be different within each context. Timmer et al. (2019) has made a good start on investigating language context effect, but more investigations are required to explore how inhibitory ability differs in each context. In addition, many language switching studies have shown inhibitory control before having to respond to a stimulus, but no one has investigated the how the brain prepare and execute these mechanisms. Wu and Thierry (2017) demonstrated a good example of CNV, but unfortunately, no language switching studies to date have looked into this pre-stimulus ERP component. As it is apparent that the magnitude of inhibition can be affected in pre-activation, I took a step further by not just looking into the behavioural results, but also the brain activity before speech onset. Taken together, this will help complement the current literature, and importantly, encourage future studies to explore the cognitive (or neural) mechanisms of bilingual language processing. In the next section, I will explain the method of the series of studies and the research questions I intended to address.

1.4 The current thesis

As aforementioned, the focus of the current thesis is language context as we observed that pervious literature did not discuss much related to from this aspect. Therefore, in a series of studies with language switching, I manipulated the ratios of L1 and L2 and develop different types of dual-language context. In addition, with EEG analysis, the current thesis will contribute to the field of bilingualism in terms of the preparation stage of the brain. As a result, with respect to Wu and Thierry (2017), I investigated CNV before speech onset.

1.4.1 Methodology and research questions

Over the years, with language switching tasks, researchers have been keen to investigate the underlying language control mechanism during bilingual speech production. This is done by asking bilingual participants to switch between languages based on a cue that signals the target language, so-called cued language switching. I am fully aware that throughout the previous studies, cued-switching paradigm is not the only type of paradigm given some researchers also used a voluntary-switching (i.e., participants can use either L1 or L2 whenever they prefer, but they were also instructed to switch during the experiment) (Blanco-Elorrieta & Pylkkänen, 2017; De Bruin & McGarrigle, 2023; De Bruin et al., 2018; Gollan & Ferreira, 2009; Kleinman & Gollan, 2016; Zhu et al., 2022).

In the current thesis, I chose cued-switching paradigm alongside to measure bilingual language control mechanisms. The reason is that cued switching paradigm enabled us to investigate the behaviour of switching immediately postulating a conflict as speakers need to immediately disengage from the current language and engage in the upcoming target language. Resembling the dual-language context, this then signals the brain to exert necessary control mechanisms (Green & Abutalebi, 2013). To that end, cued-switching paradigm becomes a popular for researchers to investigate the association between conflict monitoring and interference control. In real-life, there is always an occasion where participants need to immediately switch from one language to the other. As a result, cued-switching paradigm can create a similar switching environment for bilingual speakers. Using this paradigm, the reaction times (i.e., time in milliseconds when the participants respond to the target stimulus) are calculated to test if there is a delay when switching to another language. The importance of observing the delay provides evidence of inhibition, whereby implicating the how bilingual speakers achieve flexible language switching without interference from irrelevant information.

As language context is the central part of the thesis. In a series of studies, I manipulated ratio of L1 and L2 in each dual-language context. In particular, in each experiment, Mandarin-English bilingual speakers were instructed to do a cued-switching task in three different contexts: “L1-predominant or Context L1” (i.e., participants named most of the pictures in L1), L2-predominant or Context L2” (i.e., participants named most of the pictures in L2, as well as “Balanced” context (i.e., participants named half of the pictures in L1 and the other half in L2). Note that I only used Balanced context once in an experiment because this context was considered a baseline of bilingual speakers’ switching performance. The contexts I was more interested in were the other two. In addition, in the current thesis, I used face cues to signal the target language for each target stimulus (see also Blanco-Elorrieta & Pylkkänen, 2017; Liu et al., 2018; Timmer et al., 2024). The reason is that in previous studies mostly used either colours, flags or shapes in cued switching, but this method is problematic. The reason is that bilingual speakers do not switch languages according to these symbols, and these may conflate switching effect. In real life, bilinguals switch to another language when they see a person who do not speak the same language as they do. As a result, using face cues would create a more realistic switching environment for bilinguals, and importantly, this would avoid switch cost conflation (Blanco-Elorrieta & Pylkkänen, 2017).

It is also noteworthy that in each of my studies, I minimised the repetition of each naming stimulus. The reason is that researchers in the past tend to repeat pictures many times in an experiment. This was done by familiarising participants with the stimuli beforehand or by asking participants to name a stimulus more than four times throughout the experiment. However, this could lead to facilitation effect on reaction times (Wodniecka et al., 2020). Indeed, using the same stimuli many times can largely reduce inaccuracy rate, such that researchers do not need to exclude many trials from analysis. However, what I observed in my studies was that, most of the participants could still be accurate, meaning that researchers need to trust their participants in a way that they can perform well in an experiment and that picture repetition needs to reduced. Hence, in the current thesis, I repeated each critical only twice, once in one context, and once in the other context.

Finally, the methodology of the current thesis involves an EEG study. Behavioural studies can only indicate the statistical differences between L1 and L2 language performance. Hence, taking a step further to explore how the brain works is essential and can potentially complement the other behavioural studies in the current thesis. Mandarin-English bilingual speakers were invited to the EEG lab to complete a cued-switching study, with brain activity being recorded. As aforementioned, the key finding in Wu and Thierry (2017) was that there was strong CNV effect when bilinguals produce L2, indicating greater L1 inhibition before L2 production. Furthermore, I also investigated the classic ERP component such as N200 and N400 to test if there was a semantic processing difficulty when bilingual speakers switch between L1 and L2. More importantly, these two components would also indicate whether language context can modulate participants' ERP patterns.

From the perspective of language context and the cognitive mechanisms behind language switching, there are three research questions I intend to address in language switching. The questions are as follows:

1. How does language context affect bilingual switching production?

To address this question, I carried out a study using language switching to explore the nature of bilingual language control. I employed language switching task with pictures and another language switching task with words in two separate experiments to further complement the findings on the effect of language context. I predicted that language context would affect the pattern of switch cost and overall L1/L2 performance. In a context where L1 is the predominant language, asymmetrical switch cost should be observed, but in a context where L2 is the predominant language, symmetrical switch cost should be observed.

2. How does pre-activation affect bilingual language switching in different dual-language contexts?

To answer the effect of pre-activation and language context, I first used a pre-activation interval with only 250ms given this was the shortest interval to observe switch cost pattern in Mosca et al. (2022). With the manipulation of language context, the current thesis can further testify whether switch cost pattern and overall performance can be consistent (or not) as when pre-activation is not given. I predicted that switch cost pattern will be affected by pre-activation (e.g., reduced switch cost). However, since language context was expected to play a role during switching, the pattern should remain the same as when pre-activation is not allowed.

3. How does language context affect the pre-activation stage of the brain?

This question builds on the results from the first and the second questions. If switch cost can be reduced using pre-activation, then it is necessary to explore the cognitive mechanisms before speech onset. This question is particularly important given I conducted an EEG study focusing on CNV to explore the nature of inhibitory control. There is no language switching study investigating CNV, hence the predictions were made according to Wu and Thierry (2017). I predicted that CNV pattern should be different when switching between L1 and L2. In particular, switching to L2 should yield greater CNV than switching to L1.

1.5 Thesis structure and rationale for alternative thesis submission

The current thesis is presented with an alternative format. The core question we intended to answer is "How language context affects bilingual speech production?" and "How do bilinguals adapt to different language contexts?" Each manuscript contains independent experiment(s). There are three manuscripts in total, followed by a discussion and a conclusion section at the end of the thesis.

Manuscript 1 contained two behavioural experiments and focused on the effect of language context and production modality on language switching. With cued switching paradigm, I used a picture naming task in the first experiment. I employed three language contexts, namely context L1 (i.e., naming 75% pictures in L1), context L2 (i.e., naming 75% pictures in L2), and balanced context (i.e., naming half pictures in L1 and the other half in L2). In the second experiment, I used a read words aloud (i.e., Chinese characters and English words) task to measure the magnitude of inhibition, whereby illustrating how much inhibition bilinguals needed in a switching environment in comparison to picture naming. The ratio of L1 and L2 remained the same as in the first experiment, but I replaced picture with words.

In Manuscript 2, with language context manipulation, I tested whether pre-activation of the target language can eliminate switch cost with respect to Mosca et al. (2022). Specifically, I tested whether pre-activating the target language can eliminate switch cost, whereby indicating that inhibition is not required at all when bilinguals are fully ready to re-configure their language goal and produce the target language. A pre-activation interval was given 250ms before stimulus onset, as in Mosca and colleagues' study. It is noteworthy that in the second study, Moreover, as in the first manuscript, I also manipulated ratio of L1 and L2 (e.g., 75% pictures named in L1 in Context L1). In this experiment, I excluded balanced context since it was only a baseline and what I focused on was the predominant language effect on switch cost pattern.

Finally, in Manuscript 3, I conducted an EEG experiment focusing on how the brain prepares to switch (or to inhibit) before speech onset, and test if I would observe more or less the same CNV waveforms as in Wu and Thierry (2017). This experiment would be the first one presenting how the brain prepares to switch language and to apply language control mechanism to L1 and L2 production. Again, I employed the language contexts as in the second manuscript. The pre-activation interval was 1000ms. The reason of why we increased the interval was to prevent noise from brain signal at the language cue window. Furthermore, the face cues here were two Asian ambiguous faces, which can be used as either in English or Mandarin Chinese. This is to avoid face effect given the brain is good at predicting, hence when face cues are completely difference (e.g., an American person's face can only be used as English cue).

CHAPTER 2. Manuscript 1 – Top-down and bottom-up bilingual speech production: The effects of language context on inhibitory control

This manuscript has been submitted to *Bilingualism: Language and Cognition* and is currently under review. Revisions have been made according to the reviewers in the first two rounds.

2.1 Introduction

Bilingual speakers are known to switch from one language to another flexibly in various communicative contexts and language modalities (Green & Abutalebi, 2013). This impressive ability requires the brain to select the target language and de-select the non-target language, with the activation and the inhibition of two or multiple languages (Inhibitory Control Model; Green, 1998). However, there is a delayed response when switching language, and this "switch cost" is greater when switching from the later acquired, non-dominant language (here, L2) to the dominant native language (L1). This switch cost asymmetry is usually driven by the differences in L1 and L2 language proficiency and use, leading to greater switch cost to the dominant L1. Switch cost has been reported in previous studies that focus on language production processes such as object naming (e.g., Costa & Santesteban, 2004; Costa et al., 2006; Christoffels et al., 2007; Declerck et al., 2012; Finkbeiner et al., 2006; Ma et al., 2016; Timofeeva et al., 2023) and other production modality such as reading written words aloud (Macizo et al., 2012; Reynolds et al., 2016; Slevc et al., 2016).

In addition to language proficiency and use, factors contributing to the asymmetry still require more investigations (see Gade et al., 2021, for meta-analysis). Recently, Timmer et al. (2019) used a picture naming task and suggested that language context is another key factor which leads to the pattern of switch cost asymmetry. Picture naming in a language switching paradigm is a top-down production processing, and this has been a popular way to examine switch cost asymmetry. However, speech production does not merely involve naming pictures. When asking a bilingual person to read words aloud (e.g., Macizo et al., 2012; Slevc, 2016), this production modality becomes a bottom-up processing. The major question we ought to answer is: while being exposed to different language contexts, do bilingual speakers also perform language switching in the same way? More specifically, can the underlying language control mechanism be modulated by language context and production modality? Here, investigating different production modalities and manipulating language ratio in different contexts, we aim to further examine the pattern of switch cost asymmetry. To that end, we present a study consisting of two experiments that directly address to this ongoing debate regarding the nature of language switching in bilingual speakers.

2.1.1 Switch cost in bilingual production

Languages (dominant L1 and non-dominant L2) are activated in parallel (e.g., joint activation, Bialystok, 2017), hence the inhibition arises when two languages compete for production (Green, 1998). When bilinguals switch between languages, this casts burden upon the brain as it needs to activate the target language and de-activate the non-target language. To reduce the competition, the non-target language (i.e., language that is not currently needed) is inhibited to boost the activation of the target language. When an inhibited language needs to be re-activated again (i.e., to switch back to an inhibited language), overcoming such inhibition causes a delayed response, and this increasing naming latency depends on the magnitude of inhibition. The L1 requires more inhibition than the L2 during speech production due to underlying higher resting levels of activation (higher interference), resulting in longer delayed response when switching from L2 to L1 than vice versa. It is also known that, within different language contexts, bilinguals can adapt themselves and apply necessary mechanisms to achieve the language goal (Adaptive Control Hypothesis (ACH), Green & Abutalebi, 2013). These language contexts then shape the level of activation, whereby affecting the cognitive controls (e.g., attention, inhibition, conflict monitoring, task (dis)engagement). Hence, switching between languages as reflected in a dual-language context (i.e., a context where both languages are required), can lead to various language performances.

To test inhibition and switch cost asymmetry, a cued-switching paradigm is used where bilinguals name sets of items (e.g., pictures, digits) according to a cue signalling the target language. This paradigm contains switch trials, when the current naming language is incongruent with the preceding naming language (e.g., L1 switch trial refers to switching from L2 to L1), and non-switch trials, when the current naming language is congruent with the preceding naming language (e.g., L1 non-switch trials refers to naming in L1 in the subsequent trials).

In a seminal study, Meuter and Allport (1999) employed a cued-switching paradigm and tested unbalanced bilinguals (i.e., L1 more proficient than L2) by asking the participants to name digits in either L1 and L2 according to the colour cues presented on each trial. Supporting Green's hypothesis (1998), Meuter and Allport's showed greater L1 switch cost when switching from L2 to L1 than vice versa (i.e., switch cost asymmetry). This finding highlighted that the magnitude of inhibition the bilinguals overcome differ across languages. In particular, L1, the more proficient dominant language requires greater inhibition than L2. There are alternative accounts for greater switch cost from L2 to L1 apart from inhibitory control (e.g., response selection hypothesis, Finkbeiner et al., 2006; persisting activation hypothesis, Philipp et al., 2007; general selective mechanism hypothesis, Blanco-Elorrieta & Caramazza, 2021, see Declerck & Koch, 2023 for a review).

Language switching studies to date reported switch cost mostly, with different cue-stimulus manipulation. There are studies showing asymmetrical switch cost in unbalanced bilinguals (e.g., Costa & Santesteban, 2004; Campbell, 2005; Jackson et al., 2001; Meuter & Allport, 1999; Verhoef et al., 2009, Zuo et al., 2022; but see Liu et al., 2016), symmetrical switch cost in balanced bilinguals (Costa & Santesteban, 2004; Costa et al., 2006; Timofeeva et al., 2023), and asymmetrical switch cost pattern when language switching involves more than two languages (Costa et al., 2006; Declerck et al., 2015; Declerck & Philipp, 2018; Philipp et al., 2007). Some studies found switch cost reduction or absence of switch cost when presenting a language cue before a target stimulus (Costa & Santesteban, 2004; Ma et al., 2016; Verhoef et al., 2009; Khateb et al., 2017; Mosca & Clahsen, 2016; Mosca et al., 2022), when switching is voluntary (Blanco-Elorrieta & Pylkkänen, 2017; De Bruin & McGarrigle, 2023; De Bruin & Xu, 2023, De Bruin et al., 2018; Gollan & Ferreira, 2009; Jevtović et al., 2020), and when a contextual cue is used (Blanco-Elorrieta & Pylkkänen, 2018; Liu et al., 2019). Recently, some researchers have also investigated the effect of language contexts (Olson, 2016; Timmer et al., 2019) and processing modalities (Li et al., 2024) on bilingual language control.

2.1.2 The effect of language context and production modalities

When it comes to language switching, the performance of two languages is highly associated with the dual-language context. According to ACH, this context involves the most cognitive control processes, especially goal maintenance and interference control. The inhibitory process is embedded within interference control. Given the load of cognitive demands, bilingual speakers must show a highly flexible language processing ability, which makes switching in a dual-language context an interesting behaviour to explore. To be able to test the nature of language control mechanisms, some studies have taken a step further by manipulating the ratio of L1 and L2.

With respect to Olson (2016) and Timmer et al. (2019), language context is an important factor as bilinguals are exposed to different dual-language contexts that modulate the magnitude of inhibition, whereby determining the presence of switch cost asymmetry and highlighting their flexibility. Olson (2016) manipulated the ratio of L1 and L2 in two different language contexts i.e., "Monolingual" contexts (pictures mostly named in either L1 or L2), or "Bilingual" context (half in L1 and in L2, respectively). The findings showed a switching asymmetry in Monolingual context (greater switch cost in L1 than L2), but symmetrical switching cost in Bilingual context. These results suggest that language context might affect the amount of competition and inhibition needed during switching causing its delayed response in switching, whereas when both languages are equally used, the asymmetry became absent. It is noteworthy that Olson's (2016) asymmetrical pattern between L1 and L2 in the monolingual context could be driven by the language block itself. For instance, L1 switch trials were presented in an L2 monolingual context, whilst L1 non switch trials were presented in an L1 monolingual context. Therefore, L1 switch cost effects were the result of not only a switching manipulation but also a simultaneous language context manipulation (i.e., L1 switch in L2 context v.s. L1 non-switch in L1 context). Hence, the asymmetrical pattern found could potentially be the result of the different language contexts in which the switch and non-switch trials were presented. Timmer and colleagues (2019) took a step further and teased apart language effects (L1 v.s. L2) from context effects during language switching. They employed L1-predominant and L2-predominant contexts with both contexts including L1 and L2 switch and non-switch trials. Note that one group of Dutch-

English bilinguals completed the L1-predominant, and another group of Dutch-English bilinguals completed the L2-predominant. In contrast to Olson (2016), Timmer and colleagues found symmetrical switch cost in the L1-predominant but reversed asymmetry (i.e., greater L2 switch cost) in the L2-predominant. The authors suggest that the symmetrical patterns observed in L1-predominant could be the result of global L1 inhibition, meaning the L1 had to be delayed benefitting L2 (see also Christoffels et al., 2007). Taken together, these results indicate that language context might modulate switch cost patterns and overall L1/L2 performance. However, the underlying reasons leading to two completely different findings across these two studies remain unclear (e.g., individual bilingual life experiences, methodological choices). Moreover, in Timmer et al. (2019), the sequence of switch and non-switch trials was fixed which might also affect predictability of switching and the role of activation and inhibition (see Jackson et al., 2004).

With respect to the previous studies, what we know so far is that bilingual language control mechanism is highly adaptable, and switch cost does not remain static. The evidence of the dynamic nature of switch cost patterns in different linguistic environments have been revealed in bilingualism research by using a language switching task with same stimuli presented several times (e.g., four times or more) for each participant. This can, to some extent, cause facilitation during naming process (Wodniecka et al., 2020). To this end, the current study was set out to investigate how adaptable bilingual language control mechanism is by minimising repetition of each stimulus. Furthermore, if switch cost asymmetry can be modulated by language context, it is also intriguing to see how different language processing approaches affect switch cost asymmetry when bilinguals encounter different stimuli. To that end, the question we aim to answer is that whether switch cost asymmetry can be consistent in both top-down (naming pictures) and bottom-up (reading words aloud) speech production and whether the more frequently used language leads to delayed performance when re-activating an inhibited language.

Reading words aloud, is a bottom-up production modality in which a word form automatically activates its semantic and phonological features (see also BIA+, Dijkstra & van Heuven, 2002; see also Mosca & De Bot, 2017). Generally speaking, the speed to respond to a word is dependent on language proficiency, namely the dominant proficient L1 is expected to be faster than the non-dominant L2. This production modality has been investigated in the past, with different switch cost patterns observed (Declerck et al., 2019; Filippi et al., 2014; Macizo et al., 2012; Reynolds et al., 2016; Slevc et al., 2016; Zuo et al., 2022). This, resembling top-down production modality, has shown that when bilinguals process and produce words, competition would still emerge between languages (e.g., cross-language lexical activation, Thierry and Wu, 2007). Taking Chinese-English bilinguals as an example, they could also show either asymmetrical or symmetrical switch cost. Slevc et al. (2016) used Pinyin (i.e., Romanised Chinese phonology), Chinese characters and English words, and they revealed that participants showed symmetrical switch cost. However, in a recent study, Zuo et al. (2022) used even simpler univalent stimuli (i.e., alphabet letters) and asked Chinese-English bilinguals to read the letters aloud. Their results showed asymmetrical switch cost. To some extent, we expect inhibition to be present when we switch, but the consequence that comes after shows either symmetrical or asymmetrical. This leads to a question – What is causing (a)symmetrical switch cost in bottom-up production modality? In this experiment, we aimed to investigate not only the difference between the two production modalities, but also the effect of language context contributing to switch cost patterns.

2.1.3 The current study

In the current study, we tested how language context and production modality affect switch cost asymmetry to support the flexibility of bilingual language control mechanism in a group of highly proficient Chinese-English bilinguals living in the UK. Previous studies (e.g., Olson, 2016; Timmer et al., 2019) have revealed how bilingual speakers adapt to different language contexts, but multiple repetitions of stimuli and fixed sequence of critical trials can potentially affect the (a)symmetrical patterns within and across language contexts. To create the contexts in the current study, we minimised stimulus repetition (i.e., presenting each picture only once in each language), with a cued-switching paradigm in three language contexts, an "L1-predominant" (75% of pictures named in L1-Chinese), an "L2-predominant" (75% of pictures named in L2-English), and a "Balanced" context (50% L1-Chinese, 50% L2-English). Note that we also used face cues to establish a more natural cued-switching task in Experiment 1 and to avoid increasing cognitive demands during switching (Blanco-Elorrieta & Pylkkänen, 2017; Liu et al., 2019; Timmer et al., 2024).

Furthermore, we were also interested in how language context affects bilingual speech production in bottom-up production modality (here, reading words aloud). This then motivated us to conduct the second experiment. In the second experiment, we tested if the switch cost pattern was sensitive to different language contexts when reading out loud. In both Experiment 1 and Experiment 2, we used a within-participant design (i.e., all participants undertook all language contexts) to avoid confounding effects that could potentially modulate (a)symmetrical patterns (e.g., slightly different bilingual experiences). Our research questions and predictions are as follows:

(1) How does language context affect switch cost asymmetry in top-down language processing? If the magnitude of inhibition can be driven by language use and context, we would expect asymmetrical switching costs (i.e., greater L1 switch cost) in L1-predominant

given L1 is considered the dominant language and this context highly raises its activation, resulting in the asymmetry. Similarly, we would expect reversed asymmetry (i.e., greater L2 switch cost) in L2-predominant context since L2 would be highly activated (see also Timmer et al., 2019). Here, it is noteworthy that our sample of participants are highly proficient bilinguals living in an L2 environment. As a result, we also predicted that the asymmetry would be absent (i.e., symmetrical switch cost) in the Balanced context (Zhu et al., 2020; but see Campbell, 2005, for asymmetrical switch cost in bilinguals living in the L2 country). Given that L1 and L2 in this context are used equally, this should lead to same magnitude of inhibition and switch cost for both languages for highly proficient bilinguals. Note that the Balanced context in this study is considered a baseline condition for our sample of bilinguals, since inherent demographic language variables of a given sample from the population have been shown to lead to different switching patterns (e.g., Proficiency/Dominance, Costa et al., 2006; Age of acquisition, Bonfieni et al., 2019; Switching frequency, Han et al., 2022).

(2) How does a bottom-up production modality (i.e., reading words aloud) affect switch cost when bilinguals read words aloud? To date, there is no study investigating bottom-up production in different context, thus, here we made predictions according to our first research question to test the language context effect. We predicted that switch cost asymmetry would emerge in L1-predominant (i.e., asymmetrical switch cost) and L2-preodominant (i.e., reversed asymmetrical switch cost) since both contexts contained a predominant language. However, in Balanced context, we predicted that switch cost would be symmetrical since, again, both languages are equally.

2.2 Experiment 1

2.2.1 Methods

2.2.1.1 Participants

We ran a sample size power analysis based on Olson (2016) before recruiting participants. This was done using Superpower package developed by Lakens and Caldwell (2021). The results showed that we needed at least 44 participants to show switch effect. Sixty-one bilingual adults (54 women) (Chinese (L1) as the dominant language and English (L2) as the non-dominant language), with normal or corrected-to-normal vision volunteered to participate. Given this was an online experiment and we could not monitor participants' performance during the task, we increased the number of participants to 61 to make sure that there were still enough data to run the analysis. These Chinese-English participants (mean age = 26.8, SD = 5.1, mean months of living in the UK = 30.6, SD = 24.2) were residing in the United Kingdom. We used English LexTale (Lemhofer & Broersma, 2012) to measure participants' English proficiency. Four participants were excluded before data analysis: one with invalid audio files, one who reported learning disability, and the other two who did not follow the given instructions (i.e., naming all pictures in English throughout the experiment). In addition, another four participants were excluded because their accuracy rate was below 65%, leaving 53 participants for data analysis (see Table 2.1). Fifty-three participants scored 67.7 (SD = 12.5) on English LexTale (see Table 2.1 for LexTale and self-rating language proficiency). Of the 53 participants, 24 of them spoke other languages and dialect (e.g., French, Japanese, Korean, and Spanish and Taiwanese Hokkien). At the end of the experiment, participants received a £5 voucher. Ethics approval of this study was granted by Lancaster University (FASSLUMS-2022-0759-RECR-3).

Table 2.1. Self-rating language background (range: 0-10 for the first six components)

	Mandarin	English
Overall proficiency	9.58 (.82)	6.7 (1.25)
Listening	9.68 (.7)	7.49 (1.64)
Speaking	9.42 (1.05)	6.7 (1.39)
reading	9.55 (.85)	7.32 (1.66)
Writing	9 (1.43)	5.94 (1.89)
Exposure	5.37 (2.2)	5.11 (2.2)
Age of acquisition	1 (3.3)	5 (2.92)
English LexTale		67.7 (12.5)

2.2.1.2 Materials

Both language cues and stimuli were presented in the form of grey pictures. Faces of a Chinese and an American celebrity were used as the language cues for this study (i.e., Jacky Chan and Tom Cruise, respectively). For initial picture selection, objects scored below 1 on H-statistic index[1] (i.e., a criterion for name agreement) for both L1 and L2 were selected as critical stimuli. Given all fillers would be excluded for data analysis, pictures above 1 on H-statistic were randomly selected. For our experiment, 150 fillers were divided into 3 sets for each language context.

Three-hundred pictures (150 critical pictures and 150 fillers) were selected from Multipic (Duñabeitia et al., 2022) and divided into six sets of pictures. All critical pictures were matched in terms of their name agreement, frequency, syllables, number of phonemes

[1] Lower H-statistic values indicate higher name agreement.

(see Appendix A, Table 5.1 for means and standard deviations). In addition to Multipic Picture Dataset developed by Duñabeitia and colleagues, four other datasets were employed to retrieve more information for each lexical item. These four datasets were (1) Chinese Lexical Dataset (Sun et al., 2018), (2) SUBTLEX-UK (Van Heuven et al., 2014), (3) SUBTLEX-CH (Cai & Brysbaert, 2010), and (4) Irvine Phonotactic Online Dictionary (Vaden et al., 2009). The first one was used to retrieve number of syllables and number of phonemes for Chinese lexical items. The second one was used to retrieve English word frequency based on Zipf's law (Zipf, 1949). The third one was used to retrieve Chinese word frequency. To calculate word frequency for each target word according to Zipf's law, we used a function proposed by Van Heuven and colleagues[2]. Finally, the fourth was used to retrieve number of syllables and phonemes as well as phonetic notation for English words. Average word phonemes and frequency of the critical stimuli between the items in Chinese were statistically non-significant (Mean word phonemes = 5.61, SD = 1.72, p = .68; Mean frequency = 3.9, SD = .59, p = .36) as well as the ones in English (Mean word phonemes = 4.71, SD = 1.76, p = .83; Mean frequency = 4.13, SD = .55, p = .97) (see Appendix A, Table 5.1 for more information).

2.2.1.3 Procedure

The picture-naming experiment was conducted online via Gorilla, an online data collection platform for behavioural experiments (Anwyl-Irvine, 2020). Our language-

[2] Function: *LOG10 ((Frequency count + 1) / (total word count + number of forms)) + 3*. First, frequency count shows how many times each word appears in a given context and to calculate the Zipf law for Chinese words, this can be retrieved from SUBTLEX-CH (Cai & Brysbaert, 2010). Second, total word count shows all the observed word within a corpus (e.g., in Chinese, there are 33.546 million words, hence here we put 33.546 for total word count). Finally, number of forms shows how many Chinese word forms included within a corpus. Here, there are approximately 99,121 word forms according to Cai & Brysbaert, thus, we put 0.099 in the function.

switching task was adapted from a task structure developed by Declerck et al. (2023) (https://app.gorilla.sc/openmaterials)[3]. Each participant completed three picture-naming blocks (i.e., 200 trials each) and a practice block (i.e., 25 practice trials using non-critical stimuli), leading to 625 trials in total. Within the 200 trials of each block, 100 trials were critical trials and 100 trials were fillers. Note that the practice trials and fillers trials were later excluded from data analysis. There were four conditions in each set of 100 critical trials, namely 25 L1 switch trials (i.e., switch from L2 to L1), 25 L2 switch trials (i.e., switch from L1 to L2), 25 L1 non-switch trials (i.e., staying in L1), and 25 L2 non-switch trials (i.e., staying L2). Therefore, the ratio of critical trials for each language (L1/L2) and condition (switch/non-switch) remained constant in the three language contexts, namely we employed 50% trials for each language and 50% trials for each condition. Fillers were presented randomly and were used to create the language context conditions. We employed three language context blocks: "L1-predominant" (75% of critical pictures were named in L1, alongside 100 fillers named in L1), "L2-predominant" (75% of critical pictures were named in L2, alongside 100 fillers in L2), and "Balanced" (50% of critical pictures were named in L1 and the other 50% in L2, alongside 50 fillers in L1 and 50 fillers in L2).

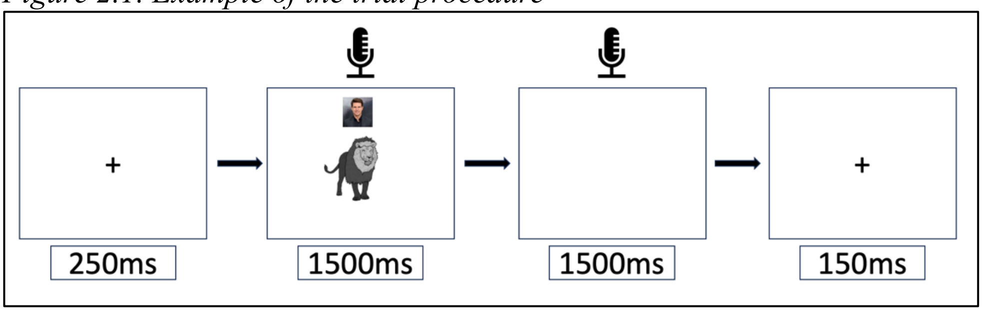
Filler pictures were presented twice within the same block. In L1-predominant and L2-predominant, fillers were named twice and the naming language was congruent with the predominant language of the context. In the Balanced context, fillers were named once in L1 and once in L2. All critical stimuli were presented only twice throughout the entire experiment, once in each language and never within the same block. For instance, if a picture was presented in an L1 switch trial in L1-predominant, the next presentation of the same picture would be presented in an L2 switch trial in L2-predominant. Six lists were created,

[3] Within this structure created by Declerck and Kirk (2023), we replaced the cognate stimuli with filler stimuli, and non-cognate stimuli with non-filler stimuli.

and participants were allocated to each list pseudo-randomly. Within each block, all stimuli were randomly presented whilst preserving a fixed order of trial type and language, and the first three trials were kept as fillers.

The apparatus used for the experiment were participants' personal computers/laptops (for stimulus presentation Gorilla) and their personal headphones (for audio recording). Before the experiment began, all participants were asked to do the tasks in a quiet place so that there was no background noise in their recordings. Participants would first be presented with instructions of each block, followed by a fixation cross was presented on screen for 250ms. Subsequently, a language cue signalling the target language and a stimulus would be presented at the same time for 1500ms. Upon the presentation of a cue and a stimulus, participants were instructed to name the picture according to the target language cue as fast and as accurately as they could. Both the cue and the stimulus appeared simultaneously, and disappeared after 1500ms, but participants would have another 1500ms to respond, namely the response window stayed for 3000ms (see Figure 2.1 for an example of the trial procedure). The trial would end with a blank for 150ms prior to the beginning of the next trial. To reduce fatigue during the experiment, participants had a 2-minute break between blocks. After completing the main tasks, participants proceeded to English LexTale (Lemhofer & Broersma, 2012) which usually takes only 5 minutes to complete and a LEAP-Q questionnaire (Marian et al., 2007). The experiment took approximately 45 minutes to complete.

Figure 2.1. Example of the trial procedure



2.2.1.4 Accuracy coding and reaction time measurement

Each participant had 625 audio files (25 practice trials, 300 critical trials, and 300 filler trials), making a total of 38,125 audio files (625 audios x 53 participants). Before measuring the accuracy rate and reaction times, audio recordings of the practice trials were excluded. Accuracy coding was done for all 600 remaining trials before excluding the filler trials for reaction time analysis. This was to ensure if a critical trial is preceded by an error (in either a filler or a critical trial), that trial would be excluded since it cannot be considered a switch nor a non-switch. To measure the accuracy rate of each trial, data were first analysed manually by adapting an accuracy coding method developed by Declerck et al. (2023) in gorilla platform (https://app. gorilla.sc/openmaterials/236318). In Declerck and colleauges' example, manual accuracy coding responses were categorised as 'Correct", "Incorrect", or "No/Other-Sound". However, we categorised the audio files based on five criteria: (1) Correct same word, (2) Correct different word (i.e. synonym), (3) Incorrect same language, (4) Incorrect different language, (5) No/other sound. We added two more accuracy criteria because participants were not familiarised with the pictures and words beforehand (this was because we aimed to minimise the potential of facilitation after second naming, see Branzi et al., 2014). If a participant named a picture with a different word (synonym in the same language), such response was considered "Correct different word". Any audio files with hesitation, filled pauses (e.g., *uh, oh, um, ah*), no sounds were considered "No/other sound".

After accuracy coding, we then measured reaction times for each recording. The reaction times were measured both via Chronset (Roux et al., 2017) and manually by the experimenter. We uploaded the 300 audio files of critical trials from each participant to Chronset to measure the voice onset time. The experimenter then randomly selected 5% of the audio files from each participant to manually measure the reaction times (this method was adopted from Declerck et al., 2021). After obtaining the results from Chronset, we ran a Pearson correlation test with results from Chronset and the manually measured voice onset time to check the reliability of both results (r = .9).

2.2.1.5 Data cleaning and processing

The data were cleaned and processed using Rstudio (R Core Team, 2021). Trials that were preceded by errors or no responses (i.e., criteria (3), (4), and (5)) were excluded from analysis because these were not considered a switch or non-switch trials (13.38%). Five items were excluded from further analyses upon inspection of item accuracy (i.e., compass, dummy, microscope, ostrich, scales) as their accuracy rate was below 20%. Physiological implausible responses (RTs below 150 ms) and timeout (RTs above 3 seconds) were excluded (0.52%). We also excluded responses above and below 2.5 standard deviations of the mean RTs for each intra participant (2.21%) and intra item variable (2.63%) with a total of 4.01%.

Accuracy rate and reaction times were analysed using logarithmic and linear mixed-effects models using lme4 (Bates et al., 2015). Fixed effects included Context (L1-predominant, L2-predominant, Balanced), Language (L1, L2), and Trial type (switch, non-switch). We first fitted maximal random models structures, and if the model failed to converge, we continue to ran principal component analysis (with rePCA function) of the random effects and drop the components that did not contribute to the cumulative variance to reach a parsimonious model (Bates et al., 2015). Language and trial type were contrast coded using sum contrasts divided by the numbers of levels (i.e., -0.5, 0.5). Context was set with "Balanced" as the reference level. For reaction time analyses, F-values for main effects and interactions were computed using the lmerTest package (Kuznetsova, et al., 2017), with

Satterthwaite approximation to degrees of freedom. For accuracy data, follow-up models for significant 3-way interactions were then conducted for each context separately using the same procedure.

2.2.2 Results

Here we present the findings including descriptive statistics, accuracy, mean RTs, and main effects according to each language context (i.e., L1-predominant, L2-predominant, and Balanced). Table 2.2 reports the descriptive analysis within each context.

Table 2.2. Descriptive statistics for the cued-switching task (Experiment 1)

	L1-predominant		L2-predominant		Balanced	
	RT	Accuracy	RT	Accuracy	RT	Accuracy
L1 – NonSwitch	1020 (248)	84 (36)	1120 (275)	80 (40)	1103 (265)	81 (39)
L1 – Switch	1203 (265)	78 (41)	1233 (273)	77 (42)	1229 (268)	79 (41)
L2 – NonSwitch	1030 (280)	82 (38)	1037 (286)	83 (38)	1059 (279)	81 (39)
L2 – Switch	1141 (281)	78 (42)	1133 (291)	80 (40)	1140 (294)	79 (41)

Note: Mean reaction times are presented in milliseconds and accuracy rates in percentage with standard deviations in parentheses

2.2.2.1 Accuracy

We ran analyses based on three predictors Language (L1 v.s. L2), Trial type (non-switch v.s. switch) and Context (L1-predominant v.s. L2-predominant v.s. Balanced) with

Balanced context as the reference level. We found a significant interaction of Context with Language [$\chi^2(2) = 8.53$, $p = .014$]. Whilst accuracy in L2 did not significantly differ across contexts (all *p*s > .338), accuracy in L1 was significantly higher in L1-predominant context than L2-predominant context ($\beta = 0.23$, SE = .08, z = 2.79, *p* = .015). L1 Accuracy in mixed language context did not significantly differ from either L1- or L2-predominant context (all ps > .248). Results also revealed a significant interaction between Context and Trial type [$\chi^2(2) = 6.05$, *p* = .039], with significant switching effects (i.e., more accurate responses in non-switch than switch trails) in L2-predominant context ($\beta = 0.41$, SE = .18, z = 2.20, *p* = .028) and L2-predominant context ($\beta = 0.61$, SE = .18, z = 3.28, *p* = .001), but only a tendency in Balanced contexts ($\beta = 0.31$, SE = .18, z = 1.67, *p* = .094).

2.2.2.2 Reaction times

We ran analyses based on three predictors Language (L1 v.s. L2), Trial type (non-switch v.s. switch) and Context (L1-predominant v.s. L2-predominant v.s. Balanced). There was a main effect on trial type ($F(1, 166.3) = 51.44$, $p < .001$) and language ($F(1, 84.3) = 6.18$, $p = .014$), showing shorter reaction times on non-switch trials than switch trials. There was a significant interaction between context and language ($F(2, 10793) = 20.10$, $p < .001$), showing that overall L1 was significantly faster in L1-predominant than L2-predominant and Balanced context ($\beta = -63.08$, SE = 7.54, t = -8.37, p < .001, and $\beta = -57.01$, SE = 7.50, t = -7.61, p < .001, respectively) with no significant differences between the latter two ($\beta = 6.08$, SE = 7.59, t = .80, p = .422). Furthermore, overall L2 performance was significantly faster in L2-predominant than Balanced ($\beta = -15.62$, SE = 7.78 t = -2.01, p = .044) but not L1-predominant ($\beta = 4.19$, SE = 7.80, t = .54, p = .591), with no significant differences in L2 between the latter two contexts ($\beta = -11.43$ SE = 7.78, t = -1.47, p = .141). A significant interaction between context and trial type was also found ($F(2, 10799) = 12.96$, $p < .001$).

Simple comparisons showed a significant switching effect in each language context (L1-predominant: $\beta = -150.09$, $SE = 17.66$, $t = -8.50$, $p < .001$, L2-predominant: $\beta = -106.20$, $SE = 17.70$, $t = -6$, $p < .001$ and Balanced: $\beta = -99.44$, $SE = 17.68$, $t = -5.63$, $p < .001$). There was also a significant two-way trial type and language interaction ($F(1, 127.2) = 5.714$, $p = .018$), which was also modulated by context, as revealed by a significant three-way interaction ($F(2, 10795.3) = 3.02$, $p = .049$).

We then ran additional analyses to check the significant interactions within each context. In L1-predominant (see Figure 2.2 and Table 2.3), there was a main effect of trial type, showing longer reaction times on switch than non-switch trials ($F(1, 136) = 77.34$, $p < .001$). While we did not find a main effect of language ($F(1, 72.7) = .21$, $p = .651$), it significantly interacted with trial type ($F(1, 88.9) = 9.72$, $p = .002$), indicating an asymmetrical switch cost pattern. Planned comparisons showed a significant switching effect in both languages (see Table 2.3). However, results revealed a significant slowdown in L1 switch trials compared to L2 switch trials ($\beta = 43.82$, $SE = 21.01$, $t = 2.09$, $p = .04$), but not in non-switch trails ($\beta = -28.34$, $SE = 20.19$, $t = -1.40$, $p = .164$, see Table 2.4). In L2-predominant, there was a main effect of trial type ($F(1, 136.5) = 30.43$, $p < .001$) (i.e., slower reaction times for switch than non-switch trials) as well as language ($F(1, 63.6) = 20.50$, $p < .001$) (slower reaction times in L1 trials than L2 trials). There was no significant two-way interaction between trial type and language ($F(1, 119.7) = .48$, $p = .488$), namely the switch cost pattern appeared to be symmetrical (see Figure 2.1). In Balanced context, there was a significant main effect of trial type ($F(1, 140.2) = 27.074$, $p < .001$), and language ($F(1, 75.7) = 7.55$, $p = .008$), suggesting that reaction times on switch trials were slower than non-switch, and L1 trials were slower than L2 trials. Additionally, the results also revealed a significant two-way interaction between trial type and language ($F(1, 126.7) = 4.54$, $p = .035$), indicating an asymmetrical switch cost pattern. Similar to L1-predocminant context, simple comparisons showed significant switch effects in both languages, but significantly slower responses in L1 trials compared to L1 only in the switch condition (see Table 2.3).

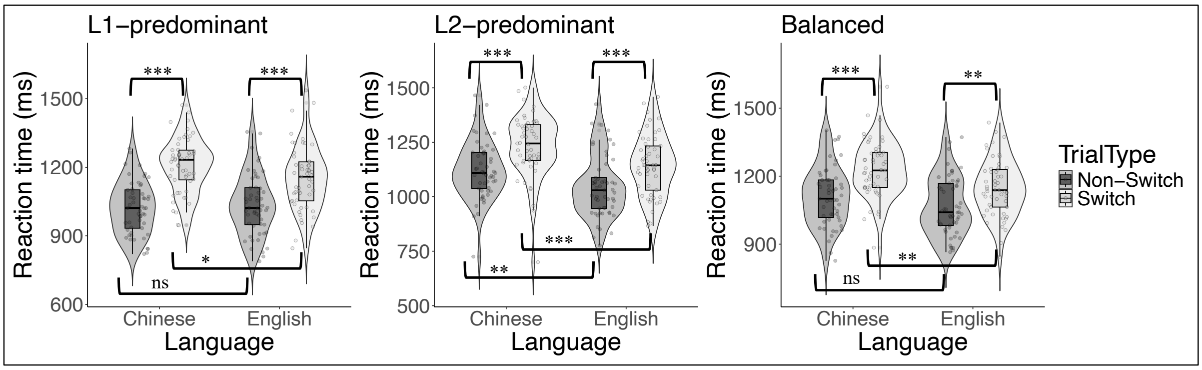
Table 2.3. Estimated fixed effects of language, trial type, and in each context

	β	SE	df	*t*	*p*
L1-predominant					
Switching effect					
L1 (Non-switch – Switch)	-186.62	17.84	100.21	-10.46	< .001***
L2 (Non-switch – Switch)	-114.46	23.15	128.59	-4.95	< .001***
Language effect					
Non-switch (L1–L2)	-28.34	20.19	81.62	-1.4	.164
Switch (L1-L2)	43.82	21.01	78.88	2.09	< .04*
L2-predominant					
Switching effect					
L1 (Non-switch – Switch)	-112.005	20.64	108.6	-5.428	< .001***
L2 (Non-switch – Switch)	-97.09	22.86	138.01	-4.248	< .001***
Language effect					
Non-switch (L1-L2)	69.4	18.413	77	3.769	< .001***
Switch (L1-L2)	84.312	21.61	68.4	3.902	< .001***
Balanced					
Switching effect					
L1 (Non-switch – Switch)	-121.9	19.53	139.7	-6.24	< .001***
L2 (Non-switch – Switch)	-73.7	24.1	142.7	-3.06	< .003**
Language effect					
Non-switch (L1-L2)	22.87	20.38	113.9	1.12	.26

Switch (L1-L2)	71.06	20.62	117.4	3.45	< .001***

*$p < .05$. **$p < .01$. ***$p < .001$. Note: the results correspond to the post-hoc analyses performed to investigate the origin of the interaction.

Figure 2.2. Mean reaction times to switch and non-switch trials in Experiment 1



2.2.3 Discussion

In Experiment 1, we manipulated the ratio of L1 and L2 in each context, with each picture and language cue presented unpredictably. We found a significant effect of language context. Based on our findings, switch cost showed an asymmetrical pattern in L1-predominant and Balanced contexts (i.e., L1 highly activated and L1/L2 equally activated, respectively), but turned symmetrical in L2-predominant (i.e., L2 highly activated). Furthermore, we also found overall slower L1 performance in L2-predominant and Balanced, meaning there was a global inhibition towards the dominant language. Although these were inconsistent with the previous findings of switch cost pattern (Olson, 2016; Timmer et al., 2019), our findings further confirmed that bilingual language switching performance can be modulated by different dual-language context.

2.3 Experiment 2

We tested whether the switch cost pattern (i.e., Experiment 1: asymmetrical in the L1-predominant and Balanced and symmetrical in L2-predominant) would also emerge in other production-based tasks (here, reading aloud) or whether it was constrained to picture naming. In this experiment, Chinese-English bilinguals were asked to read aloud Chinese characters and English words.

2.3.1 Methods

2.3.1.1 Participants

We recruited 56 participants, and same type of Mandarin dominant (L1) and English non-dominant (L2) bilinguals were residing in the UK at the time of the experiment (45 women, mean age = 30.4, SD = 7.2, mean months of living in the UK = 26.5, SD = 24.2). Five participants were excluded: two with no sounds or noisy background, two who did not follow the instructions, and the other one who reported cerebral palsy, leaving 51 participants for analysis. The remaining participants scored 65.9 on English LexTale (see Table 2.4), and some participants spoke other dialects/languages participants scored 65.9 (SD = 13.5). Ethics approval was granted by Lancaster University (FASSLUMS-2023-0759-SA-1).

Table 2.4. Self-rating language background (range: 0-10 for the first six components)

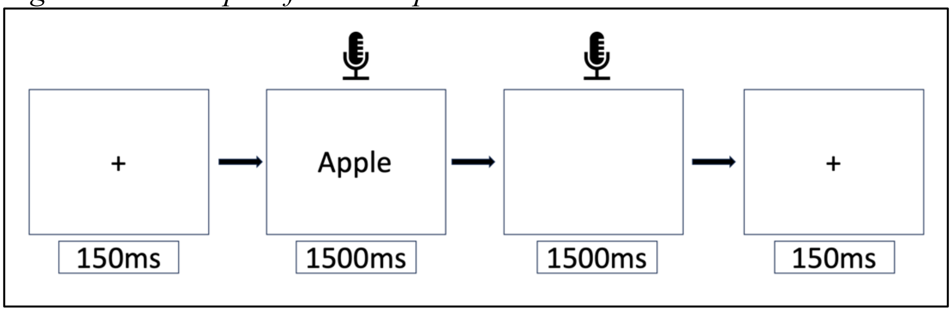
	Mandarin	English
Overall proficiency	9.86 (.53)	7.27 (1.17)
Listening	9.92 (.34)	8.04 (1.33)
Speaking	9.82 (.56)	7.27 (1.23)

reading	9.75 (.69)	7.39 (2.21)
Writing	9.02 (1.27)	6.02 (2.35)
Exposure	4.9 (2.69)	5.1 (2.69)
Age of acquisition	From birth (0.38)	7.8 (4.82)
English LexTale		65.9 (13.5)

2.3.1.2 Procedure

The procedure was identical to that of Experiment 1, including the ratio of L1 and L2 for context manipulation, but pictures were replaced with words (see Figure 2.3 for trial procedure).

Figure 2.3. Example of the trial procedure



2.3.1.3 Accuracy coding and reaction time measurement

The criteria for accuracy coding in the second experiment was identical to that of Experiment 1. The accuracy of the remaining 51 participants were high, hence were all included for analysis.

2.3.1.4 Data cleaning and processing

Method for data cleaning and processing was identical as in Experiment 1.

2.3.2 Results

2.3.2.1 Accuracy

There was only significant language effect in Balanced, with more accurate responses in L1 than in L2 (β = 1.917, SE = .73, z = 2.617, *p* = .008), while no other significant main effects or interactions between the three predictors (all *p*s>. 138) (see Table 2.5 for descriptive statistics).

Table 2.5. Descriptive statistics for the read aloud task (Experiment 2)

	L1-predominant		L2-predominant		Balanced	
	RT	Accuracy	RT	Accuracy	RT	Accuracy
L1 – NonSwitch	592 (141)	100 (5)	589 (133)	99 (8)	593 (140)	100 (5)
L1 – Switch	606 (136)	99 (9)	613 (141)	99 (8)	610 (138)	100 (5)
L2 – NonSwitch	701 (171)	99 (11)	693 (166)	99 (12)	696 (167)	98 (12)
L2 – Switch	712 (195)	98 (15)	719 (186)	97 (16)	713 (179)	98 (13)

Note: Mean reaction times are presented in milliseconds and accuracy rates in percentage with standard deviation in parentheses

2.3.2.2 Reaction times

We ran analyses based on three predictors Language (L1 v.s. L2), Trial type (non-switch v.s. switch) and Context (L1-predominant v.s. L2-predominant v.s. Balanced). There was a main effect on language ($F(1, 99) = 89.40$, $p < .001$), showing faster L1 performance that of L2. There was significant effect on trial type ($F(1, 154) = 5.86$, $p = .016$) in which participants were faster on non-switch than switch trials. There were no interactions between the three predictors (Language:Trial type: F(1, 147) = .01, *p* = .170, Language:Context: F(2, 13208) = .54, *p* = .583, Trial type:Context: F(1, 13198) = 1.80, *p* = .166, Language:Trial type:Context: F(2, 13200) = .08, *p* = .920) (see Table 2.6 for planned comparisons and Figure 2.2 for mean reaction times)

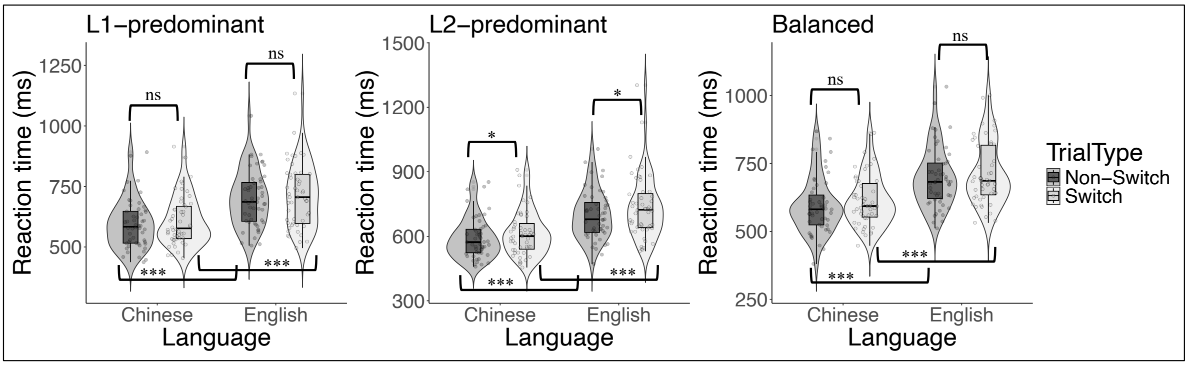
Table 2.6. Estimated fixed effects of language, trial type, and in each context

	Estimates	SE	df	*t*	*p*
L1-predominant					
Switching effect					
L1 (Non-switch – Switch)	-13.77	6.79	123.7	-2.03	.044*
L2 (Non-switch – Switch)	-15.41	14.97	156	-1.03	.304
Language effect					
Non-switch (L1 – L2)	-103.97	13.93	115.1	-7.46	<.001***
Switch (L1 – L2)	-105.62	14.87	106.2	-7.10	<.001***
L2-predominant					
Switching effect					
L1 (Non-switch – Switch)	-21.97	6.08	130.5	-3.61	<.001***
L2 (Non-switch – Switch)	-24.68	13	141.1	-1.90	.059
Language effect					
Non-switch (L1 – L2)	-111.04	13.70	104.8	-8.10	<.001***
Switch (L1 – L2)	-113.76	14.10	101.1	-8.07	<.001***
Balanced					
Switching effect					
L1 (Non-switch – Switch)	-17.80	6.68	126.6	-2.66	.008**
L2 (Non-switch – Switch)	-15.91	13.30	144	-1.20	.23
Language effect					
Non-switch (L1 – L2)	-107.37	14.57	129.8	-7.37	<.001***

Switch (L1 – L2)	-105.48	14.56	129.6	-7.24	<.001***

*$p < .05$. **$p < .01$. ***$p < .001$. Note: the results correspond to the post-hoc analyses performed to investigate the origin of the interaction.

Figure 2.4. Mean reaction times to switch and non-switch trials in Experiment 2



2.3.3 Discussion

We adopted a read-aloud task that required participants to read L1 and L2 words while switching between languages. As in Experiment 1, we manipulated the ratio of L1 and L2 in three different contexts. Inconsistent with previous studies showing asymmetrical witch cost (e.g., Macizo et al., 2012; Zuo et al. 2022), Experiment 2 showed that switch cost remained symmetrical and that bilingual speakers were faster in their dominant L1 than non-dominant L2. These findings were in line with the assumption that this production modality (i.e., reading words aloud) can lead to faster L1/L2 production speed (e.g., Slevc et al., 2016). In contrast to Experiment 1, language context here did not affect switch cost pattern.

2.4 General discussion

This study was set out to measure whether language context affected the pattern of switch cost, and importantly, whether different production modalities led to the same switch cost pattern. Adding to the accounts of bilingual language control, in our first experiment, we first investigated the effect of language context by using picture naming paradigm. To avoid potential facilitation, different from the previous studies, we minimised repetition of each critical stimulus (i.e., presenting each critical stimulus only twice throughout the entire experiment) and our participants did not receive a familiarisation training on the stimuli. In our second experiment, we further explored the dynamic of switching performance with a read-aloud task. This allowed us to test if switch cost pattern in picture naming can be consistent in reading words aloud.

2.4.1 How does language context affect switch cost asymmetry in a picture-naming tasks?

In Experiment 1, we found asymmetrical switch cost in L1-predominant and Balanced but symmetrical in L2-predominant in bilingual switching production. According to previous studies, language proficiency and use is an important factor when it comes to bilingual language processing, indicating highly proficient bilinguals will always perform better at switching (e.g., Costa & Santesteban, 2004; Costa et al., 2006). However, our findings in the Experiment 1, in line with two language context related studies (e.g., Olson, 2016; Timmer et al., 2019), we suggest that language context, with significant three-way interaction, also plays an important role in top-down language switching. Noteworthy is that the switch cost patterns were different from these two previous studies, and this is intriguing as it highlights the flexibility of bilingual language control mechanism.

To begin with, we ought to discuss why top-down language switching performance is diverse and why the asymmetry only emerged in L1-predominant and Balanced. As aforementioned, top-down production requires choosing between two languages when seeing an object that represents different lexical candidates. This often causes longer reaction times in a picture naming task and occasionally, causes better performance in the non-dominant language (i.e., dominance, Christoffels et al., 2007; Timmer et al., 2019; Casado et al., 2022, see also Goldrick & Gollan, 2023). Findings of switch cost pattern in L1-predominant have been different. Olson (2016) found greater L1 switch cost in this context and suggested switch cost pattern merely depends on the activation of the predominant language (e.g., the predominant language triggered greater switch cost than the other language). Timmer et al. (2019), with a more thorough study design, found symmetrical switch cost. However, in the current study, we found greater L1 switch cost. Particularly, at least in L1-predominant where L1 was highly activated, we speculated that greater switch cost on L1 was caused by the stronger inhibition when using L2. These findings were consistent with the classic studies (i.e., Costa & Santesteban, 2004; Green, 1998; Meuter & Allport, 1999) in which inhibition is required to prevent L1 from interfering L2 production.

Interestingly, in L2-predominant where L2 was highly activated, switch cost pattern became symmetrical. This finding was not in line with the pattern (i.e., greater L2 switch cost in Olson, 2016 and Timmer et al., 2019). Furthermore, the L2 overall performance was faster than that of L1. We assumed that there is a link between L1 slowing and symmetrical switch cost (see also Christoffels et al., 2007, Costa & Santesteban, 2004; Costa et al., 2006). The reason is that language control mechanism needs to optimise the efficiency of switching, so that bilinguals can adapt themselves within different contexts. Thus, when bilinguals are required to use L2 more often in a context (e.g., 75% of stimuli named in L2), language control mechanism needs to largely increase L2 activation and its accessibility by globally delaying L1 given our participants were more dominant in L1. This will then lead to slower L1 production, and the pattern of inhibition and switch cost on L1 and L2 becomes symmetrical when bilinguals switch between a proficient dominant language (here L1) and a highly activated language (here L2). Note that in L1-predominant, L1 overall performance was not faster than L2, suggesting that when L2 is not frequently used, the responses will not become faster than L1, at least in a picture naming task. To this end, we would like to use this assumption to further answer the findings in Balanced context.

The findings of Balanced context (i.e., 50% L1 and 50% L2) have been divergent across studies. For example, Declerck et al. (2012) and Olson (2016) did not find asymmetrical switch cost, showing unbalanced bilinguals can also produce same patterns of switch cost on L1 and L2. According to Olson, switch cost pattern in Balanced context should be symmetrical given the two languages are equally used, which was also our initial prediction for Experiment 1. Nevertheless, we found asymmetrical switch cost and global L1 slowing in this context. This, with respect to our aforementioned assumption for L2-predominant, is because of the ratio of L2. Comparing to L1-predominant (i.e., 75% use of L1), use of L2 in Balanced was increased by 25%, whereby increasing the need to boost L2 activation by globally inhibiting L1. Still, L2 activation level was not as largely increased as in L2-predominant, hence L1 was not as globally inhibited as in L2-predominant. Balanced context, thus, would still show asymmetrical switch cost with overall slower L1 performance. Alternatively, another potential reason is – our participants were unbalanced bilinguals. Putting this type of bilingual participants in a Balanced context or in a context where the non-dominant L2 was not highly required (e.g., in L1-predominant) would eventually show asymmetrical switch cost. This reason, to some extent, would be consistent with previous studies (e.g., Costa & Santesteban, 2004) that highlighted the difference between unbalanced and balanced bilinguals.

However, instead of categorising whether our bilingual participants were unbalanced or balanced, in the current study we focused on the flexibility of bilingual speakers in different contexts with respect to Green and Abutalebi (2013). For example, in Timmer and colleagues' study, L1-predominant showed symmetrical switch cost with global L1 slowing but reversed asymmetrical switch cost with no global L1 slowing in L2-predominant. In the current study we reported opposite findings, which was an interesting phenomenon in bilingual language control. This, perhaps, was because of the places our participants were living in by the time of the experiment. In particular, our participants were tested in an L2-speaking country by the time of the experiment. To that end, as bilingual speakers are residing in an L2-speaking country and still need to switch to L1 to communicate (also in our L2-predominant), they really have to rely on global L1 inhibition to balance the activation of L1 and L2, leading to global L1 slowing and symmetrical switch cost. This switching behaviour in L1-predominant, however, would not become a problem for bilingual speakers because all they needed to do was to largely activate their L1 and rely on local inhibition to switch, leading to asymmetrical switch cost. In Timmer and colleagues' study, their bilingual participants were tested in an L1-speaking country, and were exposed to L2 every day. Therefore, to be able to use both L1 and L2 in L1-predominant, bilingual speakers needed to rely on global L1 inhibition to balance both languages. However, in L2-predominant, they tended to rely on local inhibition to switch, showing reversed asymmetrical switch cost. These findings pointed out the phenomenon of how bilingual speakers adapt themselves in different contexts flexibly and potentially reflected the effect of real-life language experience on speech production. Hence, from the notion of ACH (Green & Abutalebi, 2013) and individual differences (see also DeLuca et al., 2019), future studies can expand our interpretations from "experiments" to "real life experience" by comparing participants living in L1 and L2-speaking countries and exploring how these experiences can modulate bilingual language processing.

2.4.2 How does a bottom-up production modality (i.e., reading words aloud) affect switch cost when bilinguals read words aloud?

Another focus of the current study is the effect of production modality on switch cost pattern. In Experiment 2, we manipulated ratio of L1 and L2 in each language context to test language context still had an influence on a bottom-up production modality (i.e., read words aloud). We used three language contexts, L1-predominant, L2-predominant, and Balanced with the same repetition of each critical stimulus as in Experiment 1. Previous studies (e.g., Macizo et al., 2012; Slevc et al., 2016; Reynolds et al., 2015; Zuo et al., 2022) have shown switch cost pattern can be either asymmetrical or symmetrical, and the baseline was that switch cost always emerged even when bilingual speakers read words aloud. The reason, according to the researchers, is that production involves more language control (e.g., inhibition) to reduce interferences to achieve a language goal (Declerck et al., 2019; Li et al., 2024). For example, according to Macizo and colleagues' study, reading an L2 word will also activate the L1 word, hence inhibiting the L1 is required. This will then lead to asymmetrical switch cost, supporting Green (1998). Nevertheless, due to no interaction between any of the predictors, we reported lack of asymmetry (i.e., symmetrical switch cost), and this pattern remained the same across the three contexts, regardless of the ratio of L1 and L2.

First, before going through findings of the absence of asymmetry, we would like to first discuss the overall performance of L1 and L2 across the three language contexts. For orthographically unique words, the activation of lexical candidates becomes faster, depending on one's language proficiency (Dijkstra & Van Heuven, 2022; Kroll et al., 2014). In comprehension-based studies, we can see bilingual speakers were faster at recognising words in their L1 than L2, and this was what we also found in the bottom-up production in Experiment 2. With the performance across the three contexts, bilinguals were significantly faster at reading words aloud in their L1 than L2. From the perspective of production modality, language context did not seem to affect overall performance much, indicating the higher the proficiency, the faster the performance. This, however, was not the case for Experiment 1, as L1 was not faster than L2 and it even became slower than L2 in L2-predominant and Balanced contexts. The next question we ought to discuss is the reason behind the lack of switch cost asymmetry across the three contexts.

At least according to our findings in Experiment 2, the answer to "whether language context affects language performance" is no. We did not find a three-way interaction, which means there was no statistically significant context effect when reading words aloud. This then showed that symmetrical switch cost emerged across the three contexts, which was an interesting finding given the contrasts between our results and previous studies (e.g., asymmetrical switch cost: Macizo et al., 2012; Zuo et al., 2022). Note that our results were also consistent with the other studies (e.g., symmetrical switch cost: Declerck et al., 2019; Reynolds et al., 2016; Slevc et al., 2016). We assumed that production does not always require greater need of inhibition to the dominant language that eventually leads to greater switch cost. If we explore this switch cost pattern from the perspective of ACH (Green & Abutalebi, 2013), it is possible that bilingual speakers are highly flexible, and that bottom-up production enables them to minimise the interference suppression control process. Furthermore, there might be an effect of linguistic distance. Specifically, in Experiment 2, Chinese characters and English words are written in patently two different scripts, hence it becomes easier for bilingual speakers to identify and process (see also Radman et al., 2021 for the effect of linguistic distance on bilingual cognitive control). However, in Macizo et al.

(2012), their target participants were Spanish-English bilingual speakers. This might have increased the interference when they switch, resulting in asymmetrical switch cost. Therefore, as both languages share different scripts, language processing here will then rely more on their language proficiency (with less interference) that corresponds to the activation of lexical representations. When bilingual speakers switch between languages, significantly less inhibition is needed to both languages, and symmetrical switch cost will be observed. Hence, the effect of language context on reading words aloud will not be as significant as in picture naming.

With respect to a previous study, Finkbeiner et al. (2006) proposed a hypothesis in which univalent stimuli eliminates switch cost (but see Abutalebi & Green, 2007 for an alternative account regarding Finkbeiner and colleagues' results). While some later studies contrasted with Finkbeiner and colleagues' findings (e.g., Declerck et al., 2019; Macizo et al., 2012; Reynolds et al., 2015; Slevc et al., 2016, see also Zuo et al., 2022 for naming English alphabet and Chinese characters). Here, we suggest that using univalent stimuli in a production-based study does not necessarily eliminate switch cost. But why in speech production, switch cost is hard to be eliminated? According to Declerck and colleagues, this could be contributed by "parallel language activation". Within the framework of Inhibitory Control Model (Green, 1998), all languages the lexicons are activated in parallel to compete for selection, which is why inhibition is required to reduce any form of interferences from the non-target language, but this comes with a consequence (i.e., switch cost). This cost seems to emerge more often in production than other modalities (e.g., comprehension), indicating that the parallel language activation and competition will yield more control processes to achieve the language goal (Li et al., 2024). If we look at the lack of asymmetry in Experiment 2 from the perspective of parallel language activation, we suggest that parallel activation in a read-aloud task will still be present, hence some degree of language control is required.

It is noteworthy that in a dual-language context with read aloud modality, inhibitory does not necessarily have to be as much as in picture naming modality. According to ACH, dual-language context requires the most cognitive control processes, with more magnitude of goal maintenance and interference control involved (Green & Abutalebi, 2013). Under the scope of bottom-up production, this parallel activation does not necessarily trigger strong inhibition to the dominant language, whereby reducing language context effect and making bilingual speakers to rely more on the activation of the target language. Imagine if the language cue (i.e., word) can help the target language achieve the activation threshold, why would the control mechanisms in the dual-language context (i.e., a context that pertains the most cognitive demands) stress themselves out on dealing with the much-less-activated candidate? Hence, as far as what we found, different ratio of L1 and L2 in dual-language context we employed here may not be as influential given the processing system will minimise the cognitive demands and give bilingual speakers a benefit to switch between L1 and L2. Still, at least from our results, the cost will still be present when switching production (both top-down and bottom-up) takes place with a symmetrical pattern.

Finally, we are also aware that switching does not always have to be costly. Not only in Finkebeiner et al. (2006), switch cost absence has been observed in several production-tasks using (1) pre-cuing to pre-activate the target language before naming the target picture (e.g., Mosca & Clahsen, 2016; Mosca et al., 2022) as well as (2) when the target picture is associated with a more easily accessible word (e.g., Kleinman & Gollan, 2016). To that end, we assume, apart from picture naming, a cost-free switching is possible in reading words aloud, too. Hence, future studies need to take a step forward to unpack the possibility of cost-free switching in bottom-up production modality. If in the future, switch cost absence in production studies emerges, we would indicate that the relationship between language processing and inhibition (or any interference control) remains "neutral", according to the nature of bilingual language processing in ACH. Still, inhibitory control in language switching will always be on guard to reduce interference, and this does not only occur to bilingual speakers, but also monolingual speakers, given we are always inhibiting irrelevant information via our neural network on a daily basis (Munakata et al., 2011). Taken together, the dynamic performance of language switching has much more behind when investigating how easy (or costly) it is for bilingual speakers to process their L1 and L2.

2.5 Conclusion

In the current study, we explored the flexibility of bilingual speakers. The pattern of switch cost in bilingual language switching is dependent on language context (e.g., ratio of L1 and L2), but only when a more cognitive demanding processing is needed (e.g., picture-naming). The current study showed that in picture naming, bilingual speakers rely more on top-down inhibition to reduce interferences, whereby leading to (a)symmetrical switch cost. In addition to switch cost, when the non-dominant language (L2) is highly activated in a context, the inhibition to L1 becomes more global, which in turn, causes slower L1 responses. When it comes to reading words aloud, switch cost becomes symmetrical, regardless of the ratio of L1 and L2 within a dual-language context. These findings support that bilingual speakers are flexible and that they do not always largely rely on greater inhibition to the dominant language in a production-based language task. To further tease apart the underlying control mechanism, more investigations on the association between language context and production modality are needed to gain more understandings of bilingual language processing.

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CHAPTER 3. Manuscript 2 – The effect of language pre-activation and language context on bilingual speech production

This study has been pre-registered (https://osf.io/26p4c). The supplementary materials are provided in Appendix B. This manuscript will be submitted to *Language, Cognition and Neuroscience* in June 2025.

3.1 Introduction

Bilingual speakers are adept at switching between languages, and this behaviour has been investigated in a variety of studies (e.g., Blanco-Elorrieta & Pylkkänen, 2017; Chen et al., 2020; Christoffels et al., 2007; Declerck & Philipp, 2018; Fink & Goldrick, 2015; Martin et al., 2013; Mosca & Clahsen, 2016; Mosca et al., 2022; Mosca & De Bot, 2017; Verhoef et al., 2009; Slevc et al., 2016; Timofeeva et al., 2023, see Declerck & Philipp, 2017; Olson, 2016, Timmer et al., 2019 for greater L2 switch cost, see De Bruin et al., 2018, Gollan & Ferreira, 2009 for voluntary switching, see Timmer et al., 2024 for the effect of cues). One phenomenon in which researchers have examined in the past is the cost to switch from one language to the other, so-called switch cost. Switch cost, according to most bilingualism studies, comes from the inhibition to the non-target language and reflects the amount of time to re-activate the inhibited language (Green, 1998, Meuter & Allport, 1999). Researchers continue to examine the underlying mechanism that helps achieve efficient language production. One typical language switching paradigm is widely used by presenting a language cue (i.e., an image signaling the target language) and a picture, and the participants name the picture. This is called cued-switching paradigm. Participants are asked to name the picture according to the language cue (either L1 or L2) and switch to the other language in the next trial. The ratio of L1 and L2 is often kept at 50% L1 and 50% L2. However, with a different ratio of L1 and L2 in a switching context, switch cost patterns become different as activation level changes (Timmer et al., 2019). In recent years, by presenting language cue a few milliseconds before the picture which constitute language pre-activation, several studies have revealed the effect of pre-activation (Ma et al., 2016; Khateb et al., 2017; Mosca et al., 2016; Mosca et al., 2022). While bilingual speakers can be benefitted from this manipulation with reducing magnitude of switch cost, the extent of how pre-activation effect can be modulated within different language contexts (i.e., ratio of L1 and L2) remains unknown. According to our previous study (Lee et al., under review), we showed that language context (e.g., L1-predominant, a block where participants named 75% of pictures in L1) can affect the pattern of switch cost by presenting the cue and picture simultaneously. To that end, the current study was set out to not only investigate the mechanism of bilingual switching, but importantly, the relationship between language context and pre-activation.

3.1.1 Bilingual language control in different contexts

Bilingualism research has established the notion in which languages are activated in parallel, and the network of language processing is in charge of selecting the target language and ignoring the non-target language. During parallel language activation, there is a competition between languages, but this needs to be resolved to optimize the efficiency of language processing. To achieve this, there needs to be a language control mechanism to promote the process of target language selection. One fundamental mechanism is called inhibitory control, and this is applied by the supervisory attentional system (SAS) in various language goals (Green, 1998). In bilingual speech production, language goals and the underlying mechanism are shaped by the environment one is exposed to (ranging from having to stay in one language to frequently switching between two or multiple languages)

(Grosjean, 2001), whereby affecting the language performance. For example, if a bilingual person is speaking in L1 and needs to stick to this language, then L2 should be to some extent inhibited (not completely de-activated) to avoid interfering with L1 production (but see Blanco-Elorrieta & Caramazza, 2021). When switching is required, cognitive demands should increase (because the brain needs to juggle between languages), and inhibition is applied to either one of the languages depending on which one is the target language. In addition, the magnitude of inhibition relies on the activation level of languages, such that the more activated language the greater inhibition is needed. The linguistic environment where only one language is in use is called single-language context and the one with both languages are in use refers to the dual-language context. Within these contexts, the cognitive mechanisms (e.g., conflict monitoring, interference control, goal maintenance) are highly adaptable and flexible (Adaptive Control Hypothesis "ACH", Green & Abutalebi, 2013).

Over the years, language switching resembles the dual-language context given both languages are required. This is a paradigm that aims to investigate the cognitive mechanism within (1) an immediate moment when switching from one language to the other (i.e., local control) and (2) the overall language performance of L1 and L2 when bilingual speakers know they are required to switch (i.e., global control). While researchers have shown that inhibition is at play and that switch cost is the consequence, little is known regarding how different dual-language contexts affect the pattern of switch cost and L1/L2 overall performance. A bilingual person can use one language more frequently than the other, and as long as both languages are in use, this language use will modulate the switching behaviour in a dual-language context. For instance, as the aforementioned context (i.e., 50% L1 – 50% L2), bilingual speakers switch more often than when being exposed to a context with 75% L1 (see Lee et al., under review). Some studies in the past have shown that the cognitive demands can be modulated according to different contexts, such as less frequent switching context requires less conflict monitoring. This trend increases as switching becomes more frequent and more monitoring is required, where the reaction times of bilinguals and monolinguals start to differ, showing the dynamic nature of bilingual cognitive control (Costa et al., 2009; Bialystok et al., 2004, see Bialystok & Craik, 2022). Later, in language switching studies, researchers manipulated the ratio of L1 and L2 and reported different switch cost patterns, showing the effect of language context on switch cost pattern (Olson, 2016; Timmer et al., 2019). In Timmer and colleagues' study, bilingual speakers showed greater L2 switch cost in Context L2 (i.e., 75% pictures named in L2), but not in Context L1. More recently, Lee et al. (under review) tested Mandarin Chinese (dominant L1)-English (non-dominant L2) bilinguals and revealed opposite results, meaning greater L1 switch cost in Context L1 but not Context L2. This then suggests the importance of looking into different dual-language contexts. Particularly, in Lee and colleagues' study, they asked the participants to switch between languages within different language contexts for instance: (1) L1-predominant (i.e., 75% pictures named in L1), (2) L2-predominant (75% pictures named in L2). The trials contained switch trials (i.e., current language different from the preceding language) and non-switch trials (i.e., current language same as the preceding language). Their results showed that switch cost pattern was asymmetrical in an L1-predominant context (here, Context L1). When switching from L1 to L2, strong inhibition needs to be applied to L1, but the consequence is longer reaction times to re-activate the inhibited language. However, in L2-predominant context (here, Context L2), the asymmetrical pattern became symmetrical, and the dominant L1 was globally (overall) slower than the non-dominant L2. They assumed that when the non-dominant language is (and needs to be) highly activated, the dominant language L1 should be globally delayed (global L1 slowing) and that the magnitude of inhibition for switching between the two becomes symmetrical (Christoffels et al., 2007, see also Bobb & Wodniecka, 2013 and Goldrick & Gollan, 2023).

Together with these findings, it is suggested that language context plays a role in language performance (apart from language proficiency and use), whereby modulating the magnitude of inhibition. Previous studies on language switching have established interplay of language activation and inhibition, but the current study was set out to unpack the language performance when activations of L1 and L2 largely differ. As ACH predicts that bilingual speakers can adapt themselves alongside the activation levels of L1 and L2, here we ought to investigate the extent of how language control mechanisms are adapted and what the outcomes are (e.g., longer reaction times for the dominant language) when the adaptations take place.

3.1.2 The effect of pre-activation on production

As aforementioned, language control can be investigated within an immediate switch to another language. This was done by presenting a language cue and a target picture at the same time. Interestingly, studies related to bilingual speech production have also extended to the phenomenon regarding how bilingual speakers prepare to switch and whether this preparation can affect inhibition. Specifically, this phenomenon taps into the area where language control mechanism is being prepared before one needs to articulate and respond to the target stimuli. For instance, when a bilingual individual knows that he/she needs to talk to a foreign individual who does not speak the same L1 before attending an event, then L1 will be inhibited to activate L2 in advance (i.e., pre-activation), promoting the efficiency to produce L2. This might indicate that less inhibition (or reducing cognitive demands) is needed than having to switch immediately to a different language. Hence, we aimed to examine this phenomenon alongside different language contexts. More precisely, we focused on how this pre-activation affects the bilingual language performance within a dual-language context by manipulating the ratio of L1 and L2. In language switching studies, this has been done by presenting the language cue before the target picture, and we refer to this as language "pre-activation" (also known as pre-cuing).

Pre-activation is a factor in which some researchers have employed to investigate bilingual speakers' preparation for speech production, indicating inhibition can be triggered before having to make a response. Indeed, inhibition can potentially be prepared, and this was shown in an electroencephalographic (EEG) study. Wu and Thierry (2017), for the first time in bilingual speech production, investigated negative contingent variation (CNV), an anticipatory stage demonstrated the cognitive demands of the brain before speech onset. In their study, a cue was presented 1000 milliseconds (ms) before the target picture, and participants were told to respond upon the onset of the picture. Their study was different from language switching studies given all L1/L2 naming trials were interleaved with a chunk of non-naming trials (i.e., participants did not have to make any response). This allowed them to capture L1/L2 production without the interference of switching and to have a baseline of brain signal when responses were not required. They found that when presenting the cue prior to the target picture, the magnitude of CNV differed between L1/L2 production. In particular, before producing L2, CNV was greater (i.e., deeper negative curve) than before producing L1, suggesting that increasing cognitive demands such as inhibition to L1 was applied to activate L2. This evidence was in line with Green (1998), demonstrating bilingual speakers require greater inhibition for the dominant language to be able to produce the non-dominant language. Furthermore, this shows that the brain can proactively apply cognitive mechanisms according to the dominance of each language. Hence, their findings were important and were considered an initial evidence that even when switching is not involved, inhibition can still be at play to prepare for the upcoming language production. What about in language switching? This then led us to investigate bilingual speech production from the perspective of language switching given the greater cognitive demands than staying in single language.

Some behavioural studies on language switching in the past have shown the effect of pre-activation on switch cost and global language performance, with some reporting either switch cost reduction or switch cost elimination (Costa & Santesteban, 2004; Fink & Goldrick, 2015; Ma et al., 2016; Khateb et al., 2017; Mosca & Clahsen, 2016; Mosca et al., 2022; Verhoef et al., 2009). For example, in Costa and Santesteban's study, they pre-activated the target language 500ms and 800ms before the target picture. There was switch cost reduction in pre-activation comparing to no pre-activation. However, the pattern of switch cost seemed to remain for unbalanced and balanced bilinguals. They found asymmetrical switch cost in the former and symmetrical switch cost in the latter. In Ma et al. (2016) investigating Mandarin-English unbalanced bilinguals, asymmetrical switch cost pattern was also found, with the longer the interval (i.e., 800ms), the smaller the switch cost. Different from the previous studies, interestingly, Mosca and Clahsen (2016) reported cost-free switching by pre-activating the target language 800ms before picture onset. A later study (Mosca et al., 2022), another cost-free switching was found within 250ms of pre-activation time. While cost-free switching is less observed over the years in bilingual speech production than other language processing modalities (e.g., comprehension), Mosca and colleagues revealed that the switching process can be fully prepared within a short period of pre-activation. One can say that the trial procedure was somewhat predictable (e.g., presenting a trial chunk in which the first three trials sharing identical target language, followed by an unidentical language to switch to). Alternatively, it could be that their participants were Dutch-English bilinguals who were constantly exposed to an English environment, hence pre-activation offered a "bonus" to optimise switching efficiency, resulting in cost-free switching (see Blanco-Elorrieta & Pylkkänen, 2017). With respect to these previous studies, either switch cost reduction or cost-free switching, this suggests that the pre-activation of target language promoted the switching process, and the non-target language can be inhibited in advance, which enhances the effect of pre-activation on bilingual speech production.

Another noteworthy phenomenon is the global language performance across the switching process when pre-activation is given. Even when switch cost was largely reduced and showed that bilingual speakers can be ready to switch, the findings on global language performance has been inconsistent. For instance, some studies found reduced switch cost (i.e., from asymmetrical to symmetrical) alongside global L1 delayed response (e.g., Costa & Santesteban, 2004, Mosca & Clahsen, 2016; Mosca et al., 2022) but some did not as they only found with asymmetrical switch cost (e.g., Ma et al., 2016; Khateb et al., 2017). Some researchers have associated symmetrical switch cost with global L1 slowing (see Bobb & Wodniecka, 2013 and Declerck, 2020 for a review), and linked such language behaviour with language proficiency (Declerck et al., 2020; Gollan & Ferreira, 2009). With the inconsistent findings, this raises a question regarding the role of pre-activation. For example, Mosca et al. (2022) suggested that bilingual speakers need to rely on global L1 inhibition when switching between languages. However, the question that goes behind the findings of global L1 slowing is "Why do bilingual speakers still need to rely on global L1 inhibition when pre-activation is already enough to switch?"

In summary, pre-activation allows bilingual speakers to become ready to switch, and most of the relevant studies supported the fact that switch cost magnitude can be reduced. Nonetheless, since language context, according to the previous studies, plays a role in switching, the relationship between language context and pre-activation requires more investigations. That is, if language context can affect the pattern of switch cost, then using pre-activation should reduce the magnitude of switch cost, but bear in mind that the "pattern" of switch cost (i.e., asymmetrical or symmetrical) should be similar to switching without pre-activation.

3.1.3 The current study

This then leads to the current study focusing on how language context and pre-activation modulate the pattern of switch cost and overall L1/L2 performance. To our knowledge, no study has investigated the effect of pre-activation within dual-language contexts with different ratio of L1 and L2. Thus, in the current study, we proposed to investigate the effect of language contexts and pre-activation on bilingual speakers' switching performance. Language pre-activation was prompted 250ms prior to the onset of the target picture (as in Mosca et al., 2022). Furthermore, according to Lee et al. (under review), we manipulated ratio of L1 and L2, using an L1-predominant context (Context L1 hereafter) and an L2-predominant context (Context L2 hereafter) and asked bilingual participants to name different pictures according to the face cues. The reason behind using faces as language cues was to create a more realistic switching environment for participants (see also Blanco-Elorrieta & Pylkkänen, 2017; Liu et al., 2019; Timmer et al., 2024). Note that we also minimise the repetition of each picture to avoid facilitation effect, and this manipulation is different as stimuli were repeated a lot of times in many previous studies. Inserting 250ms of interval, we focused on switch cost pattern and global L1 slowing with two questions:

(1) How does language pre-activation manipulate switch cost pattern in different language contexts (i.e., Context L1 and Context L2)?

    To our knowledge, there has not been one study focusing on the interaction between pre-activation and language context. As a result, we made predictions in accordance with the previous study (Lee et al., under review). To being with, we predicted that that pre-activation should result in switch cost reduction. However, as language context is expected to affect switch cost pattern, switch cost should be asymmetrical in Context L1 and symmetrical in Context L2.

(2) How do bilingual speakers rely on global control in different language contexts with pre-activation?

We predicted that, according to the previous study (Lee et al., under review), there should be no global L1 inhibition in Context L1. In Context L2, we predicted that global L1 slowing (i.e., global L1 slowing) should be observed given L2 was highly activated.

3.2 Methods

3.2.1 Participants

Fifty-one Mandarin (L1)-English (L2) speakers (Female = 38) participated in the study (mean age = 32 years old, SD = 6.8) (see Table 3.1 for participants' overall language proficiency). The participants were more dominant and proficient in L1 than in L2. Participants were living in the United Kingdom by the time of the study. A Language and Social Background Questionnaire (LSBQ, Anderson et al., 2018) consisting of 22 sections of questions was completed. LSBQ We also calculated the composite score to (see Appendix B, Table 5.2) to better understand the degree of bilingualism. At the end of the task, an Amazon voucher was given to the individuals who completed the study. Five participants were excluded because of low accuracy percentage (below 65%, n = 2), invalid audio files (n = 1), and not following the task instructions (n = 2), leaving 46 participants for analysis (Female = 35).

Table 3.1. LSBQ Self-rated language proficiency

	L1	**L2**
Listening	98.04 (8.06)	77.61 (15.66)
Reading	98.04 (8.06)	71.96 (21.15)

Speaking	97.83 (8.14)	73.48 (17.8)
Writing	94.13 (17.96)	59.13 (28.35)

Note: Language proficiency rated on a 100-point scale. Each score is presented in mean and standard deviation in parentheses.

3.2.2 Materials

The study was conducted on Gorilla (Anwyl-Irvine, A. L., 2020), hence participants used their personal laptops and headphones to complete the task. The target stimuli (both critical and fillers) were used in Lee et al. (under review). The experiment contained 144 pictures for critical stimuli (i.e., trials included for analysis) and 144 pictures for filler stimuli (i.e., trials excluded for analysis) from Multipic (Duñabeitia et al., 2022). The critical stimuli were matched according to the name of agreement to ensure these pictures were identifiable. Here the index for name of agreement is H-statistics[4]. The index of all critical stimuli was below 1. Language cues were also identical to the ones used in Lee and colleagues' study. Faces of an American and a Chinese celebrity was associated with English and Mandarin Chinese, respectively. To avoid conflating switch effect, we used face cues to create a more natural speech production environment to detect inhibitory control (see also Blanco-Elorrieta & Pylkkänen, 2017 and Liu et al., 2019).

The experiment consisted of two blocks (i.e., Context L1 and Context L2) of 144 critical and 144 filler trials, with switch (i.e., preceding target language different from the subsequent target language) and non-switch (i.e., preceding target language same as the subsequent target language) trials presented pseudo-randomly. Within the 144 critical trials, the number of each condition (i.e., L1 switch, L1 non-switch, L2 switch, and L2 non-switch) was kept at 36. This trial distribution was employed in accordance with Timmer et al. (2019)

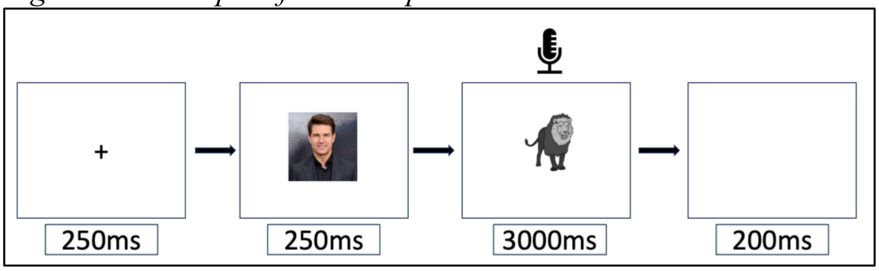
[4] Lower H-statistic values indicate higher name agreement.

because this can avoid conflated switch effect. All critical trials were counterbalanced for the four conditions but were presented only once in each block for each participant (i.e., presented twice in total throughout the experiment). Pictures for the filler trials were presented twice within each block and were named in congruent with the predominant language in two blocks, "Context L1" (i.e., 75% of the pictures were named in Mandarin) and "Context L2" (75% of the pictures were named in English).

3.2.3 Procedure

After completing a consent form, the participants first completed 20 practice trials (i.e., 10 practice trials x 2 sessions) then proceeded to the experiment. The pictures used for practice trials were selected from the filler trials. In the actual experiment, instructions were provided again before each block started. The sequence of each trial started from a 250ms fixation cross. Then, a language cue signaling either L1 (i.e., a Chinese celebrity's face) or L2 (i.e., an American celebrity's face) appeared on screen for 250 ms, then immediately followed by a picture to be named in the target language. The picture stayed on screen until 3000ms, and the participants were instructed to name the picture in the target language as quickly and accurately as possible within this time period. In previous studies, some researchers have used multiple preparation intervals in one experiment (Costa & Santesteban, 2004; Ma et al., 2016; Mosca & Clahsen, 2016), but here we chose to use only one due to time constraints (i.e., using more preparation time would require participants to sit in a longer testing session, causing fatigue). We particularly chose 250ms as the interval between the cue and the stimulus in accordance with Mosca et al. (2022) as they were the first one (in language switching studies) that showed switch cost elimination within such short time, comparing to other researchers who used longer intervals in their studies (e.g., 500ms and 800ms in Costa & Santesteban, 2004). However, their trial procedure was presented in a predictable fixed sequence. Hence, we adopted 250ms in our study (with more thorough pseudo-randomisation) to investigate whether switch cost can be eliminated. We are also aware that any change in switch cost pattern can emerge in a shorter or a longer interval. Hence, this cue-to-stimulus interval can be treated as a continuum in future studies to fully investigate bilingual speakers' language performance over time (e.g., increase the interval every 50ms). After the target picture, a white blank (i.e., participants did not see anything) was presented for 200ms (see Figure 3.1 for trial procedure). Between Context L1 and Context L2, the participants were given a 2-minute break to avoid fatigue. After completing the task, participants then completed an LSBQ questionnaire (Anderson et al., 2018) at the end of the experiment. The entire task took approximately 40 minutes. Note that participants did not receive picture familiarisation before the task because we intended to avoid facilitation effect (as in Lee et al. under review).

Figure 3.1 Example of the trial procedure



3.2.4 Data analysis

To check the accuracy of each trial, we adopted the method in Declerck et al. (2023). All critical trials and filler trials that were preceded before critical trials were included for accuracy coding. Here we included filler trials for accuracy coding given it was necessary to know if participants answered correctly (e.g., if the preceding trial was an error, then the following trial should not be considered a switch nor a non-switch trial). There were 5 components in accuracy coding criteria, Correct (same word), Correct (different word) (e.g., synonyms), Incorrect (same language) (e.g., check if participants produce the correct target language with the wrong word), Incorrect (different language), and No/other sounds (e.g., filled/silent pauses). As aforementioned, participants did not receive picture familiarisation as we tried to avoid facilitation effect. Therefore, our accuracy coding included those responses with the corresponding synonyms. Participants with below 65% of accuracy rate (n = 2), those who did not follow the instructions (n = 2), and had nearly 200 invalid recordings (e.g., very little voice that neither Chronset (Roux et al., 2017) nor the experimenter was able to identify) (n = 1) were excluded.

Reaction times were first measured using Chronset developed by Roux et al. (2017), a tool that helps detect speech onset time automatically. We selected 5% of the audio recordings from each participant to measure the reaction times manually (see also Declerck et al., 2021). To check the reliability of Chronset , we then ran Pearson's correlation based on reaction times generated by Chronset and those recordings manually measured by the experimenter on Audacity ($r = 0.9$). We cleaned the data by participant and trial. Responses below 150 milliseconds or above 3000 milliseconds and above/below 2.5 standard deviations. We cleaned our data within item (1.21%), within participant (2.46%), and by items and participant (3.39%). For reaction times analyses, the predictors for fixed effects were Language (i.e., L1 v.s. L2), Trial type (i.e., switch v.s. non-switch), and Context (Context L1 v.s. Context L2). We fitted maximal random models structures using lmerTest package, using Satterthwaite approximation to degrees of freedom (Kuznetsova, et al., 2017). We first ran a full model, but if a model failed to converge, we then ran principal component analysis (rePCA) to drop the predictors that contributed the least variances (Bates et al., 2015). We also ran accuracy analyses with the three predictors using the same procedure for reaction times analyses

3.3 Results

Note: In the pre-registration, three-way interaction analyses were not specified. However, as three-way interaction was strongly suggested by the reviewers of our previous study (Lee et al., under review), here we chose to do this so that the method for analyses was consistent with our previous study (Lee e al., under review). Still, analyses for each separate block were reported in Appendix B.

Here we first present the overall reaction times and accuracy in Table 3.2. Accuracy analyses are reported in the next section, followed by reaction time analyses.

Table 3.2. Mean reaction times in milliseconds (SD in paratheses) by language, trial type, and context

	Context L1		Context L2	
	RT	Accuracy	RT	Accuracy
L1 non-switch	994 (277)	.97 (.17)	1030 (295)	.95 (.21)
L1 switch	1068 (306)	.94 (.24)	1092 (303)	.93 (.26)
L2 non-switch	1010 (289)	.93 (.26)	1027 (305)	.94 (.24)
L2 switch	1050 (293)	.89 (.31)	1076 (303)	.90 (.29)

Note: Mean reaction times are presented in milliseconds and accuracy rates in percentage with standard deviations in parentheses

3.3.1 Accuracy

We ran accuracy analyses with language (L1 versus L2), trial type (switch versus non-switch), and context (Context L1 versus Context L2). The results showed a main effect on trial type (β = .42, SE = .09, z = 4.47, p < .001), but not on language (β = -0.04, SE = .22, z

= -0.19, p = .849). We only found two-way interaction between language and context (β = .39, SE = .12, z = 3.13, p = .002), and no other interactions were significant (Trial type by Language: β = -0.14, SE = .18, z = -0.76, p = .446, Trial type by Context: β = .07, SE = .12, z = .61, p = .538, Trial type by Language by Context: β = -0.03, SE = .25, z = -0.13, p = .897). The significant interaction was contributed by the L1 accuracy performance, where L1 accuracy rate was higher in Context L1 than that of Context L2 (β = .29, SE = .08, z = 3.35, p = .004). The results of L2 accuracy rate were not significantly different between the two contexts (ps > .707).

3.3.2 Reaction times

The results showed that there was a main effect on trial type (β = -58.03, SE = 7.35, t(48.90) = -7.90, p < .001), showing that participants were faster in non-switch trials than in switch trials. Moreover, this predictor also interacted with language (Trial type by Language: β = -35.50, SE = 15.70, t(40.72) = -2.26, p = .029), suggesting there was a switch cost for both languages (see Table 3.3 for planned comparisons). There was also a context effect (β = -30.80, SE = 10.72, t(38.65) = -2.87, p = .006), showing faster overall performance in Context L1 than in Context L2. However, this did not interact with the other two predictors (Language by Context: β = -8.62, SE = 16.69, t(42.70) = -0.51, p = .608, Trial type by Context: β = -8.30, SE = 10.91, t(77.50) = -0.76, p = .449, Language by Trial type by Context: β = -19.99, SE = 20.89, t(47) = -0.96, p = .343), meaning the switch cost remained symmetrical in both contexts (see Table 3.3 for planned comparisons).

Figure 3.2. Mean reaction times by language, trial type and context

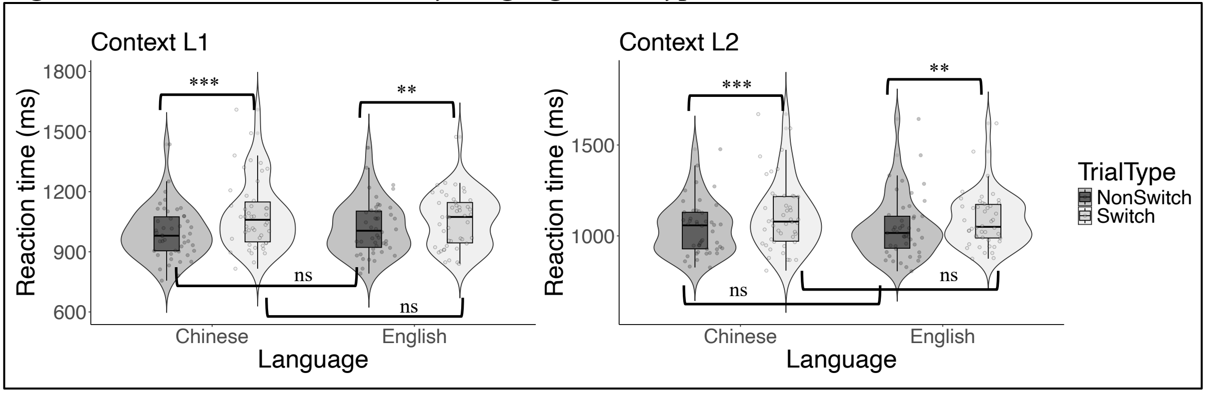


Table 3.3. Estimates fixed effects by language, trial type and context

	β	SE	df	*t*	*p*
Context L1					
Switching effect					
L1 (Non-switch – Switch)	-85.44	14.96	46.20	-5.71	< .001***
L2 (Non-switch – Switch)	-44.24	12.52	44.20	-3.53	< .001***
Language effect					
Non-switch (L1–L2)	-25.95	15.29	58.80	-1.70	.094
Switch (L1 – L2)	15.24	19.22	56.90	.79	.431
Context L2					
Switching effect					
L1 (Non-switch – Switch)	-65.20	12.74	45.80	-5.11	< . 001***
L2 (Non-switch – Switch)	-41.44	11.23	44.4	-3.98	< . 001***
Language effect					
Non-switch (L1–L2)	-9.32	18.71	61.30	-0.50	.620
Switch (L1-L2)	14.43	20.22	52.20	.71	.479

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

3.4 Discussion

The purpose of the current study is to investigate whether language context and pre-activation can modulate switch cost pattern. We aimed to provide more evidence in accordance with the flexibility of bilingual speakers in dual-language context. Previous studies have revealed how bilingual speakers dealt with immediate language switch through a context with 50% L1 – 50% L2, while previous studies have shown that different ratios can affect how inhibition is applied to achieve successful language selection (Olson, 2016; Lee et al., under review; Timmer et al., 2019). This further indicates that the dual-language context can be tease apart by manipulating the use of L1 and L2. Therefore, we used a cued-switching paradigm alongside two language contexts: Context L1 and Context L2. Moreover, given pre-activation can affect the magnitude of switch cost, we took a step further by tapping into how this mechanism is prepared to benefit bilingual production (e.g., whether the magnitude of switch cost can be reduced or eliminated). Hence, in the current study, we presented the language cue 250ms before the target language as in Mosca et al., 2022 given this was the first study presenting cost-free switching in literature.

We made our predictions for switch cost patterns and overall L1/L2 performance according to our previous study (Lee et al., under review). Note that there was no pre-activation in our previous study (i.e., cue and picture presented at the same time). We predicted that pre-activation would lead to switch cost reduction (see also Costa & Santesteban, 2004; Ma et al., 2016), but we predicted different switch cost pattern in both contexts. In Context L1, we predicted that asymmetrical switch cost should be observed and that there should be no global L1 slowing. There were two reasons: (1) When L1 (the dominant language) is highly activated, it requires strong inhibition to be able to activate L2, hence bilingual speakers suffer from the amount of time to overcome the inhibition; (2) Globally delaying L1 responses should not be needed given L1 holds higher activation, hence global L1l slowing should not be found. In Context L2, we predicted that asymmetry should disappear (i.e., symmetrical switch cost) and that global L1 slowing should be observed. The reasons were: (1) When L2 (the non-dominant language) is highly activated, the dominant L1 needs to be globally inhibited (or delayed) to benefit L2 production (Christoffels et al., 2007; Declerck, 2020), hence (2) switching between L1 and L2 becomes symmetrical. Nevertheless, in the current study, switch cost pattern remained symmetrical and global L1 slowing was not observed in both contexts. In the next section, we explain the differences and associate the language context effect with pre-activation effect.

3.4.1 How does language pre-activation manipulate switch cost pattern in different language contexts?

We discuss this from the perspective of how pre-activation and context affected the outcome of switching. This includes (1) bilingual speakers' readiness to pre-activate the target language and inhibit the non-target language and (2) whether language context can modulate switch cost pattern when pre-activation is given. Broadly speaking, switch cost has been commonly found in a variety of studies (especially in speech production, Li et al., 2024), both voluntary and involuntary switching (e.g., Meuter & Allport, 1999; Costa & Santesteban, Costa et al. 2006; Christoffels et al., 2007; De Bruin & Xu, 2023 Declerck & Philipp, 2017; Declerck et al., 2012; Declerck et al., 2020; Ma et al., 2016; Olson, 2016; Timmer et al., 2024; Timofeeva et al., 2023). The reason is that speech production involves a top-down language control processing that bilingual speakers need to select the target language before the onset of production within a few milliseconds. Furthermore, with different ratio of L1 and L2 without pre-activation, switch cost pattern can be largely modulated by language context (Lee et al., under review; Timmer et al., 2019). This selection process takes time, causing an amount of cost when switching between languages. Note that not all types of production modality elicit switch cost (e.g., univalent stimuli, Finkbeiner et al., 2006, voluntary switching, Blanco-Elorrieta & Pylkkänen, 2017, but see Abutalebi & Green, 2007).

In the current study, we showed that pre-activation can reduce the magnitude of switch cost and help bilingual speakers become ready to switch to the other language. Here we will compare the switch cost in Lee et al. (under review) and the current study. First, switch cost was overall reduced, and the pattern was particularly affected in Context L1. In Lee and colleagues' study, we found asymmetrical switch cost in Context L1, but in the current study, we found symmetrical switch cost. This then highlighted the role of pre-activation in language switching. That is, we understand that language context can modulate the way how bilingual speakers switch between languages, but pre-activation plays the role of balancing the effect from language context. Specifically, in a context where the dominant L1 was highly activated, switch cost can be efficiently reduced within 250ms. Previous studies have also found switch cost reduction using pre-activation. Costa and Santesteban (2004), with either a 500ms or a 800ms interval, found that switch cost pattern can be reduced for unbalanced bilinguals and balanced bilinguals[5]. Later in Ma et al. (2016), switch cost pattern was also reported to be reduced by presenting the target language in advance (same pre-activation duration as in Costa & Santesteban, 2004), but both did not report the change in switch cost pattern, suggesting unbalanced bilinguals would yield asymmetrical switch cost when pre-activation is allowed. In our findings, however, we demonstrated that switch cost pattern can largely change within 250ms for unbalanced bilinguals. Second, while switch cost remained symmetrical in Context L2 (the same pattern as in Lee and colleagues' study), there was an interesting finding regarding global L1 performance (we will explain this in the next

[5] Costa and Santesteban (2004) found asymmetrical switch cost in unbalanced bilinguals and symmetrical switch cost in balanced bilinguals, with switch cost being reduced.

section). If we look at the symmetrical switch cost in Context L2, the pattern was not much affected as in Context L1. If pre-activation can turn the switch cost from asymmetrical to symmetrical in Context L1, than the trend for Context L2 should be from symmetrical to no cost at all, which will partially support Mosca et al. (2022). Nevertheless, this did not happen in the current study. We assume that language switching with pre-activation will mostly elicit switch cost (Costa & Santesteban, 2004; Verhoef et al., 2009; Ma et al., 2016; Khateb et al., 2017, but see Mosca & Clahsen, 2016; Mosca et al., 2022), including being exposed to a dual-language context where either the dominant or the non-dominant language needs to be at its highest activation level. This then brings us back to the notion of parallel activation (Declerck et al., 2019). To begin with, bilingual speakers encounter an object and activate the lexical representations (or words) for both their L1 and L2. At this moment when both words are activated, the attentional system applies inhibition to either one of them, depending on which lexical representation belongs to the target language. As a result, switching behaviour casts some extent of cognitive demands in which the attentional system needs to be constantly on guard to make sure bilingual speakers achieve the language goal (see also Bialystok, 2024). This applies to the occasions when switching is predictable and unpredictable or voluntary and involuntary, revealing why dual-language context requires the more cognitive controls than the other two contexts (i.e., single-language where only one language is in use and dense code-switching where bilingual speakers inter-mix words in one language within the syntactic structure of the other language) (Green & Abutalebi, 2013). In particular, when language processing requires production, the pattern of switch cost would be symmetrical at the least, and the factor that causes asymmetrical switch cost can vary (e.g., language proficiency, age of acquisition, see Bonfieni et al., 2019). This switch cost phenomenon can also be observed not only in picture naming but also other switching tasks involving reading words/letters aloud (e.g., Declerck et al., 2019; Lee et al., under review;

Macizo et al., 2012; Reynolds et al., 2016; Slevc et al., 2016; Zuo et al., 2022). This does not necessarily mean that pre-activation loses its role in helping bilingual speakers eliminate the “effort” to switch. In fact, we suggest that cost-free switching should not be the only goal in bilingual speech production, because what matters more is how the cognitive mechanisms cooperate with each other and promote the efficiency to switch. Furthermore, what we demonstrated here is that pre-activation plays an essential role of balancing the effect of language context on switch cost pattern, such that language context does not directly affect bilingual language processing. In other words, pre-activation prevents bilingual speakers from the greater magnitude of cognitive demands they encounter in other switching contexts without pre-activation. This also highlights the anticipatory skill of the brain, suggesting that the demands to switch between languages can be proactively prepared (see also Wu and Thierry, 2017). Taken together, pre-activation, is sufficient for bilingual speakers to carry out a more efficient switching behaviour, comparing to being exposed to two language contexts without pre-activation.

3.4.2 How do bilingual speakers rely on global control in different language contexts with pre-activation?

Global L1 slowing (i.e., slower L1 performance than L2) is considered a consequence that emerges when L1 performance is globally inhibited (Branzi et al., 2014; Christoffels et al., 2007; Costa & Santesteban, 2004; Gollan & Ferreira, 2009; Kleinman & Gollan, 2018; Wodniecka et al., 2020, see also Declerck, 2020). Here, we also compared the results in Lee et al. (under review) and the current study. In the current study, we did not observe this global L1 slowing phenomenon in neither of the contexts, contrasting our previous study (Lee et al., under review) where global L1 slowing was shown particularly in Context L2. Here, we start by explaining the overall performance in Context L1 given the findings of this context was consistent with our predictions, and we then focus on the inconsistent one, the performance in Context L2. To being with, it is reasonable to see no global L1 slowing in Context L1. The reason is that, in a context where L1 was highly activated, L1 should not be globally inhibited. If L1 was globally inhibited, then having to reach its high activation level again when switching from L2 to L1 would be additionally effortful. Hence, we assume that bilingual speakers do not need to rely on global L1 inhibition to switch (or to benefit L2 production) and that pre-activation did not affect the global L1/L2 performance much in Context L1 (as it is not necessary). Nevertheless, Context L2 revealed quite an interesting outcome of global control, revealing the effect of pre-activation again.

As aforementioned, we found global L1 slowing in Context L2 in Lee et al. (under review), suggesting that bilingual speakers relied on global control to switch between L1 and L2. The reason behind was that L2 had to be highly activated, and to achieve this, L1 needed to be globally inhibited to boost L2 activation. Here in the current study, such global slowing pattern was absent, revealing the effect of pre-activation within 250ms. To that end, bilingual speakers become ready to switch with the help of pre-activation because the brain is adept at predicting and executing corresponding cognitive controls. As Wu and Thierry (2017) suggested, the amplitude of CNV before producing L1 and L2 was different, with L2 production receiving greater CNV, indicating L1 was largely inhibited. Hence, we could assume that 250ms of pre-activation was ample for bilingual speakers to switch and to inhibit the less activated language such as L1. This could the reason why we only observed symmetrical switch cost in Context L2, showing pre-activation reduces bilinguals' dependency on global L1 inhibition. However, in Mosca et al. (2022), global L1 slowing was still observed even within 800ms of pre-activation. Regardless the fact that bilinguals had more time to pre-activate the target language, the finding of global L1 inhibition seemed to persist throughout their experiment. One potential reason could be the ratio of L1 and L2 in their study. For instance, the ratio of L1 and L2 was kept the same in their study (i.e., 50% L1 – 50% L2), and in this context where bilingual speakers were expected to maintain equivalent activation level for L1 and L2, the dominant language would have to be globally inhibited to make access for the non-dominant language. This could explain the reason why their bilingual speakers rely more on global control even when the target language was pre-activated before picture onset (see also Costa & Santesteban, 2004). Alternatively, as Mosca and colleagues' stated, this global L1 slowing can be explained by the consequence of bilinguals "over-applying" inhibition to the dominant language (Gollan & Ferreira, 2009; Declerck et al., 2020, see Goldrick & Gollan, 2023). As stated in Declerck et al. (2023), highly proficient bilinguals tend to "over-shoot" (or called "over-apply" in Gollan & Ferriera, 2009) inhibition to the dominant L1, and this often leads to worse L1 performance. In a context with 50% L1 – 50% L2, switching between the two languages makes the bilingual speakers become more aware of language competition in which their attentional system shifts between re-configuring the language goal for either L1 or L2. Consequently, this "over-applying" ability can be easily detected, leading to global L1 slowing. However, when bilingual speakers are exposed to Context L2 (as in Lee et al., under review), the nature of language processing becomes different, yielding global L1 slowing. To that end, in the current study, we suggest that the role of pre-activation here is to prevent bilinguals from over-applying global inhibition to the dominant L1. This, at least in our results, indicates that pre-activating the target language even within 250ms can effectively avoid the over-applying behaviour. However, the bottom line is that this does not necessarily facilitate L1 responses such that L1 performance becomes faster than that of L2 (as we can see in Table 3.2 for overall performance in Context L2). The reason is that production language processing or a task that requires the brain to select either one of the target responses under parallel language activation, L1 will not become faster, unless the task involves bottom-up language processing (e.g., comprehension-based task, note that in our previous study with reading words aloud, switch cost disappeared in some contexts) (e.g., Declerck et al., 2020). Hence, the findings of "L1 was not faster even when pre-activation was at play", our answer is that pre-activation could only avoid the inhibition from being over-applied, but will not necessarily facilitate L1 responses. If pre-activation was excluded from the experiment, we would find the same results as in Lee and colleagues'.

Still, this does not mean that dominant L1 will never become significantly faster than L2 in language switching when pre-activation is allowed. For example, Ma et al. (2016), with Mandarin-English bilinguals with the same ratio of L1 and L2, showed asymmetrical switch cost in conditions in both short and long pre-activation times, and importantly, overall L1 Mandarin performance was faster than L2 English. One might wonder why in their case, bilinguals could perform faster in their dominant L1 than non-dominant L2, while some other studies showed reduced/eliminated switch cost either with global L1 slowing (e.g., Costa & Santesteban, 2004; Khateb et al., 2017; Mosca et al., 2022). The reason can be the daily use of L1 and L2 or the place where participants lived in by the time of the experiment because this could potentially explain the difference. From our perspective, bilinguals in Ma and colleagues' may not have used L2 often (e.g., living in an L1-speaking country), hence may have relied on local control during switching, eliciting greater L1 switch cost than L2 switch cost. This fits into Green (1998) in which stronger inhibition applies to the dominant L1 than the non-dominant L2, causing greater switch cost to the strongly inhibited language. In this case, the phenomenon of global inhibition to entire L1 (or even applying a few global L1 inhibition) would not be a problem because the activation level of L1 and L2 largely differs, and L1 will be activated and produced faster than L2, even when pre-activation was allowed. Hence, we suggest that since a higher degree of bilingualism may affect how bilinguals rely on global L1 inhibition, future studies can focus on different types of unbalanced bilinguals and further explore how language control mechanisms operate through language processing and how individual differences modulate language performance.

3.5 Conclusion

In the current study, we asked bilinguals to switch between L1 and L2 by using two language contexts (i.e., Context L1 and Context L2) and pre-activating the target language 250ms before the target stimuli. We observed that bilinguals showed symmetrical switch cost pattern in both language contexts. This shows that bilingual language control mechanism is highly adaptable and is flexible depending on ratio of L1 and L2 in a dual-language context (Green & Abutalebi, 2013) and that pre-activation plays the role of balancing the language context effect. Furthermore, while switch cost pattern remained symmetrical within different dual-language contexts, absence of global L1 slowing is another phenomenon in our bilingual speakers. According to our results, we suggest that using pre-activation with such a short interval in a top-down picture naming task can not only effectively help bilingual speakers pre-activate the target language, whereby reducing cognitive demands in switching and helping bilinguals reduce the chance of "over-applying" global inhibition to the more dominant language. More importantly, given the various contexts bilinguals are exposed to and their diverse language background, we suggest that taking language context (e.g., manipulating ratio of L1 and L2) and individual differences into account in future studies can help establish a bigger picture of how bilingual language control mechanisms operate in speech production. This also highlights the limitation of the current study. The components (e.g., degree of switching and language engagement) in LSBQ (Anderson et al., 2018) were collected but were not analysed in the current study given we focused on the overall switch cost and L1/L2 performance within a group of Mandarin-English bilingual speakers living in the UK. However, we understand that individual variability is where the field is shifting towards (Gullifer & Titone, 2020), and we also agree that different factors (apart from language context) can influence each bilingual speaker's switching performance. Hence, for future directions, running an analysis using LSBQ can tap further into the nature of bilingual language control mechanisms. This issue is discussed further in Chapter 5.

3.6 References

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CHAPTER 4. Manuscript 3 – What is the brain doing before speech onset? An EEG study on bilingual language control mechanism

This study has been pre-registered on OSF (https://osf.io/ctb7a). The supplementary materials are provided in Appendix C. This manuscript will be submitted to *Brain and Language* in March 2026.

4.1 Introduction

Being able to switch from one language to the other is dependent on a variety of reason. The environment where switching is required where both languages are actively in use relates to the dual-language context (Adaptive Control Hypothesis "ACH", Green & Abutalebi, 2013). Within the framework of ACH, bilingual speakers' attentional system executes more cognitive controls in the dual-language context than in the other contexts (i.e., single language and dense code-switching contexts). Hence, during switching process, bilingual speakers need to successfully select the target language and ignore the irrelevant information, and one of the cognitive control mechanisms at play is inhibition (Green, 1998). Over the years, plenty of studies have shown that inhibition was at play during the dual-language context (e.g., picture/digit naming, Declerck et al., 2012; Meuter & Allport, 1999; Ma et al., 2016; Costa & Santesteban, 2004, Costa et al., 2006; reading words aloud, Ahn et al., 2020; Macizo et al., 2012; Filippi et al., 2013; Reynolds et al., 2016, Slevc et al., 2016, Lee et al., under review; voluntary switching, De Bruin et al., 2018; De Bruin & Xu, 2023; contextual cue effect, Timmer et al., 2024).

When inhibition is applied, the consequence researchers have found is the switch cost given the re-activation process of a language requires bilingual speakers to overcome the inhibition. The magnitude of inhibition can become greater to the dominant language (here, L1) than the non-dominant one (here, L2), whereby increasing the cognitive demands to overcome. This can reveal the pattern of how bilingual speakers “locally” deal with an immediate language switch (Meuter & Allport, 1999). Another one is global L1 slowing, revealing the pattern of how bilingual speakers rely on “globally” inhibiting the dominant language to be able to activate the non-dominant language (Christoffels et al., 2007; Branzi et al., 2014; Wodeniecka et al., 2020). The extent of bilingual speakers relying on either “local” or “global” control has been indeed inconsistent across studies. The inconsistency can be caused by language proficiency in which highly proficient bilingual speakers have been reported to yield better language switching performance comparing to less proficient bilingual ones (Costa & Santesteban, 2004; Declerck et al., 2020). However, given bilingual speakers can be exposed to different linguistic environment, one factor that also plays a role during language processing is the ratio of L1 and L2 within a dual-language context (Olson, 2016; Timmer et al., 2019). While studies have reported that inhibition takes place when there is an interference between languages (but see Blanco-Elorrieta & Caramazza, 2021), some researchers have also revealed that inhibition can be prepared. This then causes switch cost reduction or elimination (Costa & Santesteban, 2004; Khateb et al., 2017; Philipp et al., 2007; Ma et al., 2016; Mosca & Clahsen, 2016; Mosca et al., 2022; Verhoef et al., 2009). Even when switching is not required (i.e., staying in one language), with electroencephalographic (EEG) approach, inhibition has also been found to be at play before having to produce the target language, complementing the anticipatory ability of the brain (i.e., before speech onset, Wu & Thierry, 2017). However, to date, little is known of how a dual-language context affects the brain activity before speech onset. To that end, the current study was set out to tap into the dynamic nature of bilingual language processing within different dual-language contexts, whereby investigating how inhibition can be "prepared" before speech onset.

4.1.1 Language control in dual-language context

Bilingual language switching has been widely employed to investigate the underlying cognitive mechanisms. Researchers have used cued-switching paradigm (i.e., the target language signalled by a cue which bilingual speakers are required to use) (Jackson, 2001; Christoffels et al., 2007; Declerck et al., 2012; Declerck et al., 2015; Liu et al., 2019; Meuter & Allport, 1999; Philipp et al., 2007; Timmer et al., 2024; Timofeeva et al., 2023; Verhoef et al., 2009; Verhoef et al., 2010) and voluntary switching (i.e., bilinguals are allowed to switch anytime) (De Bruin et al., 2018; De Bruin & Xu, 2023; Gollan & Ferreira, 2009; Kleinman & Gollan, 2016), read-aloud paradigm (Declerck et al., 2019; Macizo et al., 2012; Slevc et al., 2016; Reynolds et al., 2016; Zuo et al., 2022). One common phenomenon of these paradigms is the effort to switch from one language (say L1) to the other (say L2), which is driven by the parallel activation of two (or more) languages. Hence bilingual speakers need to have the ability to identify the target language and ignore the interference from the non-target language. Successful selection of the target language involves a variety of cognitive mechanisms distributing from the supervisory attentional system (SAS). To be able to ignore the interferences, the mechanism behind has been referred to as inhibition (Green, 1998). In a seminal study, it is usually the dominant language (here, L1) requires more inhibition than the non-dominant language (here, L2) because the former receives more activation than the latter. Consequently, switching back to the stronger language elicits a greater switch cost than to the weaker language (Meuter & Allport, 1999). Additionally, it was shown that bilingual speakers often need to globally delay their dominant language to be able to benefit the non-dominant language (Christoffels et al., 2007). The reason behind is that the non-dominant language needs to receive activation when it becomes the target language. For instance, we know the brain needs to deal with a strong language and a weak language. However, if the strong language (or competitor) is always kept at its peak activation (especially when switching takes place), producing a weak language will become a difficulty on a cognitive level. Therefore, the strong language will be globally inhibited (but not all the time) to benefit the weak language. These, including switch cost and global delay of the dominant language, are the phenomenon in which inhibition emerges to optimise switching efficiency. However, the findings regarding the magnitude of inhibition bilingual speakers rely on have been inconsistent.

Over the years, the magnitude of inhibition can be modulated by a variety of factors (e.g., language proficiency/use, Costa & Santesteban, 2004; Costa et al., 2006, Declerck et al., 2019; age of acquisition, Bonfieni et al., 2019, cognitive flexibility, Liu et al., 2016, see Gade et al., 2021 and Gollan & Goldrick, 2023). But fewer studies, in language switching, have focused on the interplay between the activation of a frequently used language than a less frequently used language. If we tap into the linguistic environment where bilingual speakers are exposed to when they switch, one aspect has been less discussed is language context effect (see Olson, 2016; Timmer et al., 2019). This "language context" refers to the ratio of L1 and L2 and is usually determined by how much activation of L1/L2 is required to reach the language goal. With respect to ACH, there are three contexts in which L1/L2 use varies, single-language context (i.e., only one language in use), dual-language context (i.e., two languages in use), and dense code-switching context (i.e., intermixing L1/L2 words within the syntactic rules of one language) (Green & Abutalebi, 2013). Within these contexts, bilingual speakers can highly adapt themselves, whereby applying necessary cognitive control mechanisms, but there is one context that is more challenging for bilingual speakers. In particular, dual-language context resembles most language switching studies as L1/L2 are in use, and is the most cognitively demanding context given bilingual speakers need to be constantly aware of a sudden switch and re-configure their language goal flexibly. In fact, bilingual speakers can be exposed to different dual-language contexts. For instance, an individual can be exposed to a context where L1 is the most activated and predominant language (e.g., an L1-speaking country) but still required to switch to their L2, increasing the variability during bilingual language processing. As a result, the question behind is how inhibition operates through the different activation level of L1 and L2. Here, we refer to this as language context effect.

In a previous study, Timmer et al. (2019) employed a Context L1 (i.e., most pictures named in L1) and a Context L2 (i.e., most pictures named in L2) with a cued-switching paradigm. Dutch-English bilinguals were asked to name a set of pictures according to the language cue. Their findings showed that switch cost pattern between the two contexts were different as they found symmetrical switch cost in Context L1 but reversed asymmetrical switch cost (i.e., greater L2 switch cost) in Context L2. Moreover, the global L1 slowing only occurred in Context L1. This reveals that bilingual speakers' L1/L2 performance and the dependency on local or global control can be modulated as a function of language contexts. To that end, in our recent study (Lee et al., under review), we used a similar context manipulation with Mandarin-English bilinguals living in the UK. We asked the bilingual participants to switch between languages according to two face cues (i.e., Chinese person's face associated with Mandarin, American person's face associated with English). Our findings showed that Context L1 showed asymmetrical switch cost but symmetrical switch cost global L1 slowing in Context L2. Both studies, while reporting opposite findings on switch cost and global L1 slowing, we supported the notion that language context can also affect the way how bilingual speakers switch and the way they deal with the interplay between L1/L2 activation. More importantly, this then provides evidence to the current language switching literature in a way that bilingual speakers are highly flexible and the approach to reach the language goal relies on the context.

Across previous language switching studies, by presenting the language cue and target stimulus at the same time, researchers have well-established that there are cognitive demands when bilingual speakers switch. Interestingly, some researchers found that this magnitude of switch cost and inhibition can be reduced when presenting a cue before a target stimulus, showing the pre-activation effect on switching performance. To achieve this, researchers presented the language cue before the target picture onset (e.g., 500ms before), enabling bilingual speakers to pre-activate the target language in advance. This then results in the target language pre-activation before speech onset, and here, we will call this "pre-activation" (while some researchers call it "pre-cuing" or "cue-to-stimulus interval"). To date, there have been some studies focusing on how this pre-activation affects bilingual speakers' switching behaviour (Costa & Santesteban, 2004; Philipp et al., 2007; Khateb et al., 2017; Ma et al., 2016; Mosca & Clahsen, 2016; Mosca et al., 2022). One trend we can see is the reduction of switch cost. For example, Costa and Santesteban found switch cost can be reduced for Spanish-Catalan balanced bilingual, with smaller symmetrical switch cost alongside global L1 slowing. What they did was that they compared the switching performance by presenting the language cue either 500ms or 800ms before the target picture. The findings were straightforward as switch cost was reduced given the pre-activation was granted before speech onset. In Ma and colleagues' study, adopting Costa and Santesteban's paradigm, reduced switch cost (i.e., smaller asymmetrical switch cost) without global L1 slowing was found for Mandarin-English unbalanced bilinguals when pre-activation was given. Moreover, Mosca and colleagues' reported that, within a much shorter pre-activation time (250ms), switching can be cost-free (i.e., switch cost elimination) for bilingual speakers. However, none of the pre-activation intervals eliminated global L1 slowing. Taken together, while switch cost pattern and global L1 performance appeared to be different across studies, pre-activating the target language can sufficiently help bilingual speakers prepare for the inhibition process of the non-target language. As a result, switching to a different language is not necessarily as effortful as when presenting the cue and the picture at the same time (i.e., the typical switching paradigm).

More recently, in our previous study (Lee et al., in preparation) with Mandarin-English bilinguals, we adopted 250ms of pre-activation (as in Mosca et al., 2022) and manipulated the ratio of L1 and L2 by giving participants two different dual-language contexts, Context L1 and Context L2 (as in Timmer et al., 2019). The purpose was that we intended to further investigate the relationship between “language context” and “pre-activation” and test the role of pre-activation when one language was more predominantly used than the other. We also compared the switch cost pattern and overall L1/L2 performance without pre-activation (Lee et al., under review). Our results showed that language context did not affect much and that switch cost remained symmetrical without global L1 slowing in both contexts. This pattern of language performance was inconsistent with Lee et al. (under review), suggesting pre-activation can reduce language context effect and the need to globally inhibit the dominant language (but see Mosca & Clahsen, 2016; Mosca et al., 2022).We assumed that pre-activation modulated the pattern of global inhibition by reducing the global inhibition that bilingual speakers usually need when pre-activation is not given. We did not observe a cost-free switching as in Mosca and colleagues’ study given it may have been led by individual differences (and this indeed also plays a role in language processing, see DeLuca et al., 2019) or the sequence of the trials as their trial procedure was somehow highly predictable for the participants which could lead to no switch cost at all (we will get to this in the later sections). Still, the baseline we found was that pre-activation represented the phase when the attentional system pre-applied the necessary mechanisms within such short milliseconds before speech onset. That is, inhibition can be prepared to suppress interference from the other language, and many behavioural studies in language switching to date have revealed this phenomenon. Nevertheless, this has not been discussed much in EEG studies in a way of how the bilingual brain prepares for a language switch.

First, we shall mention that inhibition has been examined during L1/L2 production by using event-related potential (ERP) approach (Branzi et al., 2014; Christoffels et al., 2027; Declerck et al., 2021; Guo et al., 2013; Jaskson et al., 2001; Kang et al., 2023; Timmer et al., 2019; Wodniecka et al., 2020; Zhang et al., 2021). For example, in bilingual speech production studies, N200 is a commonly investigated ERP component associating with inhibition. During language switching process, switch trials elicited greater magnitude of N200 than non-switch trials, indicating the effort to switch to a different language (Verhoef et al., 2010), but there are other studies reporting the opposite results (Christoffels et al., 2007; Liu et al., 2016). In addition, the N400 has been used to investigate the semantic processing difficulty for L1/L2 lexical selection. For instance, greater N400 indicates naming difficulty, especially when bilingual speakers access L2 lexical representations than that of L1 (Proverbio et al., 2004, Jankowiak & Rataj, 2017, Wu & Thierry, 2017). In language switching, N400 amplitudes have also found to be more negative for switch trials than non-switch trials (Kang et al., 2020). These findings, using EEG approach, have revealed cognitive demands when having to make a response in L1 and L2 (see also neuroimaging studies De Bruin et al., 2014; Guo et al., 2011; Liu et al., 2010). Luk et al. (2012) mentioned that presenting a cue in advance can help promote language processing and activate the related brain regions. That said, little is known regarding how, within the pre-activation stage, bilingual speakers become ready to switch. More precisely, if in behavioural results, pre-activation can promote bilingual speech production by pre-applying inhibition to the non-target language, then this phenomenon should also be observed in brain activity.

Interestingly, in a previous study focusing on contingent negative variation (CNV). CNV is a negative amplitude indicating the anticipatory ability of the brain, and normally can be observed in the pre-stimulus phase. Wu and Thierry (2017) demonstrated that inhibition was at play during the pre-activation stage when Mandarin-English bilinguals (dominant in Mandarin) saw a cue 1000ms before the target picture (i.e., 500ms for the cue followed by a 500ms blank). The experimental design did not involve language switching as they separated the L1 naming and L2 naming trials with several non-naming trials (i.e., participants would see several blanks where they did not have to respond to anything). Namely, they avoided the switching effect to capture the pure L1/L2 production. The CNV here reveals the pre-activation stage of the brain, indicating the cognitive demands towards an upcoming language production. Wu and Thierry observed that the CNV showed more negative amplitude before having to produce L2 than L1. That is, the cognitive demands to inhibit L1 before L2 production were greater than vice versa. This was in line with Green's (1998) Inhibitory Control Model in which the more dominant language should be more difficult to inhibit, whereby increasing the magnitude of inhibition. Wu and Thierry presented an example in bilingualism literature (speech production in particular) in a way that inhibition can be pre-applied to the . The reason is that languages are activated in parallel, one language cannot be completely de-activated when the other is in use. Thus, the brain, by seeing the cue in advance, can pre-apply inhibition to the non-target language, and this phenomenon was visualised through CNV. The paradigm Wu and Thierry adopted was similar to a dual-language context, except that L1 and L2 naming trials were separated by non-naming trials, and this would largely reduce the need to inhibition. However, in language switching studies where bilingual speakers are exposed to a more frequent switching linguistic environment, no one has investigated how the inhibition process can be prepared before switching. With respect to ACH, this also raises a question of whether language context can modulate the brain activity when switching between languages. Timmer et al. (2019) have established an example investigating the effect of language context on switching performance, with a focus of late positive component (i.e., an ERP component indicating difficulty in lexical access) after speech onset. They exposed their participants to a Context L1 (i.e., 75% pictures named in L1) and a Context L2 (i.e., 75% pictures named in L2) with a cued-switching paradigm. In their results, Context L1 yielded greater LPC for an L2 switch than an L1 switch, indicating more challenging L2 (the weaker language) lexical access. Linking this to their behavioural results, bilingual speakers need to globally delay L1 responses to benefit L2 activation which they found symmetrical switch cost and global L1 slowing. Timmer and colleagues' suggested language context can affect ERP signals, whereby reflecting the brain activity during switching, but we can only tell that this difference occurred in the post-stimulus phase. To that end, the current thesis aims to explore how the brain responds to a language cue before speech onset and testify whether language context effect can also be observed for L1/L2 pre-activation.

4.1.2 The current study

To investigate how bilingual speakers prepare to switch, we aimed to focus on the effect of language context and pre-activation on the magnitude of inhibition with reference to our previous study using 250ms of pre-activation (Lee et al., in preparation). In the current study, adopting from Wu and Thierry's paradigm, we will use a 500ms of pre-activation followed by a 500ms of blank before the target picture (i.e., 1000ms of interval before stimulus presentation). This was to ensure there was enough time to measure CNV. From behavioural results, we measured the reaction times when switching between L1 and L2 within two dual-language contexts: a Context L1 (i.e, 75% pictures named in L1) and a Context L2 (i.e., 75% pictures named in L2). We then recorded participants' EEG pre-stimulus activity and measured the pattern of CNV (as in Wu and Thierry, 2017) to explore the inhibition pattern before speech onset. For post-stimulus, we then explored N200 and N400 to complement the results of CNV. Here, we present two research questions:

(1) How does pre-activation modulate switch cost and global L1/L2 performance? Here the behavioural performance was measured after stimulus onset. In our previous study (Lee et al., in preparation) with 250ms of pre-activation), we found symmetrical switch cost in both contexts, with no global L1 slowing at all. In the current study, we expected to observe the same results. That is, with 1000ms of pre-activation, the results should show symmetrical switch cost, alongside absence of global L1 slowing.

(2) How do language contexts modulate CNV during switching and how does pre-stimulus CNV affect post-stimulus ERPs? Here we investigate the ERP components before stimulus onset. There is no language switching study investigating the effect of language context on CNV pattern, hence we made our predictions according to Wu and Thierry (2017). Given CNV takes place before stimulus onset, brain signal should be modulated by language context. If language context can affect CNV pattern, we should observe greater CNV when Mandarin-English bilinguals (L1 dominant) switch to L2 than vice versa in Context L1 given greater L1 inhibition was expected. In Context L2, we should observe the same CNV pattern for both switching directions given we found symmetrical switch cost in our Context L2 given similar inhibition was expected. As for the L1/L2 non-switch trials, there should be no significant differences, even if there was, then the difference should be marginal, with L2 non-switch trials yielding greater negativity than L1 non-switch trials. For the post-stimulus N200, the inhibition that is often observed in N200 should show greater negative amplitudes for switch conditions than non-switch conditions. For post-

stimulus N400, this should show greater negative amplitudes for switch than non-switch trials since we predicted symmetrical switch effect in behavioural results. Language context was not expected to affect post-stimulus ERPs.

4.2 Method

4.2.1 Participants

Thirty healthy Mandarin-English bilinguals (20 females), with paper consent to participate, were recruited from Lancaster University. Each participant had normal or corrected-to-normal vision and reported no cognitive impairment. All participants spoke Mandarin as their native language (the dominant L1) and English as their second language (the non-dominant L2). Before coming to the lab, participants were asked to complete a language and social background questionnaire (LSBQ, Anderson et al., 2018) (see Appendix C, Table 5.3 for participants' language background).

Table 4.1. LSBQ self-rated L1/L2 proficiency

	L1	**L2**
Listening	98 (4.1)	69.5 (12.3)
Reading	98 (4.1)	73 (11.7)
Speaking	97 (5.71)	74.5 (12.3)
Writing	95.5 (6.86)	62.4 (20.2)

Note: Language proficiency rated on a 100-point scale. Each score is presented in mean and standard deviation in parentheses.

4.2.2 Materials and procedure

All materials for stimuli were identical as in Lee et al. (in preparation). We selected 288 grey pictures from Multipic (Duñabeitia et al., 2022) and these same pictures were also used in our previous language switching studies. Of the 288 pictures, half were critical ones (i.e., pictures included for data analysis) and the H-statistics[6] were below 1 and half were fillers (i.e., pictures excluded). The pictures were matched in terms of their H-statistics, number of phonemes and number of syllables. For language cues, we selected two Asian-like faces to create a more natural cued-switching environment (see Blanco-Elorrieta & Pylkkänen, 2017; Liu et al., 2019). Our previous studies used two famous celebrities' faces as language cues (i.e., Jack Chan for Mandarin, and Tom Cruise for English). However, in the current study, we used less conspicuous faces. These two Asian-like faces were ambiguous and can be counterbalanced across participants. In this way, the effect of visual cues on brain signal can be prevented.

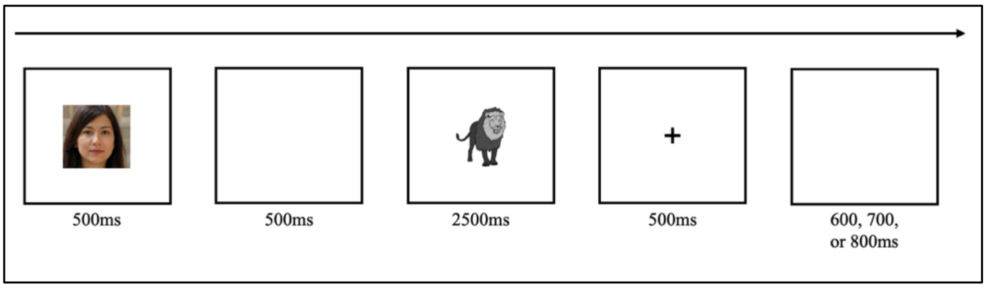
In the current study, there were four conditions within two blocks: L1 switch (switching from L2 to L1), L1 non-switch (staying in L1), L2 switch (switching from L1 to L2), and L2 non-switch (staying in L2). The number of these conditions were kept at 36 each. The two blocks were: Context L1 (i.e., 75% picture were named in L1) and Context L2 (i.e., 75% pictures were named in L2). The critical pictures were presented once in each block and were never repeated within the block. Previous studies tend to repeat the same picture several times, and here our purpose was to prevent facilitation effect by minimising repetition. The filler pictures were named in the predominant language of each block and were only presented twice within each block. These were then excluded from analysis.

At the beginning of the experiment, participants were first trained to name the filler pictures in both L1 and L2 according to the faces. The practice session started with 25 practice trials to familiarise the participants with the trial procedure. Here, only 25 fillers were used in the practice session. The cues and pictures were presented on a white

[6] H-statistics indexing name agreement of each picture were calculated by Duñabeitia and colleagues. The larger the index indicates less name agreement. Hence, pictures we included in data analyses were all below 1.

background operated by E-prime. We adopted the trial procedure in Wu and Thierry (2017). Each trial began with a language cue for 500ms and a blank for another 500ms. After this, participants saw the target picture and responded either in L1 or in L2. The target picture stayed on the screen for 2500ms, followed by a fixation cross for 500ms. We placed a fixation cross after the target picture to allow participants to blink. Then, there was a blank interval jittered for either 600ms, 700ms, or 800ms to decrease predictability of the next trial onset. The participants were encouraged to blink upon the fixation cross onset to avoid artifacts in the EEG data (see Figure 4.1 below for an example of the trial procedure). Half of the participants started from Context L2 and the other half started from Context L1.

Figure 4.1. Example of the trial procedure, language cue, and target stimuli



4.2.3 EEG recording and analysis

EEG activity, with the two electrodes at the mastoids (A1 and A2) set as the references, was recorded using Neuroscan with a fitted 36 channel EasyCap. The EEG data were pre-processed and analysed using EEGLAB (Delorme & Makeig, 2004) in MATLAB. We also used 4 additional eye-electrodes to monitor eye movements. The impedances were kept below 5kΩ. Two participants were excluded from analysis we failed to keep their impedances at the threshold. The data were filtered with a low-pas filter, 25-Hz, and a high-pass filter 0.05-Hz. We understand that the threshold can be either 15Hz, 25Hz, 30Hz or

40Hz across studies (e.g., Christoffels et al., 2007, Declerck et al., 2021; Jończyk et al., 2019; Timmer et al., 2019). The current study chose 25Hz is a relatively conservative threshold than the other ones. However, the research paradigm was conducted in accordance with Wu and Thierry (2017), hence we followed their ERP analysis pipeline (i.e., using 25Hz). For future directions, if we were to analyse our data using time-frequency analysis, we would focus on lower-frequency bands such as alpha and theta (e.g., Timofeeva et al., 2023). High-frequency bands (e.g., beta/gamma) bands were beyond the scope of the current study. Eye movement artifacts were corrected by using Independent Component Analysis (ICA). We measured the epochs ranged from -100ms to 1000ms for pre-stimulus brain activity (CNV) and -100ms to 600ms for post-stimulus brain activity (N200, N400). We selected this time window after stimulus onset to prevent speech artifacts. Baseline correction was employed in pre-stimulus activity. Independent Component Analysis (ICA) was conducted, and the ocular artifacts were rejected automatically. The non-ocular artifacts were then rejected with amplitudes below and above 150 μV within a 200ms moving window (see also Timmer et al., 2019). Participants who lost more than half of the epochs in one of the four conditions by each context (i.e., L1 switch, L1 non-switch, L2 switch, L2 non-switch) were then excluded for analysis. ERPs were averaged in reference to the peak latency of the four conditions.

We explored the negative-going mean amplitudes for both CNV, N200 and N400, with respect to Wu and Thierry (2017). The two ERP components were extracted according to the conditions in the two contexts. We analysed four ERP components: CNV, N200, and N400. The moving window for CNV was set at 120ms between 569ms and 689ms, with a focus on the anterior and central electrodes (F3, Fz, F4, FC1, FCz, FC2, C3, Cz, C4). We also selected the CNV electrodes for N200 analysis, with a 40ms moving time window (196ms – 236ms). To analyse N400 amplitudes, we focused on the central electrodes (FC1, FCz, FC2, C3, Cz, C4, CP1, CPz, CP2), with a 100ms moving time window (286ms – 386ms). We first aggregated the mean amplitudes for each participant, and then used ANOVA with the three predictors: Language (L1 and L2), Trial type (switch and non-switch), and Context (Context L1 and Context L2). We compared ERP waveforms according to the four conditions: L1 switch, L1 non-switch, L2 switch and L2-nonswitch.

4.2.4 Behavioural data cleaning and analysis

First, with respect to Declerck et al. (2021), we measured the reaction time of each response on Chronset (Roux et al., 2017), and accuracy on Gorilla (Anwyl-Irvine et al., 2020). The method was in accordance with the previous studies (Lee et al., under reivew; Lee et al., in preparation). To measure the accuracy, there were five categories we employed in accordance with our previous studies: (1) Correct (same language), Correct (synonyms), Incorrect (same language), Incorrect (different language) and No/Other sounds. In addition, we also extracted 5% of the recordings from each participant and manually measured the reaction time. Then, we ran a Pearson's correlation test between the reaction times generated by Chornset and the experimenter (r=0.9) (Declerck et al., 2021). Next, we cleaned the data by participants and item. Any reaction times shorter than 150ms or above/below 2.5 standard deviations were excluded. In the end, we excluded data within participants (1.9%) and within items (0.31%) and by participants and items (2.16%). Finally, we used lmerTest (Bates., 2015) to run reaction times analysis with three predictors: Language (L1 and L2), Trial type (switch and non-switch), and Context (Context L1 and Context L2). The analyses were conducted in accordance with the pre-registration. All predictors were contrast coded at ±0.5 before running the model. If a full model failed to converge, then we ran principle component analysis (rePCA, Bates et al., 2015) to find the predictor that contributed to the least variance. Accuracy was also analysed using general linear mixed-effect model with the same procedure in reaction time analysis.

4.3 Results

Note: The analyses were conducted in accordance with the pre-registration. In the pre-registration, we specified that we would run a three-way interaction (Language:Trial type:Context) to testify the effect of language context because the reviewers of the first manuscript (Chapter 2) strongly suggested that a three-way interaction was crucial. If the three-way interaction failed to show significant results, then running analyses separately for each context were not allowed. Still, in this PhD thesis, we ran analyses separately given we were also interested in the behavioural and ERP results in each context. Thus, we provide the separate results in Appendix C.

4.3.1 Accuracy

Accuracy analysis was conducted with the three predictors: Language (L1 and L2), Trial type (switch and non-switch), and Context (Context L1 and Context L2) (see Table 4.2 for overall accuracy). There was a main effect on trial type, showing participants performed more accurately in non-switch trials than in switch trials (β = .61, SE = .27, z = 2.27, p = .023). The results also showed marginal effect of context, showing Context L1 elicited more accurate responses than Context L2 (β = .38, SE = .23, z = 1.67, p = .094). The results showed no significant interactions nor other effects between the three interactions (p > .133).

4.3.2 Reaction time

Reaction time analysis was conducted with the three predictors: Language (L1 and L2), Trial type (switch and non-switch), and Context (Context L1 and Context L2) (see Table 4.2 and Figure 4.2 for overall reaction times). There was a main effect on trial type, showing participants were faster in non-switch trials than in switch trials (β = -58.34, SE = 14.75, $t(17.5) = -3.96$, $p < .001$). Between language and context, there was a marginal two-way interaction (β = -31.06, SE = 17.44, $t(4026) = -1.78$, $p = .075$). The results showed no other significant two-way and three-way interactions nor effects between the three predictors ($p > .236$) (see Table 4.3 for planned comparisons according to each context).

Figure 4.2. Overall performance by language and trial type

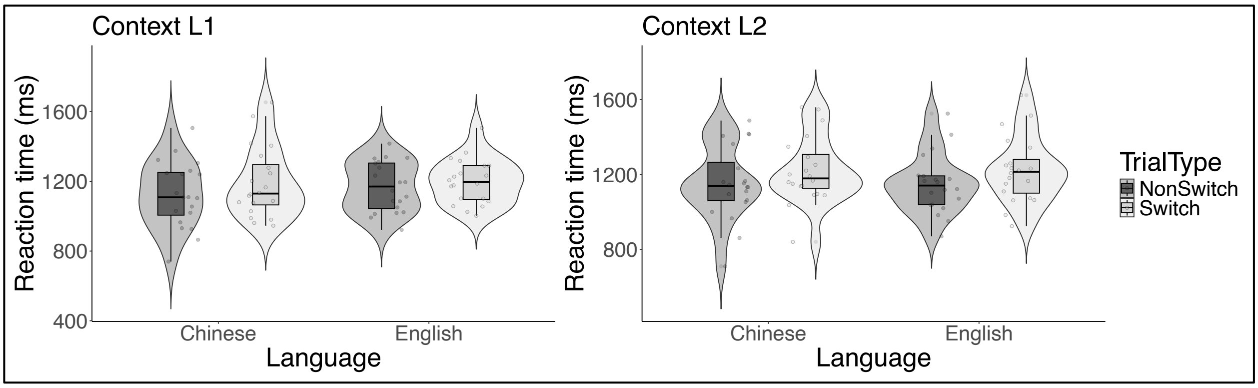


Table 4.2. Mean reaction times and accuracy

	L1-predominant		L2-predominant	
	RT (ms)	Accuracy (%)	RT (ms)	Accuracy (%)
L1 – NonSwitch	1118 (315)	97 (17)	1154 (339)	94 (23)
L1 – Switch	1191 (362)	94 (24)	1216 (320)	92 (27)
L2 – NonSwitch	1170 (345)	93 (26)	1143 (339)	92 (27)
L2 – Switch	1189 (320)	91 (29)	1203 (362)	89 (32)

Note: Standard deviations are reported within the parentheses.

Table 4.3. Estimates of language and trial type in each context

	β	SE	df	*t*	*p*
Context L1					
Switching effect					
L1 (Non-switch – Switch)	-69.59	22.92	16.7	-3.04	.007**
L2 (Non-switch – Switch)	-25.23	30.78	17.7	-0.82	.423
Language effect					
Non-switch (L1–L2)	-56.61	33.38	21.2	-1.70	.104
Switch (L1-L2)	-12.26	38.33	20.1	-0.32	.752
Context L2					
Switching effect					
L1 (Non-switch – Switch)	-65.38	18.22	55.7	-3.59	< .001***
L2 (Non-switch – Switch)	-75.25	27.93	16.1	-2.69	.020*
Language effect					
Non-switch (L1-L2)	-6.07	31.21	20.0	-0.19	.847
Switch (L1-L2)	-15.95	35.69	18.0	-0.45	.660

*$p < .05$. **$p < .01$. ***$p < .001$. Note: the results correspond to the post-hoc analyses performed to investigate the origin of the interaction.

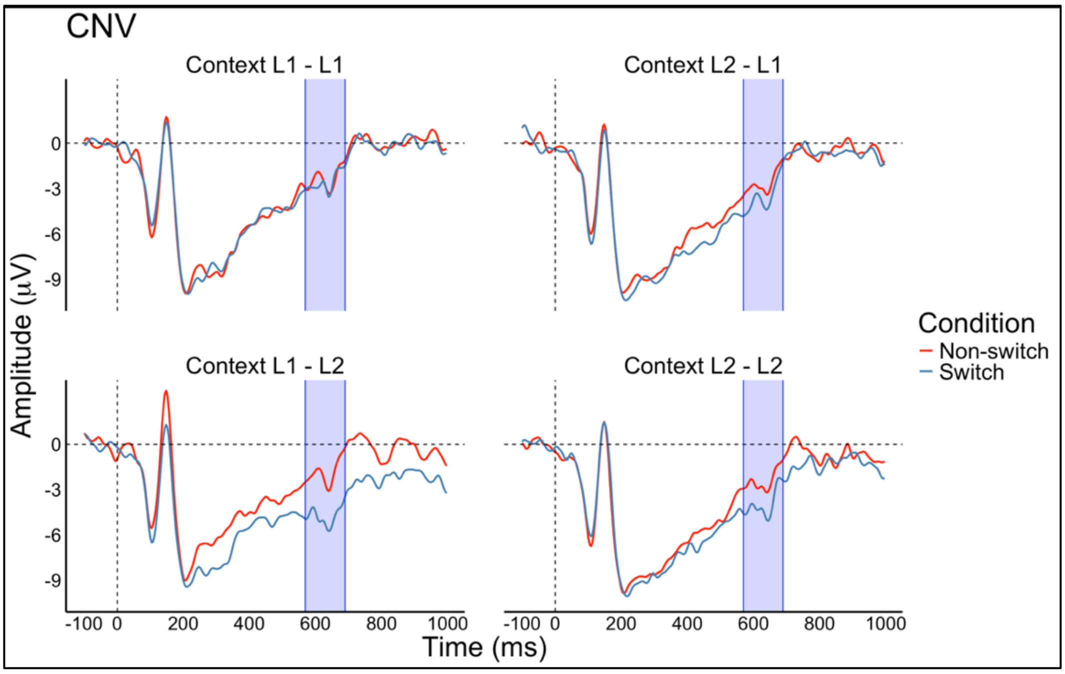
4.3.3 ERP results

4.3.3.1 CNV (569ms – 689ms)

The results showed an effect of trial type ($F(1, 19) = 20.67$, SE = 3.76, $p < .011$) in which switch trials yielded more negative amplitudes than non-switch trials (β = 1.39, SE

= .30, *t*(19) = 4.55, *p* < .001). This also interacted with language (F(1, 19) = 7.99, SE = 3.46, *p* < .011). Additional analyses showed more negative amplitudes towards L2 switch trials than L2 non-switch trials (β = 2.22, SE = .42, *t*(19) = 5.27, *p* < .001). There was no significant difference between L1 switch trials and L1 non-switch trials (β = .56, SE = .43, *t*(19) = 1.32, *p* = .204). We did not observe any other interactions or effects (*p* > .167) (see Figure 4.3).

Figure 4.3. CNV pattern by language, trial type, and context

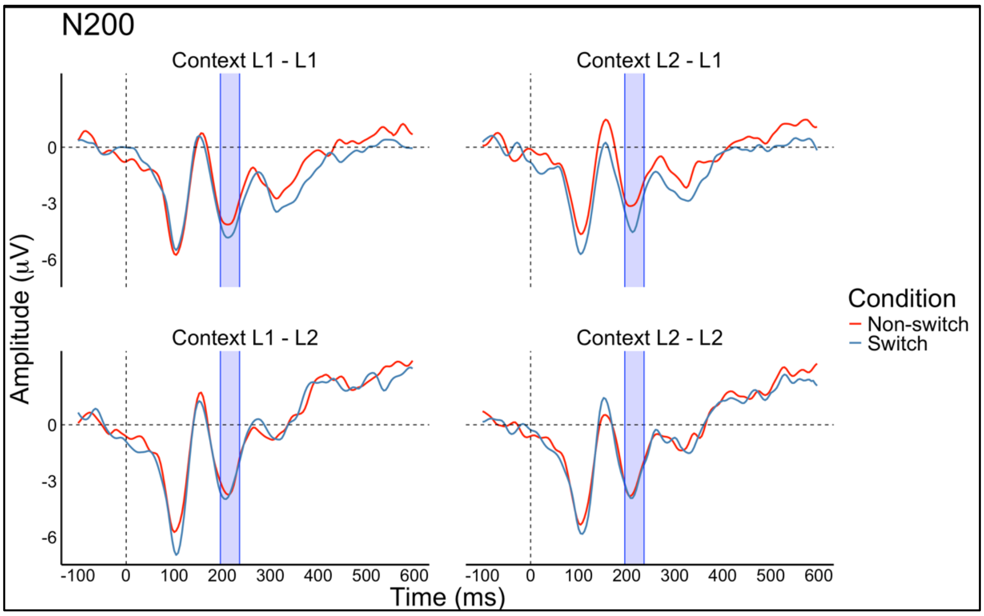


Note: Upper left: L1 in Context L1, Bottom left: L2 in Context L1,
Upper right: L1 in Context L2, Bottom right: L2 in Context L2

4.3.3.2 N200 (196ms – 236ms)

The results showed a marginal effect of language (F(1, 19) = 7.99, SE = 2.65, *p* = .083), but no other effects nor interactions were found (*p* > .123) (see Figure 4.4).

Figure 4.4. N200 pattern by trial type, language, and context



Note: Upper left: L1 in Context L1, Bottom left: L2 in Context L1,
Upper right: L1 in Context L2, Bottom right: L2 in Context L2

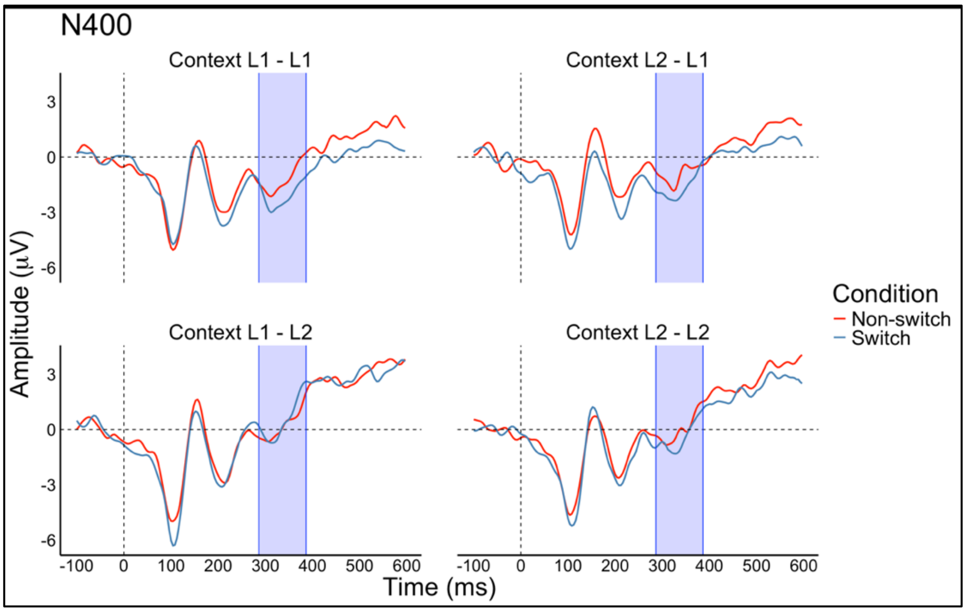
4.3.3.3 N400 (286ms – 386ms)

The results showed a language effect (F(1, 19) = 17.95, SE = 9.75, $p < .001$), indicating more negative amplitudes in L1 production than L2 production (β = -1.54, SE = .36, $t(19) = -4.24$, $p < .001$). There was a marginal effect of trial type (F(1, 19) = 3.97, SE = 2.11, $p = .061$). No other interactions were found ($p > .181$) (see Figure 4.5).

In the current study, we measured the mean amplitude and peak latency for N400 and the electrodes around the centre-parietal region were selected according to Wu and Thierry (2017). However, N400 appeared around 500ms – 620ms in their study. On the contrary, our negative amplitudes for N400 appeared relatively early, which can potentially be a different, earlier ERP component. For example, this can be considered N200 (appearing around 250ms – 350ms, see Christoffels et al., 2007), whereby indexing the early inhibitory effects during language switching. Alternatively, given we used a picture-naming paradigm, this can also be considered another ERP signals appear between 200ms – 300ms or 250ms – 350ms, meaning

N300 signals (Truman & Mudrik, 2018; Chen et al., 2022). This indexes picture object identification that is distinct from N400. However, N300 waveforms are rarely discussed in language switching studies, we believe this requires further analyses. While we followed a fixed-window approach, we suggest that a moving time window approach can be adopted to fully capture brain activity. This will then enable a more precise ERP measurement and further link it to the underlying cognitive mechanisms. Furthermore, this approach will allow more flexible comparisons between conditions and individual variability, particularly from the perspective of how these factors contribute to variations in brain signals. Note that the sample size of the current study is relatively small, it is necessary to increase the power for inter-individual comparisons.

Figure 4.5. N400 pattern by language, trial type, and context



Note: Upper left: L1 in Context L1, Bottom left: L2 in Context L1,

Upper right: L1 in Context L2, Bottom right: L2 in Context L2

4.4 Discussion

In the current study, we aimed to investigate the effect of pre-activation on switching performance. More importantly, with respect to Wu and Thierry (2017), we took a step forward by exploring how the brain prepared for a language switch and how language context affected the EEG activity before speech onset. To complement our results of pre-stimulus CNV, we also looked at the post-stimulus ERP components (i.e., N200, N400). This enabled us to capture how CNV affected the post-stimulus brain activity. In the behavioural findings, switch cost remained symmetrical and no global L1 slowing was found, which was in line with our predictions. In the pre-stimulus ERP, we predicted that CNV pattern should be greater when switching to L2 than to L1. Moreover, language context should affect the pre-stimulus CNV, namely the difference between switching to L1/L2 in Context L1 should be greater than in Context L2. In addition, if CNV can show the inhibition before having to switch to a language, then the post-stimulus brain activity should show less cognitive demands to switch. In the next section, we will discuss our results according to the research questions.

4.4.1 How do pre-activation and language contexts modulate switch cost and global L1/L2 performance?

Regarding the first research question, here we aimed to investigate whether pre-activation can affect participants' switching behaviour. We presented the language cue 1000ms before the target picture, which was a similar trial procedure as in Wu and Thierry (2017), except that we adopted a cued-switching paradigm. In this way, we would also be able to have enough time to measure CNV and the magnitude of inhibitory control before speech onset. Furthermore, as we were also interested in how language context affected switching performance, we presented Mandarin-English bilingual speakers with Context L1 (75% pictures named in L1) and Context L2 (75% pictures named in L2). We predicted that symmetrical switch cost would show in both contexts, with no global L1 slowing at all. The behavioural results were in line with our predictions.

We did not observe the effect of language context on switch cost. This was not surprising as language context effect was not significant in our previous study with 250ms of pre-activation, neither. To begin with, the magnitude of switch cost was largely reduced. Referring back to Lee et al. (under review) without pre-activation, the language cue was presented simultaneously with the stimulus, leading to language context effect on switch cost and overall performance. However, in the current study, the language cue was presented 1000ms before stimulus onset, which was an even longer interval allowing bilingual speakers to prepare for the upcoming target language. Here, in line with our previous study, we assumed that pre-activation plays the role of reducing the cognitive demands when switching between L1 and L2. In other previous studies, asymmetrical switch cost was observed, indicating switching to L1 was more cognitively demanding than switching to L2 (Green, 1998; Meuter & Allport, 1999, Costa & Santesteban, 2004; Lee et al., under review; Ma et al., 2016; Verhoef et al., 2009). The reason is that L1 normally receives more inhibition than L2 because the former yields greater interference than the later. In turn, when the cue and stimulus are presented simultaneously, this then leads to greater switch cost to L1 than to L2. However, when bilingual speakers were allowed to pre-activate the target language 1000ms before having to respond to anything, the brain would have enough time to overcome the strong L1 inhibition. As a result, asymmetrical switch cost would then be largely reduced, whereby showing symmetrical switch cost.

It is noteworthy that the change of switch cost pattern (i.e., from asymmetrical to symmetrical) has been inconsistent. For example, in Costa and Santesteban (2004), presenting the language cue 500ms and 800ms before the target picture had some effect on unbalanced bilinguals, but this effect did not change the pattern of switch cost. Indeed, there was switch cost reduction in unbalanced bilinguals, but the pattern of switch cost remained asymmetrical, suggesting that unbalanced bilinguals will always show the asymmetry. Similar results were also reported by Ma et al. (2016) when they recruited unbalanced Mandarin-English bilinguals. Nevertheless, Mosca et al. (2022) and Mosca and Clahsen (2016) did not report such asymmetrical trend for switch cost. Mosca and colleagues presented the language cue 250ms, 500ms, and 800ms before the target picture and reported switch cost elimination for Dutch-English bilingual speakers. They further indicated that pre-activation help bilingual speakers become fully ready to switch to the other language, whereby eliminating all switch cost, whereas the current study reported symmetrical switch cost. In Mosca and colleagues' study, the reason can be the trial procedure as the switch and non-switch trials were presented using a fixed sequence. For instance, in an L2 switch condition, the preceding trials would have to be three L1 trials (i.e., L1-L1-L1-L2). For L1 switch condition, the same manipulation was also employed. This allowed the researchers to calculate the pure switch effect after naming the three trials in the same language. The benefit of this was to avoid any sudden switch, whereby reducing the magnitude of switch cost. However, this can potentially increase the predictability of the next trial. The brain is adept at predicting the next upcoming trial and this phenomenon has been reported in previous studies using pre-activation in behavioural and EEG studies. In a meta-analysis, furthermore, Luk et al. (2012) highlighted the effect of presenting a cue before the target picture, whereby giving the brain an opportunity to apply necessary language control to achieve the goal. As a result, when using pre-activation interval alongside the fixed procedure of the trials, this can presumably reduce interference and the need of inhibition, whereby showing no switch cost at all. For this, in our previous study using 250ms of pre-activation and the current study with

1000ms, alongside switch and non-switch trials presented pseudo-randomly (i.e., the participants could not predict the next switch), our results revealed symmetrical switch cost. As a result, here we suggest that, unless the trials are highly predictable, cued-switching would elicit switch cost at least in a symmetrical pattern.

Second, language context did not affect global L1/L2 performance, meaning L1 was not globally delayed. Global L1 slowing has been reported in some previous studies (Timmer et al., 2019; Chirstoffels et al., 2007; Mosca & Clahsen, 2016; Mosca et al., 2022). The reason is that a dual-language context sometimes requires global L1 inhibition to benefit the non-dominant L2 (see also Declerck et al., 2020). However, in the current study, absence of global L1 slowing was not surprising as we did not observe global L1 slowing either when 250ms of pre-activation was given (Lee et al., in preparation). The pre-activation of the target language largely reduces the need of global L1 inhibition, hence language context does not necessarily affect much on overall production. Unlike in Lee et al. (under review), L1 was globally delayed, showing symmetrical switch cost in Context L2. We assumed that it was because of the highly activated L2, and that the dominant L1 would have to be globally inhibited (see also Timmer et al., 2019 that showed language context effect on switching, global L1 slowing and symmetrical switch cost in Context L1). In the current study, by presenting the language cue before the target picture, language context effect did not play a significant role. Interestingly, Mosca et al. (2022), even when switch cost was eliminated, still reported global L1 slowing, suggesting bilingual speakers had to rely on global inhibition in a dual-language context. However, the current study did not show such global inhibition. Do bilingual speakers still rely on global inhibition in each context when pre-activation is allowed?

While some researchers suggested that language proficiency (i.e., unbalanced bilinguals v.s. balanced bilinguals) can play a role regarding the way how global L1 inhibition is found in switching (see Declerck et al., 2020), but here our answer leans towards language context. This can potentially explain why our studies using pre-activation did not yield global L1 slowing at all. For example, the ratio of L1 and L2 in Mosca et al. (2022) was 50% L1 – 50% L2. This can potentially increase the need of global L1 inhibition. Going back to Lee et al. (under review), there was global L1 slowing in Balanced context (50% L1 – 50% L2). This means that Mandarin-English bilinguals also need some extent of global L1 inhibition to benefit L2 activation. This reveals that the activation of L2 in a context can largely determine how much bilingual speakers rely on global L1 inhibition. In turn, when Mosca and colleagues exposed their participants with a context similar to Balanced context, global L1 inhibition will be observed. Furthermore, alongside 50% L1 – 50% L2 manipulation, global L1 inhibition will potentially become even more obvious when trial procedure is fixed and predictable (as in Mosca et al., 2022). The reason is that this enables bilingual speakers to prepare for a language switching environment, and when bilingual speakers are exposed to such environment (highly predictable and balanced context), the dominant L1 can be proactively globally delayed. To that end, in our studies with Context L1 and Context L2, global L1 inhibition may not become the main language control that bilingual speakers rely on as trial procedure was unpredictable. This then complements the control processes in ACH (Green & Abutalebi, 2013) in terms of the different language switching performance in the dual-language context. In particular, bilingual speakers are highly flexible, whereby executing different necessary mechanisms. Although no language context effect was found to modulate the pattern of language performance in the current study, we provide extra evidence showing how bilingual speakers can perform differently in the dual-language context.

4.4.2 How do pre-activation and language contexts modulate the pre-stimulus and post-stimulus brain activity?

The second question aims to address how pre-activation of the target language and language contexts affect participants' brain activity before speech onset. Previous studies in language switching (the ones with pre-activation) have largely focused on bilingual speakers' language performance using behavioural method, hence we know there is an effect when target language is pre-activated. The outcome contributed by this effect mostly reveal in inhibition and switch cost, in which bilingual speakers can prepare and inhibit the non-target language beforehand, leading to less effort to switch (Costa & Santesteban, 2004; Ma et al., 2016; Mosca & Clahsen, 2016; Mosca et al., 2022; Khateb et al., 2017; Verhoef et al., 2009). Bilingual speakers' preparation ability has also been investigated in the past (see also Bonifacci et al., 2011 for bilingualism effect on anticipation; Singh & Mishra, 2016 for the effect of language proficiency on anticipation). However, in the language switching literature to date, little is known regarding the underlying mechanisms in the pre-activation stage and the role of language context.

This, among all language switching studies, would be the first results focusing on the CNV before the target stimulus, which was the main ERP component of this study (i.e., 569ms – 689ms pre-stimulus). We also explored the post-stimulus ERP components, which were N200 (196ms – 236ms) and N400 (286ms – 386ms). The predictions were made in accordance with Wu and Thierry's (2017) findings and ICM (Green, 1998). We predicted that greater CNV (i.e., more negative amplitude) should be observed when switching to L2 than to L1. The CNV for the non-switch trials would not differ much. The reason is that switching to L2, in terms of ICM, requires more inhibition to reduce the activation of the dominant language L1. Hence, if greater L1 inhibition is needed, then we should observe greater CNV in the brain activity before switching to L2. Furthermore, in our predictions, this

CNV pattern (i.e., switching to L2) should yield greater difference when participants are exposed to Context L1 than Context L2. We made this prediction because in Lee et al. (under review) as there was a significant language context effect on switch cost, showing that L1 requires the most inhibition given its high activation in Context L1. Hence, if language context plays a role in the pre-stimulus CNV, greater CNV pattern should be observed when bilingual speakers switch to L2 than to L1, especially in Context L1.

The results in the current study were in line with Wu and Thierry (2017). As in our paradigm with Mandarin-English bilingual speakers, Wu and Thierry presented the language cue 1000ms before the target picture. Within this 1000ms interval, it was sufficient for bilingual speakers to apply necessary mechanisms towards the non-target language. Seeing a language cue promotes the anticipatory ability of the brain. In Wu and Thierry's study, knowing L2 was the target language stimulated a greater effort to inhibit L1. Similarly, in the current study, we found that bilingual speakers needed greater L1 inhibition when they knew they were about to switch to L2. This phenomenon was particularly shown in the CNV pattern (see Figure 4.3), in which switching to L2 elicited greater negative amplitudes than switching to L1. We assumed this was driven by the inherent language dominance of bilinguals, which also goes in line with Green's ICM (1998). The ICM (as well as Meuter & Allport, 1999 and Costa & Santesteban, 2004) predicts that the cognitive demands required for unbalanced bilinguals can be modulated by language proficiency and use, suggesting greater inhibition is applied to the dominant language. For our Mandarin-English bilingual speakers whose dominant language is L1, greater inhibition is required when they switch to L2. Up to here, the CNV pattern shows the language performance when bilingual speakers "switch away from" a language (e.g., switch away from L1 to L2). But what about "switch to" a different language?

Across most language switching studies, researchers have been dedicated to exploring the reaction times when bilingual speakers switch to a language. This can be seen in the switch cost reported in each study. For example, one classic finding is the greater switch cost when switching to L1, reflecting more time to overcome the strong inhibition. However, not much relevant behavioural studies have investigated the effort to “switch away from” a language. This then brings us back to the two control processes in ACH (Green & Abutalebi, 2013), namely task engagement and disengagement. Both these two are essential in the dual-language context, but the effort needed for each is less straightforward across the studies in bilingual language switching. In the scope of language switching, task engagement requires speakers to engage in a language (e.g., switch away from L2, then “engage” in L1), while task disengagement requires them to switch away from a language in order to activate a different language (e.g., switch “away from” L1). Blanco-Elorrieta et al. (2018) conducted a language switching study with bilingual speakers who use American Sign Language and English (i.e., bimodal bilinguals). They investigated the activated brain regions (i.e., anterior cingulate cortex, ACC and dorsolateral prefrontal cortex, dlPFC) within two phases, “switch to” and “switch away from” a language. Their MEG results showed that switching away from a language tended to recruit more activation in the brain regions. In other words, ACC and dlPFC were more activated when participants need to switch away from a language than to switch to a language. In the current study, the CNV showed a similar pattern, suggesting switching to L2 (i.e., disengage from L1) was more cognitively demanding than switching to L1 (i.e., disengage from L2) (see also Verhoef et al., 2010). However, the effort to switch to L1 (i.e., the cost to overcome inhibition) was not significant, at least according to the results of CNV in the current study. Still, this does not necessarily mean that switching to L1 is not effortful. We speculated that CNV at this stage cannot show the effort when bilingual speakers engage in/switch to a language because it is still before stimulus presentation.

Hence, to be able to observe how bilingual speakers "engage in/switch to" the subsequent language event, researchers might need to investigate the components after stimulus presentation, and how CNV affects the post-stimulus ERPs (e.g., N200, N400[7]).

The post-stimulus N200 has been widely investigated in bilingual language switching (e.g., Jackson et al., 2001; Guo et al., 2013; Kang et al., 2018; Verhoef et al., 2009). For example, Jackson and colleagues used a switching paradigm without pre-activation in their study, and they found more negative N200 amplitudes when switching from L2 to L1 than vice versa. This indicated the asymmetrical switch cost effect in the ERPs. Nevertheless, in other studies (e.g., Guo et al., 2013; Kang et al., 2018; Verhoef et al., 2009) using pre-activation before the target stimulus, the post-stimulus N200 showed no difference in switching between L1 and L2 with overall more negativity in switch trials than non-switch trials. This, to some extent, showed the effect of pre-activation, which can later be reflected in the post-stimulus phase. In our results, we only found marginal effect of language in which L1 almost elicited more negativity in N200 than L2. This could suggest that the inhibition normally shown in post-stimulus N200 was largely reduced by the pre-stimulus CNV. In post-stimulus N400, a negative ERP component that can reflect the semantic processing difficulty of the trials, has been reported in previous studies (e.g., Chang et al., 2016; Declerck et al., 2021; Kang et al., 2020). These studies showed greater N400 for switch trials than for non-switch trial, suggesting symmetrical switch effect. In Chang and colleagues' study, greater N400 elicited in L1 switch trials, indicating asymmetrical switch effect. However, this was not observed in the current study. The results showed greater N400 in L1 than in L2 overall but without any switch effect, meaning accessing (or engaging in) L1 was

[7] We also analysed Late Positive Component (LPC) which peaks around 400ms after stimulus onset (430ms – 530ms in the current study), and this has also been considered an inhibition-related component as N200 (Timmer et al., 2019; Martin et al., 2013). However, we did not specify that we would investigate LPC in the pre-registration. Hence, we put the plots and results in Appendix C.

overall more difficult than L2. Alternatively, there may have switch effect for L1 as there was a tendency in Figure 4.5. This, perhaps, reveals the overall cognitive demands to engage in L1 in post-stimulus brain activity. Alternatively and according to Figure 4.5, there was a tendency showing greater N400 towards L1 switch conditions than L2 switch conditions. However, we did not have enough statistical results to claim this. Together with the results in N200 and N400, we assumed this was because of the pre-stimulus interval (i.e., 1000ms). Specifically, the CNV showed that the brain has already coped with the interference, hence the results showed the absence of switch effect in N200 and N400.

Finally, it was a pity that the results showed no effect of language context on the three ERP components. Although the figures reported in the results section show a tendency towards language context effect (especially CNV and N400), the current study failed to replicate the language context effect as in Lee et al. (under review). We assumed that it was because of the sample size, since there were only 20 participants left for data analysis. We further ran a Bayes factor model to testify whether our data are more likely to reach significance. However, the results (factors < .0001) showed that it is very unlikely that our data can reach such significant effects. Frankly, the lack of significant language context effect in post-stimulus ERPs was not so surprising given there was no such effect in the behavioural results neither. The reason is that the pre-activation of the target language was sufficient to balance the language context effect, unlike language switching without pre-activation. As suggested in Luk et al. (2012), the relevant brain regions can proactively apply necessary mechanisms to achieve the language goal. In ACH (Green & Abutalebi, 2013), while the dual-language context requires the most control processes comparing to the other two contexts (i.e., single language and dense code-switching), presenting a cue before speech onset can largely reduce the need to execute those control mechanisms. Therefore, neither ERP nor behavioural results (i.e., post-stimulus stage of speech production) will be manipulated by language contexts. For the pre-stimulus CNV, as Figure 4.3 shows a tendency towards context effect, here we suggest that with more participants (e.g., more than 30 participants), language context effect can be successfully detected. To sum up, the current study goes in line with Wu and Thierry's (2017) results (i.e., producing L2 reveals greater CNV) that revealed the effort to produce one language and inhibit the other.

4.5 Conclusion

The current study was conducted using a cued-switching paradigm. Being exposed to two different dual-language contexts, the participants were presented with a face language cue 1000ms before the target picture. Using EEG method, we were able to measure how the brain prepares for a language switch. We, for the first time, revealed that switching to L2 requires more inhibition to L1 before speech onset because the participants were inherently more dominant in L1 than in L2. While no language context effect was found, the current study then provides evidence for future studies to tap into the anticipatory ability of bilingual speakers not only in speech production, but also in other behavioural tasks.

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CHAPTER 5. GENERAL DISCUSSION

This thesis aims to explore how Mandarin-English bilingual speakers switch between L1 and L2 flexibly in different dual-language contexts, whereby complementing ICM and ACH. Using a cued-switching paradigm in each study, bilingual speakers were asked to name a set of target stimuli according to the language cue. As the central part of the thesis is the effect of language context on switching, I manipulated the ratio of L1 and L2 to investigate switch cost pattern and the overall language performance. An EEG study was also conducted and serves as the last study complementing the behavioural results of inhibitory control. This thesis will contribute to the field of bilingualism in terms of the flexible bilingual language control on switching and lexical selection.

5.1 Summary of findings

The second chapter (Manuscript 1) introduces the first study consisting of two experiments with top-down (i.e., picture naming) and bottom-up (i.e., reading words aloud) language switching. Each experiment contained L1-predominant, L2-predominant and Balanced contexts. Linear mixed-effects model was used to run analysis based on the three predictors: Language (L1 and L2), Trial type (switch and non-switch), and Context (L1-preodminant, L2-predominant, and Balanced).

The results showed that bilingual speech production become more sensitive to language context when top-down production is involved. This was shown in the significant three-way interaction between the three predictors. In a context where L1 was the predominant language and was highly activated, switch cost pattern became asymmetrical indicating greater L1 inhibition. The same pattern of switch cost was found in Balanced context, where L1 and L2 were used equally (global L1 slowing was also significant). However, this was not the case in the other context, namely Context L2, as this showed symmetrical switch cost and globally delayed L1 responses.

Nevertheless, in read aloud task, language context did not modulate switch cost pattern nor overall L1/L2 performance. This shows that switch cost pattern remains symmetrical across dual-language contexts with different L1/L2 ratio. Across all read-aloud studies, switch cost pattern tends to be inconsistent, and this can possibly be contributed by linguistic distance (discussed in future direction).

To better understand how the magnitude of inhibition was modulated by language context, the next study was conducted to investigate the effect of the pre-activation on switching performance. In the third chapter (Manuscript 2), I used Context L1 (previously called L1-predominant) and Context L2 (previously called L2-predominant) contexts alongside a short pre-activation interval (i.e., 250ms) interleaving a language cue and a stimulus (i.e., 250ms, see Mosca et al., 2022). This manipulation was to test if inhibitory control can be prepared before having to respond to the target stimulus. Data analysis method was consistent with the first study. The results showed that, with 250ms of interval, inhibition can be pre-applied to the non-target language and the target language can be pre-activated. This will then reduce the cognitive demands to switch. Particularly, I found that switch cost pattern was symmetrical and global L1 slowing was absent in the two contexts.

In the fourth chapter, the results showed constant symmetrical switch cost, which contradicted with Mosca and colleagues' study. The findings showed that even within 1000ms of pre-activation, switch cost still could not be eliminated. I assume, again, this was caused by the trial procedure as aforementioned. Another focus of the study is the brain activity before speech onset. With respect to Wu and Thierry (2017), an EEG study focusing on CNV (i.e., pre-stimulus activity), N200 (i.e., post-stimulus inhibition) and N400 (i.e., post-stimulus semantic processing) was conducted. The language cue was presented 1000ms before the target stimulus to measure the CNV. The statistical results, again, did not show any effect of language context on L1/L2 performance as the switch cost pattern remained symmetrical. Furthermore, no global L1 slowing was observed. Here, it was shown that using a pre-activation interval 1000ms before the target stimulus can observe greater cognitive demands while the brain prepare for an L2 switch than an L1 switch. The results then complemented the previous behavioural results. Additionally, this provides the first CNV evidence (in language switching studies) indicating the anticipatory process before bilingual speech production. Although, in the plot, there was a tendency to significant language context effect, this cannot be claimed given no statistical significance was yielded (perhaps the sample size was relatively small).

5.2 The effect of language context

In line with Timmer et al. (2019), language context plays a role in bilingual language switching, suggesting the underlying mechanisms can be modulated according to different dual-language context. While Timmer and colleagues' findings on switch cost pattern and global L1 slowing were different from my results (as we found opposite findings for each context), our findings contribute to the notion of ACH (Green & Abutalebi, 2013). In particular, I found that bilingual speakers were able to adapt themselves in different dual-language context, and importantly, the inhibitory control can be modulated during switching. There have been studies discussing which type of bilingual speakers should produce (a)symmetrical switch cost (Costa & Santesteban, 2004; Meuter & Allport, 1999; Christoffels et al., 2007; Jackson et al., 2001, Declerck et al., 2020). In a recent meta-analysis (Gade et al., 2021), the researchers suggested to explore other factors given the inconsistency across literature. Hence, the current study aimed to shed light on the effect of language context on switching because apart from language proficiency, the activation and inhibition can largely influence each other, yielding switch cost differences. Furthermore, the results will then explain a question regarding the model of inhibitory control Declerck (2020) raised in his review. In his review, he stated that one phenomenon that ICM (Green, 1998) cannot fully explain is the reason why sometimes bilingual speakers were slower to switch back to L2 than to L1 (note that in ICM, it is hypothesised that switching to L1 should be slower). The answer is straightforward – language context. Greater L2 switch cost has been found in some previous studies, and here I will mention Timmer et al. (2019) given they reported these results by comparing different language contexts (see also Olson, 2016). While I did not find greater L2 switch cost in Manuscript 1, we can see that bilingual speaker had to rely on global inhibition to their dominant language to highly activate their non-dominant language. To contribute to ICM, thus, language context should be taken into account when we intend to investigate bilingual speakers' language performance.

However, this does not mean that language context will always significantly affect the way how bilingual speakers switch between languages. In my studies, I further showed that production modality and pre-activation potentially play a role in bilingual language processing. First, in Manuscript 1 (Experiment 2), switch cost remained symmetrical across the contexts, suggesting reading word aloud should not be affected by language context. In addition, this shows that even in a production task where words (i.e., univalent stimuli) are used a language cue, switch cost will mostly be observed (Macizo et al., 2012; Slevc et al., 2016; Reynolds et al., 2016; Zuo et al., 2022). Hence, this challenges the framework proposed by Blanco-Elorrieta and Caramazza (2021) and Finkbeiner et al. (2006) regarding cost-free switching with univalent stimuli. The reason is that parallel activation leads to interference from the irrelevant information, even when bilingual speakers read words aloud.

Therefore, there needs to be some extent of interference control (e.g., inhibition) to help promote the activation of the target language. Their framework based on cost-free switching has been less reported in switching production studies (see also Li et al., 2024). While it seems that the intention is to challenge ICM (Green, 1998), it is not clear of how bilingual speakers can carry out a cost-free switching production. Indeed, ACH (Green & Abutalebi, 2013) proposed a context called "dense code-switching" context where all control processes are less needed than dual-language context and single-language context. If bilingual speakers (e.g., the balanced bilingual speakers) code-switch every day, then less to no switch cost can be observed. However, more investigations on language control in dense code-switching are required in the future to truly understand the underlying mechanisms (see Jiang et al., 2024).

5.3 The preparation of speech production

In Manuscript 2 and 3, it was apparent that pre-activation plays the role of balancing the effect of language context because switch cost showed symmetrical across the two contexts. This then highlighted the anticipatory ability of the brain, contributing to language switching literature. The role of pre-activation has been investigated in some studies (Costa & Santesteban, 2004; Declerck et al., 2015; Verhoef et al., 2009; Ma et al., 2016; Khateb et al., 2017; Mosca & Clahsen, 2016; Mosca et al., 2022). It is noteworthy that Mosca and colleagues found switch cost elimination in language switching with the same pre-activation interval, suggesting language switching can be cost-free. The studies in the current thesis did not show such results. To address this difference carefully, here I suggest that bilingual speakers can be prepared to switch by presenting a cue 250ms in advance, and that this preparation can largely reduce switch cost magnitude. However, to be able to eliminate switch cost within 250ms, researchers need to make the trial procedure much more predictable. Declerck et al. (2015) tested switch cost difference between fixed sequence and random sequence trial procedure, and they found smaller switch cost for the former. As a result, future studies can focus on manipulating the predictability of trial procedure, with both random and fixed presentation, and testify whether switching to a different language can be prepared such that the cognitive demands can be eliminated.

What further complements the behavioural findings is the EEG evidence showing the anticipatory ability of the brain. In Manuscript 3, the results were in line with Wu and Thierry's study by adding evidence to the language switching literature. Moreover, this CNV seemed to modulate the post-stimulus brain activity. For example, N200 and N400 only showed marginal and significant language effect respectively, but not switch effect (see also Appendix C for the LPC pattern). We speculated that the ability to prepare for a switch can reduce the cognitive demands before having to respond to the target stimulus. Interestingly, the CNV at the pre-stimulus stage only showed the effort to "disengage from" a language, which in Manuscript 3, this means that disengaging from L1 to engage in L2 was more demanding than vice versa (see also Blanco-Elorrieta & Pylkkänen, 2018). This then highlights the role of CNV in future studies. In language switching, mostly researchers focused on the post-stimulus activity, which previous studies have shown the effort to engage in a language. However, this does not fully capture the process of speech production. Some pre-stimulus ERP components have been investigated before (e.g., Verhoef et al., 2010 showed switch trials yielded greater negative amplitudes for an N200-like ERP), but studies in language switching have not paid too much attention to how the brain "anticipates" a language switch. The EEG study in the current thesis has established an example (with a tendency showing language context effect), suggesting future studies are encouraged to investigate the control processes using CNV to unpack the cognitive mechanisms (e.g., attention) of bilingual speakers in language contexts with different cognitive demands. With sufficient sample size, the effect of language context can potentially be observed at the pre-stimulus stage.

5.4 Contribution

This thesis contributes to the field of bilingualism in two perspectives. With the contributions below, it is expected that future researchers can take these into account and investigate bilingual language control more thoroughly.

The first one is the theoretical implication. With respect to Green (1998) and Green and Abutalebi (2013), this thesis will further the understandings of bilingual language control and how inhibition works in a dual-language context. Most of the previous studies related to language switching have revealed the effect of language proficiency. In particular, some researchers have investigated switch cost pattern in balanced and unbalanced bilinguals, and they reported that balanced bilinguals are more likely to show symmetrical switch cost than the other (see Declerck et al., 2020 for a review). This is often contributed by the equivalent proficiency of L1 and L2, leading to same magnitude of switch cost. While language proficiency is still an important factor contributing to different language performance and cognitive control, the current thesis took a step forward by stressing on the interplay between the level of activation and inhibition within a dual-language context. The purpose was to investigate the dynamic nature of the interference control, which is one of the most needed control processes in dual-language context (Green & Abutalebi, 2013). This was achieved by manipulating the ratio of L1 and L2. When a language becomes more used and activated than the other, the language processing system will then adjust the need of inhibition, whereby yielding different patterns of switch cost. Hence, the pattern of switch cost is dynamic, and is dependent on the activation of the predominant language in a dual-language context. In the other chapters, the results further revealed how bilingual speakers prepare for language switching. Therefore, being the first one using CNV to investigate language switching, this will not only highlight the brain activity during the pre-activation stage, but also strengthen the notion that bilingual speakers there is an effort to switch to a language, and this effort (i.e., to inhibit L1 in order to switch to L2) can be dealt with through the preparation of speech production.

The second one is methodological implication. As aforementioned, I minimised the repetition of each stimulus, which could reduce facilitation effect during switching. The current thesis is expected in a way that future studies should take “minimising stimulus repetition” into account. Furthermore, familiarisation before the actual task should also be re-considered. While the current thesis is not rejecting using familiarisation, researchers should consider this in a more practical way. The reason is that familirisation in language switching studies makes participants being restricted to one potential name for each picture. For example, when seeing a picture of a “painter” (which can be also known as “artist”), researchers would ask participants to name the picture “painter” and consider “artist” a wrong answer. This will lead to two situations. First, the wrong answer will then be excluded for analysis, even when the picture is named in the correct target language (Branzi et al., 2014). Second, if a participant uses “artist” more often than “painter” on a daily basis, naming the picture “painter” might increase the reaction time for the target stimulus. Either way will affect the final results. It is noteworthy that in language switching studies, participants are instructed to name the target stimulus as fast and accurately as possible, with only 3 seconds (or less) to respond. According to Levelt (1999), requiring participants to retrieve a lexical representation (within parallel activation and very short milliseconds) will make them select the most frequent one they usually use. Hence, if researchers aim to use familirisation before participants being to do the actual task, I suggest that they should not only look at the restricted responses, but also the other synonymously correct responses.

5.5 Limitations

The first limitation is that bilingual individual differences was not fully taken into account. In the three studies, I recruited Mandarin-English unbalanced bilinguals, and these participants were studying or working in the UK by the time of the experiment. For example, while most of them are exposed to a context where Mandarin and English are in use, some of them can switch between languages more often than the other. Furthermore, some of them have some knowledge of a third foreign language. These are the potential factors that can be further investigated to capture a fuller image of bilingual speakers' language behaviour and the underlying neural mechanisms (see also DeLuca et al., 2019).

In bilingual language switching studies, over the past two decades, researchers have been discussing the factors contributing to the difference between L1 and L2 switching performance (see Gade et al., 2021 for a meta-analysis). These factors include language proficiency, age of acquisition, language pre-activation, (in)voluntary switching, contextual cues, and trial-to-trial presentation interval. Many of the factors are methodological manipulation, which we certainly can predict that there should be an effect of "something" on bilingual language processing. However, to keep the field moving forward, researchers have suggested to take individual differences into account when we discuss bilingual speakers' performances (Bonfieni et al., 2019; Rodriguez-Fornells et al., 2012). Bonfieni and colleagues investigated language switching performance from the perspective of language proficiency (i.e., low and high L2 proficiency), age of acquisition (i.e., AoA, early and late L2 acquisition), exposure (i.e., less and more L2 exposure). Taking age of acquisition as an example, while this did not affect the pattern of switch cost, they found longer L2 responses overall for the bilingual speaker with early AoA. This indicated that early L2 acquisition increases L2 dominance, whereby increasing the competition between L1 and L2 during lexical selection. In addition to age of acquisition, bilingual speakers who were exposed to L2 on a daily basis showed less L1 switching cost, comparing to those who were less exposed to L2. Therefore, here I suggest that including bilingual language experience can gain broader understandings of bilingual speakers.

Bilingual speakers' switching performance has been investigated from the perspective of language proficiency and use. In language switching studies, researchers often recruit one group of bilingual speakers from a specific population (e.g., Mandarin-English adults living in the UK, from a variety of language backgrounds). These bilingual speakers are categorised as "highly proficient speakers" and the analyses conducted often focus on the group-level cognitive mechanisms when bilingual speakers are required to switch between a dominant and a non-dominant language. However, without fully tapping into the effect of individual differences, we often miss the opportunity to explore the background factors contributing to language performance as well as the domain-general cognitive ability.

In recent years, researchers have paid more attention to unpacking the effect of individual differences on language processing (see Gullifer & Titone, 2020). There are two reasons. First, the way we classify participants can be problematic. While people who speak two languages (or use both languages equally on a daily basis) are classified as bilingual speakers, we often miss the fact that there are a lot of them who speak dialects or other languages on other occasions. For example, a bilingual speaker mainly speak Mandarin to communicate with their friends and English with their colleagues at work, but on top of that, they speak a dialect (or another language) to communicate with their families from home. This may increase the complexity of one's language processing system and can differ largely from a person who only speaks two languages. Do we still classify them as bilingual speakers or multilingual speakers? This is the question we ought to find out in future language/cognition-related studies. The answer to this question is individual differences. The purpose of using this as a factor is to understand bilingual speakers' switching performance is to take different language use into account and further explore the effect of speaking languages other than the two that are mainly spoken.

Second, bilingual speakers' switching frequency and language use has not been thoroughly investigated. The daily L1/L2 use of bilingual speakers differs given everyone has their own switching habit/necessity. Particularly, a bilingual person may switch between L1 and L2 very frequently in class and at home, but the other bilingual peoples do not (e.g., switch sometimes, but main use L1 at home and L2 in class). This switching frequency can affect the process of their lexical retrieval and cognitive flexibility given the more a person switches the better language switch he/she becomes. In Timmer et al. (2019), for instance, bilingual speakers were given a Context L1 and Context L2 in an experimental setting, but in real life, their bilingual participants use L2 for different purposes (e.g., speaking, reading, listening). Additionally, unpacking one's switching frequency and use will become even more important in voluntary switching studies where bilingual speakers can choose to switch whenever they want. The reason is that voluntary switching largely relies on bilingual speakers' switching habit as we do not cue when participants need to switch. From the perspective of domain-general cognition, switching frequency plays a role in language processing. Gosselin and Sabourin (2024) reported that bilingual speakers who switch more habitually performed better in a domain-general inhibitory control task and a bilingual Stroop task, comparing to those who switch less habitually. This showed that there is a large overlap between domain-general cognition and language processing, whereby highlight the importance of the effect of language experience on task performance.

The abovementioned two reasons constitute different abilities of adaptations for bilingual speakers. Depending on their language experience and background, the individual difference can facilitate (or delay, if there is a large interference between languages) the speed they adapt themselves to a given experimental task, and this is the directions for future studies. To be able to fully unpack the inter-individual variability, questionnaires we adopted are important. For example, we have used LSBQ (Anderson et al., 2018) in the current thesis to quantifies participants' language experience including language use in different contexts and switching frequency. Hence the other language background components (apart from L1/L2 proficiency) could be taken into account for analyses. We do not need to dichotomise participants (e.g., having a group of participants who switch habitually and another group for those who do not). The reason is that using this type of questionnaire enables us to treat a language background component as a continuum to investigate the effect of individual differences on task performance. Especially when exploring brain activity, different language experiences can contribute to brain structural changes (see DeLuca et al, 2019). Nevertheless, LSBQ is not the only questionnaire as it mainly focuses on L1/L2 language use. For participants in other contexts where three or more languages are required, LHQ3 (Li et al., 2020) can be employed to fully understand the multilingual language background of participants. Taken together, individual differences investigations would provide more insights to form an experience-based model to explore bilingual speakers' cognition.

The second limitation is the association between domain general executive function and language processing. In this thesis, the series of studies I presented were specifically investigating language switching and participants were instructed to name pictures either in L1 or L2. Across switching-related studies, some researchers used task switching (e.g., switching between naming the category of an object and naming the colour shown on screen) and language switching (Branzi et al., 2016; Calabria et al., 2015; Declerck et al., 2017; Prior

& Gollan, 2011; Prior & Gollan, 2013, see Jiao et al., 2022). Similar to language switching, inhibitory control was also investigated in task switching. The purpose is to testify whether the locus of language control and general task control overlaps, but the results have been relatively inconsistent. For example, Prior and Gollan used switch cost in language switching and task switching as the main observation, suggesting language control and task control are fully overlapped (see also Declerck et al., 2017). Nevertheless, Calabria et al. (2015) did not find such overlap between language control and task control when they investigated switch cost in younger and older adults. Their results showed that language switch cost was not much affected by age difference (i.e., symmetrical switch cost across the participants), but task switch cost was significantly affected (i.e., older adults showed the slowest task performance). There was also a correlation between age and the task switch cost, suggesting age effect on participants' performance (i.e., greater switch cost for older adults). This then suggested that there might not be a full overlap between both cognitive processes. Therefore, to further contribute to the field of bilingualism, the overlap between language control and domain-general executive functions can help unpack the nature of bilingual speakers' switching process.

5.6 Future directions

To further contribute to the field of bilingualism, future studies are encouraged to explore the nature of bilingual language control from three perspectives. Firstly, bilingual language control in switching can be investigated using time-frequency analysis (i.e., TFA, brain oscillations). Over the past decades, TFA has been used to unpack the "rhythm" of the brain, and can provide more evidence of how individuals process certain tasks. Complementing ERP analysis, TFA addresses the phase-locked brain frequency, but this approach has been significantly less used in bilingual language switching. More recently, researchers have indicated the benefit of looking into oscillations to better understand bilingual speakers (Rossi et al., 2023). Especially in a dual-language context, the process of juggling between languages increases the complexity and demands of one's cognitive abilities. Throughout language switching studies, to date, researchers have investigated alpha and theta power band to answer whether the magnitude of inhibitory control can be modulated by language proficiency (using EEG: Liu et al., 2015; using MEG: Timofeeva et al., 2023). As the field is moving towards the relationship between individual differences and bilingual cognition, brain oscillations can further provide more evidence to reveal the underlying mechanisms of switching production.

Secondly, cued-switching paradigm in the current thesis and other switching paradigms have revealed the flexibility of bilingual speakers, which support the notion of ACH (Green & Abutalebi, 2013). To benefit bilingualism research from a broader perspective, language switching can be adopted in the future studies to answer whether this approach can improve older adults' cognitive ability. As mentioned in previous chapters, cognitive deficits in ageing can lead to certain task/language processing difficulties. In addition, ageing society has long been an issue, and the government needs to launch social welfare to keep the older adults active in society. For example, many older adults are learning a new language to help train their memory system, and previous studies has reported that older adults can learn novel pseudo-words implicitly without any instructions (Ge et al., 2024). While older adults can perfectly learn a new language, Ge and colleagues observed that, comparing to younger adults, older adults' learning performances stopped improving later during the experiment (e.g., ceiling effect). To improve older adults' learning ability, language switching can potentially be used to preserve cognitive ability of older adults, as this approach has been reported to benefit younger adults' executive functions (Liu et al., 2019, see also Chen et al., 2021). For example, Liu and colleagues gave bilingual speakers a language switching training session and later asked them to do an anti-saccade task before and after the session. They observed improvement in the post test, suggesting that language switching can strengthen one's cognitive control. In the same vein, to help preserve cognitive ability of older adults, future studies can focus on how language switching (especially cued-switching paradigm) whereby improve learning ability.

Third, linguistic distance is a worth investigating factor for future directions. The target population of the current thesis is Mandarin-English bilingual speakers living in the UK. The target languages we aimed are controlled to avoid other language effects. However, Mandarin and English are distant languages that share less linguistic similarity between each other than other language pairs (e.g., Spanish and English). Given the different similarity between languages, the magnitude of interference can also depend on the target languages. This issue, in language switching studies, will become more evident in a read-aloud task. For example, in an experiment we conducted using Mandarin characters and English words (study 1, experiment 2), the effort to switch between the two was symmetrical, but in Macizo et al. (2012) who used Spanish and English words, the effort became asymmetrical. The potential reason is that the interference between language Mandarin and English was smaller than Spanish and English given the less similarity both languages share. The magnitude of interference, hence, will become greater for the languages such as Spanish and English, leading to greater inhibition and switch cost to the dominant language. As for Mandarin and English, the cues (i.e., words) that activate the target language does not necessarily have to be largely inhibited given the two distinct scripts of both languages. Language processing, hence, will then rely more on a language-specific mechanism (i.e., Costa et al., 1999, target language cue automatically facilitates the target language) to achieve the language goal. This then reflects that extent of how bilingual speakers adopt different switching strategies and adapt their language control mechanism when switching is required. Not only will the switching strategies be different in read-aloud task, but also picture naming task

Costa and Santesteban (2004) investigated language switching in two language groups (i.e., Spanish-Catalan vs Korean-Spanish). While switch cost showed an asymmetrical pattern for both groups, the researchers found that the strategy of switching differ between the two types of bilinguals. Particularly, they found that there was a global slowing in the Spanish-Catalan group but not in the other group. Costa and Santesteban's study mainly focused on observing switch cost asymmetry in light of Meuter and Allport (1999), but here I assume that there is an effect of linguistic distance on switching. Given the similarly between Spanish and Catalan, interference may become greater for bilingual speakers. This makes the Spanish-Catalan bilingual speakers to proactively inhibit their dominant L1, whereby benefiting the non-dominant L2. However, this proactive mechanism was not needed for Korean-Spanish bilingual speakers given Korean and Spanish are distant languages.

According to the abovementioned examples, languages that share similar linguistic properties (e.g., orthography) are likely to trigger greater interference from each other because of parallel activation, causing different switching strategies (but see Radman et al., 2021). Nonetheless, this does not mean that languages with less linguistic distance will always suffer from greater interference. Taking Spanish-English as an example, while both languages share very similar orthography, words that share the same phonology (e.g., cognates) will facilitate the switching process. In Christoffels et a. (2007), they used cognates in Dutch and English in a language switching experiment. The results demonstrated that bilingual speakers became faster at naming pictures when the lexical representations of both languages are cognates. This then reflects the language-specific mechanism in which responses with similar phonological properties are facilitated instead of being delayed. Specifically, when both lexical representations share the same orthography as well as phonology, bilingual speakers rely more on the activation, and inhibitory control will be less needed. Taken together, for future directions, it would be interesting to investigate the effect of linguistic distance and lexical overlap in other language groups. This will enable us to meaningfully unpack the interplay between different linguistic properties.

Finally, future studies are encouraged to not only focus on inhibitory control, but also on bilingual speakers' attentional system. According to ICM (Green, 1998), there is a supervisory attentional system (SAS) that elicits necessary control processes to achieve the language goal. To some extent, inhibitory control cannot be treated as an external cognitive system that works independently over language processing. The reason is that the process of inhibition is assisted through attention, whereby suppressing interference from irrelevant information. As a result, it has been suggested that we should also explore the attentional ability of bilingual speakers to be able to L1/L2 language performance (see Bialystok, 2025; Bialystok & Craik, 2022). Language switching studies tend to stress on inhibition much more than other domain-general cognition studies, and the reason is that bilingual speakers need inhibition to be able to switch, leading to a massive focus on inhibition. With respect to Green and Abutalebi (2013), however, dual-language context revolves various cognitive abilities, and inhibitory control is merely one of the important processes. To that end, exploring bilingual speakers' attentional system would help get a bigger picture of how bilingual speech production is achieved successfully. Bialystok (2025) has highlighted that the field of bilingualism should move towards looking at selective attention. Moreover, we should also bear in mind that (according to Bialystok) this approach does not necessarily answer the controversy of bilingual advantage, but to answer which task elicits more attention and how bilingual speakers perform during the task. Taken together, bilingual language control in switching has been widely investigated and we know that inhibition plays a role. For future studies, I believe that going beyond inhibition is a potential trajectory in bilingualism research and that this will also complement the previous language switching studies.

5.7 Conclusion

To summarise, the current thesis presents a series of studies focusing on Mandarin-English bilingual speakers. In each study, I manipulated the ratio of L1 and L2 to create different dual-language context, whereby investigating the magnitude of inhibitory control. Furthermore, using EEG approach, the current thesis revealed the phenomenon of how the brain prepares to switch to the other language.

This then provides evidence of how Mandarin-English bilingual speakers adapt to different language contexts flexibly, supporting the notion of ACH. More importantly, with the CNV brain activity in the EEG study, the current thesis (for the first time among language switching studies) revealed the preparation stage of a switch, meaning the brain indeed can fully anticipate an upcoming language event and proactively apply necessary mechanisms. These results are expected to provide a better language switching paradigm for future studies to not only investigate how bilingual speakers switch, but also how language switching can be employed to modulate bilingual speakers' cognitive abilities.

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Appendix A. Supplementary materials for Chapter 1

We ran an analysis based on this factor (Language*Trial type*Repetition)

In experiment 1, there was a main effect of Repetition [$F(1,7371) = 43.87$, $p < .001$)], suggesting that overall second naming was significantly faster than first naming ($\beta = 36.85$, $SE = 5.56$, 95% CI = [25.94 – 47.75]). This factor also interacted with Language [$F(1, 7732.3) = 14.58$, $p <.001$]. Follow up comparisons revealed a significant facilitation of second naming in L2 (after this was named L1) compared to first naming ($\beta = 58.54$ $SE = 7.97$, 95% CI = [42.92 – 74.16], $t = 7.35$, $p < .001$), but only a trend for L1 second naming compared to first naming ($\beta = 15.15$, $SE = 7.93$, 95% CI = [-0.40 – 30.71], $t = 1.91$, $p = .056$). There was also an effect of repetition that interacted with blocked type and language [$F(2, 716.6) = 3.62$, $p = .027$]. To better understand this 3-way interaction, the effects of repetition in the two languages were analysed separately for each block. In L1-predominant, repetition effects were only significant for L2 ($\beta = 120.86$, $SE = 28.37$, 95% CI = [63.69 – 178.04], $t(38.8) = 4.26$, $p < .001$) , but not L1 ($\beta = 16.20$, $SE = 26.741$, 95% CI = [-37.9 – 70.293], $t(4.261) = .605$, $p = .548$). A similar pattern was found also for L2-predominant, with faster reaction times for second vs first naming only for L2 (L2: $\beta = 71.23$, $SE = 32.96$, 95% CI = [4.83 - 137.63], $t(44.7) = 2.16$, $p = .036$); L1: $\beta = 24.33$, $SE = 26.48$, 95% CI = [-28.62 - 77.27], $t (61.3)= .92$, $p = .361$). However, in the Balanced context repetition effects were not found for neither L1 nor L2 (L2: $\beta = 48.37$, $SE = 26.83$, 95% CI = [28.61 – 90.61], $t(1.8)= 26.83$, $p = .078$); L1: $\beta = 33.39$, $SE = 22.97$, 95% CI = [-13.38 – 80.17], $t(32.3) = 1.45$, $p = .155$), see Figure S1 and S2 below.

Appendix A

Below we also provide a plot to visualise L1/L2 performance in experiment 1. Two conditions of repetition were included: “First naming” refers to pictures named first and “Second naming” refers to pictures named secondly. The plot shows the overall L1 Chinese and L2 English performance by Repetition. We can see that L2 English was the one that became affected the most. In line with Branzi et al. (2014), who used single-language task, here we further support that even in a switching environment, the non-dominant L2 can still be facilitated when the pictures are named in L1 beforehand. Similarly to Branzi et al., (2014), L1 was much less affected by repetition effects. Here we only found significant L1 repetition effects in the Balanced block context. Importantly, L1 was already slower than L2 in the first naming condition, so was the second naming condition. It is worth noting that repetition effects didn’t significantly impact trail type or higher order interactions including trial type as suggested by the lack of significant interactions.

Figure 5.1. L1/L2 overall performance by repetition (experiment 1)

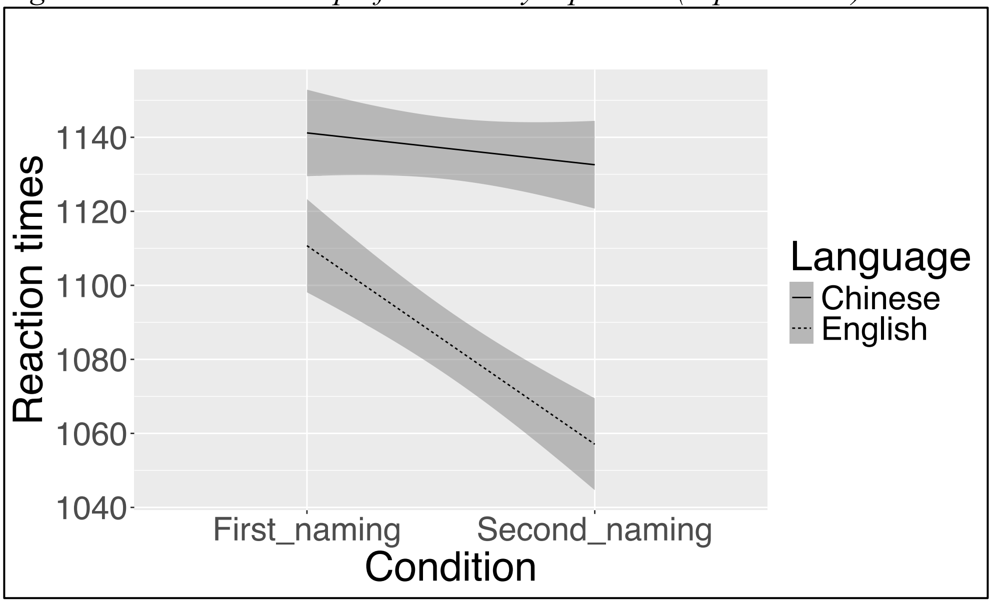
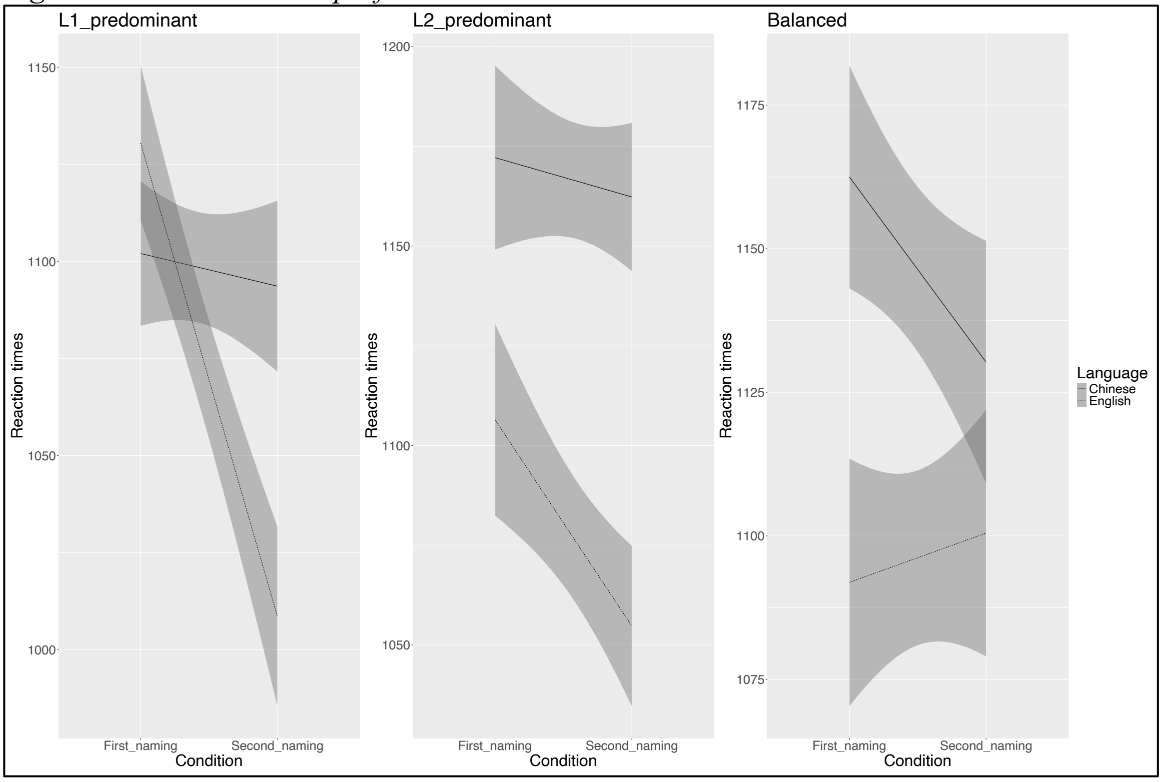
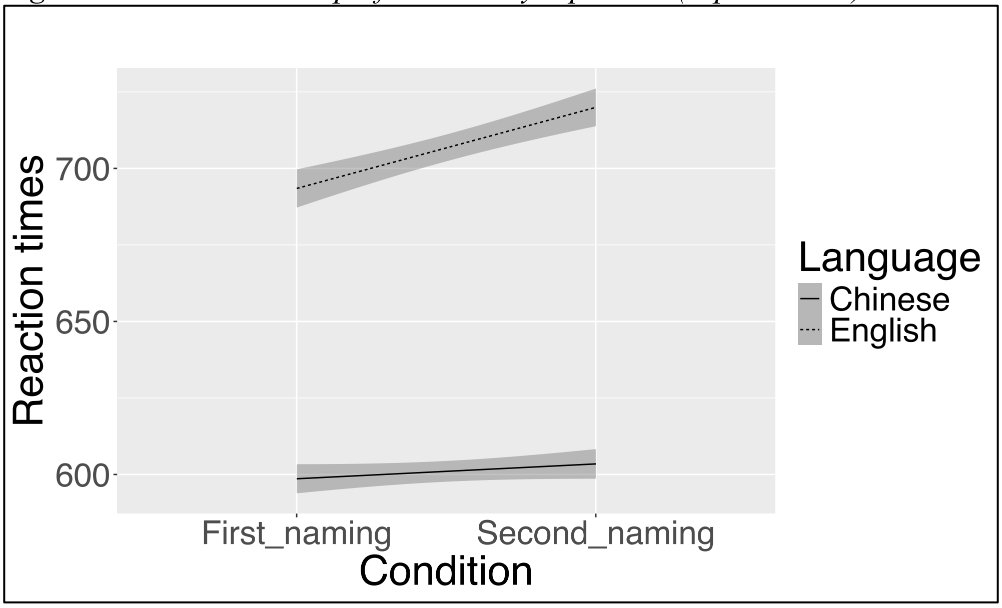


Figure 5.2. L1/L2 overall performance in each context



In experiment 2, there was a main effect of Repetition [F(1, 11906.6) = 36.43, p < .001)], suggesting that overall first naming was significantly faster than second naming (β = -12.96, SE = 2.15, 95% CI = [-17.17 – -8.75], p < .001). This factor also interacted with Language [F(1, 11917.9) = 9.24, p =.002]. Follow up comparisons revealed a significant facilitation of second naming in L1 (after this was named in L2) compared to first naming (β = -19.51, SE = 3.08, 95% CI = [-25.55 – -13.47], t = -6.33, p < .001), and also for L2 second naming compared to first naming (β = -6.41, SE = 3.0, 95% CI = [-12.29 – -0.52], t = -2.13, p = .032; see Figure S3 below). The effect of repetition did not significantly interact with any other variable.

Figure 5.3. L1/L2 overall performance by repetition (experiment 2)



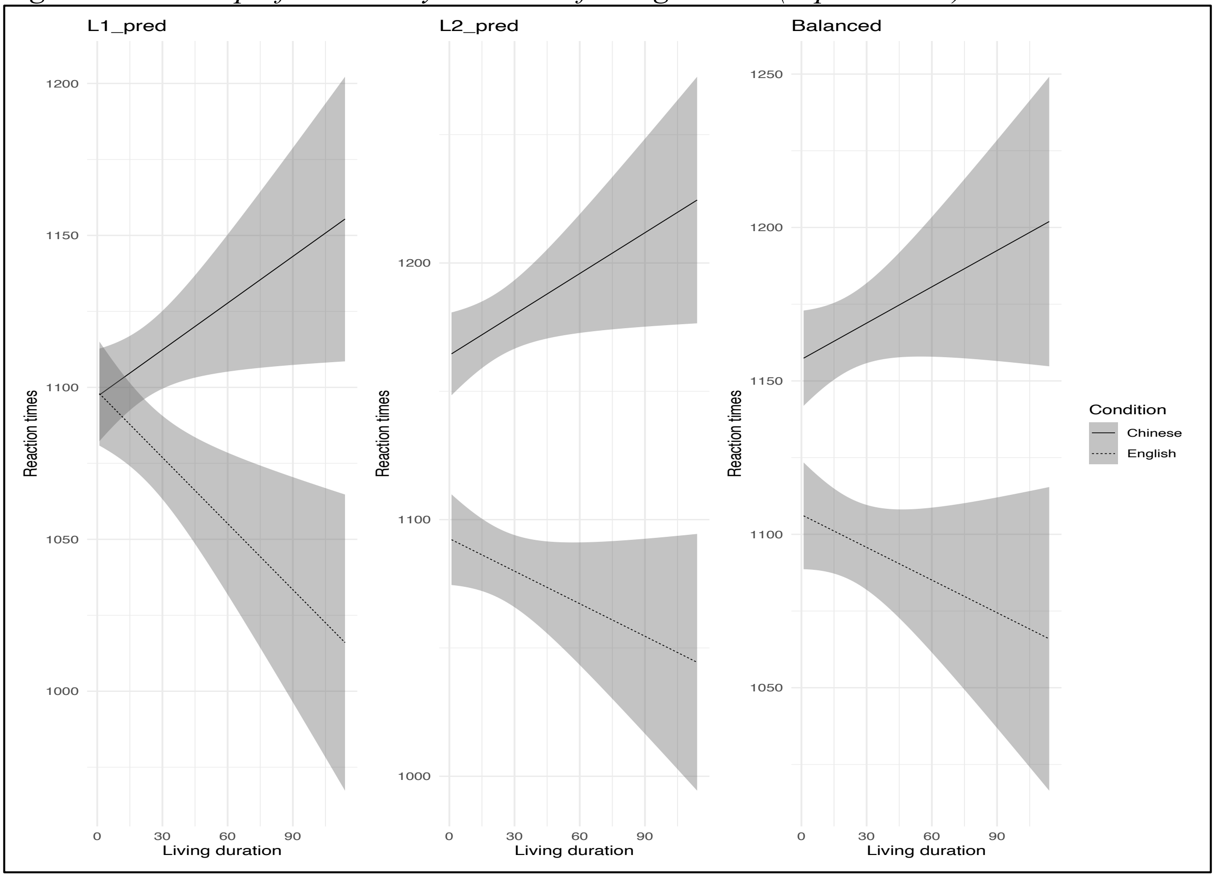
Appendix A

We ran a mixed-effects model based on Language*Trial type*Duration of living abroad.

Experiment 1

In L1-predominant, duration of living broad interact with language, meaning the longer they stay in the UK, the slower they become in L1 ($\beta = 1.45$, SE = .58, $t = 2.49$, $p = .016$), but trial type was not affected ($\beta = -0.30$, SE = .31, $t = -0.99$, $p = .323$). There was a tendency to significant interaction between the duration of living abroad and language ($\beta = 1.18$, SE = .60, $t = 1.95$, $p = .057$), but not between duration of living abroad and trial type ($\beta = -0.50$, SE = .43, $t = -1.62$, $p = .111$). Finally, in Balanced context, there was no interaction between duration of living abroad and language ($\beta = .94$, SE = .59, $t = 1.59$, $p = .118$), nor between duration of living abroad and trial type ($\beta = -0.30$, SE = .31, $t = -0.99$, $p = .323$). We did not observe three-way interactions between the three predictors ($p > .1$). Below we visualise L1/L2 performance by duration of living abroad:

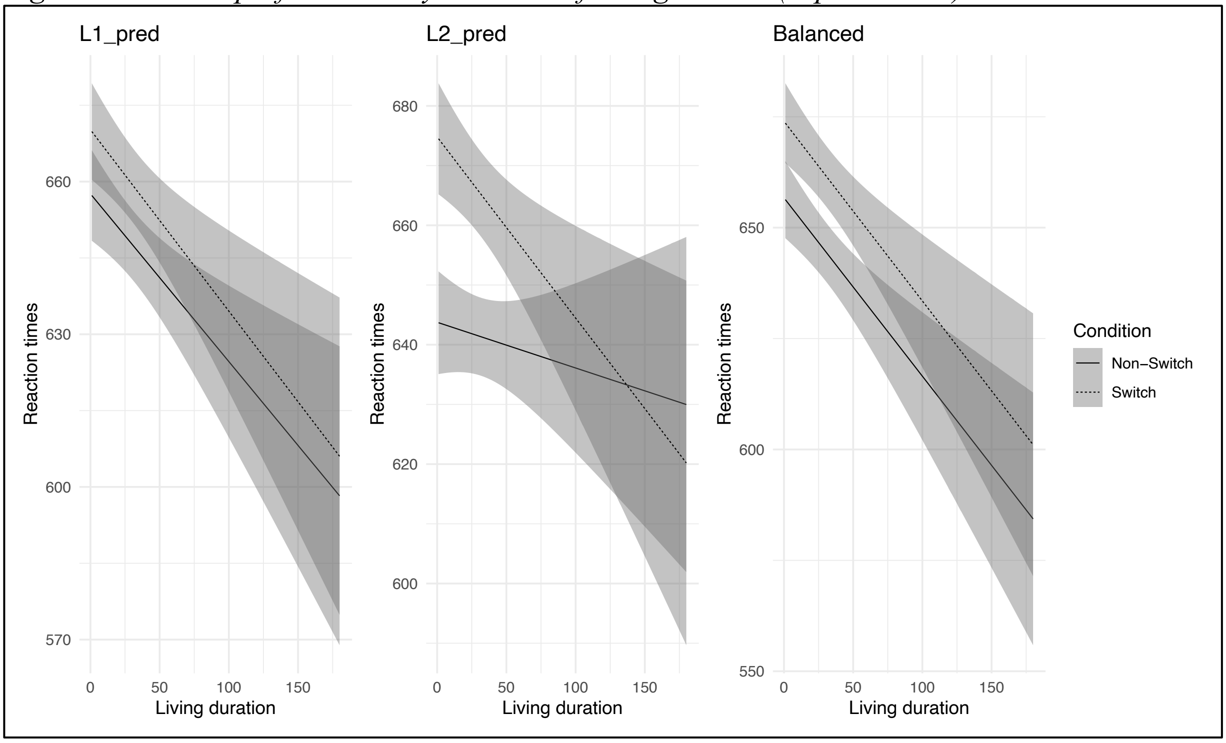
Figure 5.4. L1/L2 performance by duration of living abroad (experiment 1)



Experiment 2

In L1-predominant, duration of living broad did not interact with language (β = -0.92, SE = 2.98, *t* = -0.31, *p* = 0.758), nor with trial type (β = -0.003, SE = 0.09, *t* = -0.04, *p* = .971). In L2-predominant, there was a significant interaction between the duration of living abroad and trial type (β = .23, SE = .10, *t* = 2.37, *p* = .019), but not between duration of living abroad and language (β = .22, SE = .30, *t* = .75, *p* = .456). Finally, in Balanced context, there was no interaction between duration of living abroad and language (β = .08, SE = .31, *t* = .26, *p* = .796), nor between duration of living abroad and trial type (β = -0.02, SE = .10, *t* = -0.15, *p* = .879). There were no three-way interactions (*p* > .1). Below we visualise L1/L2 performance by duration of living abroad:

Figure 5.5. L1/L2 performance by duration of living abroad (experiment 2)



Appendix A

We ran analysis to check if there was an interaction between trial order, trial type, language separately for each context (Trial order * Language * Trial type)

Experiment 1

In all three contexts, there were no interactions between the three predictors ($p > .1$). There was main effect on trial order in L2-predominant (β = .18, SE = .08, $t = 2.43$, $p = .015$) and in Balanced (β = .14, SE = .07, $t = 1.98$, $p = .048$), but not in L1-predominant ($p > .1$). Below we visualize L1/L2 performance across trial order:

It is interesting to see that in L1-predominant, L1 Chinese became gradually faster at the end of the block, but this trend was not found in the other two contexts, where L1 became slower than at the beginning.

Figure 5.6. L1/L2 performance by trial order and trial type (experiment 1)

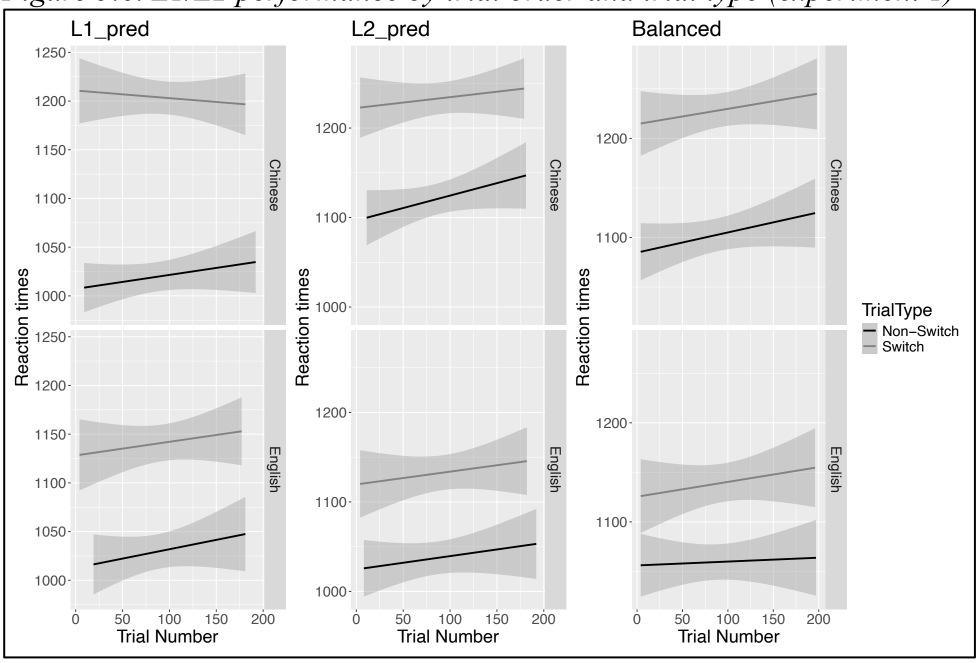
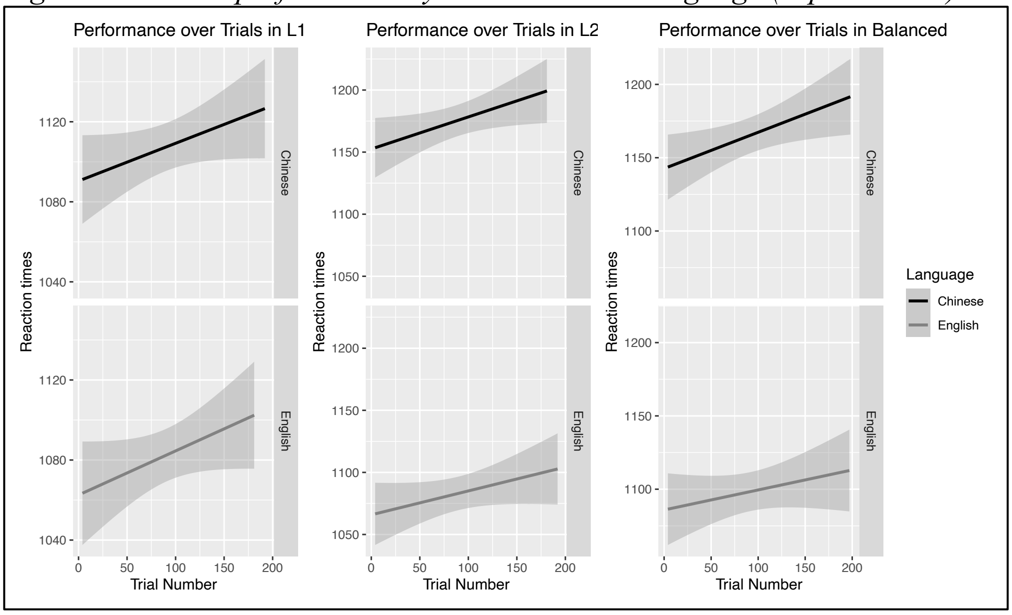


Figure 5.7. L1/L2 performance by trial order and language (experiment 1)



Experiment 2

There was a tendency to significant interactions between the three predictors in Balanced (β = -0.22, SE = .12, t = -1.91, p = .057), but not in the other two contexts (p > .4). The significant interaction was caused by the L1 (Chinese) performance (i.e., if participants stayed longer in a Balanced context, L1 switch performance became slower). There was main effect on trial order in L2-predominant (β = .11, SE = .03, t = 3.52, p < .001) and in Balanced (β = .10, SE = .03, t = 3.63, p < .001), but tendency to main effect in L1-predominant (β = .06, SE = .03, t = 1.87, p = .053). Below we visualise L1/L2 performance:

Figure 5.8. L1/L2 performance by trial order and trial type (experiment 2)

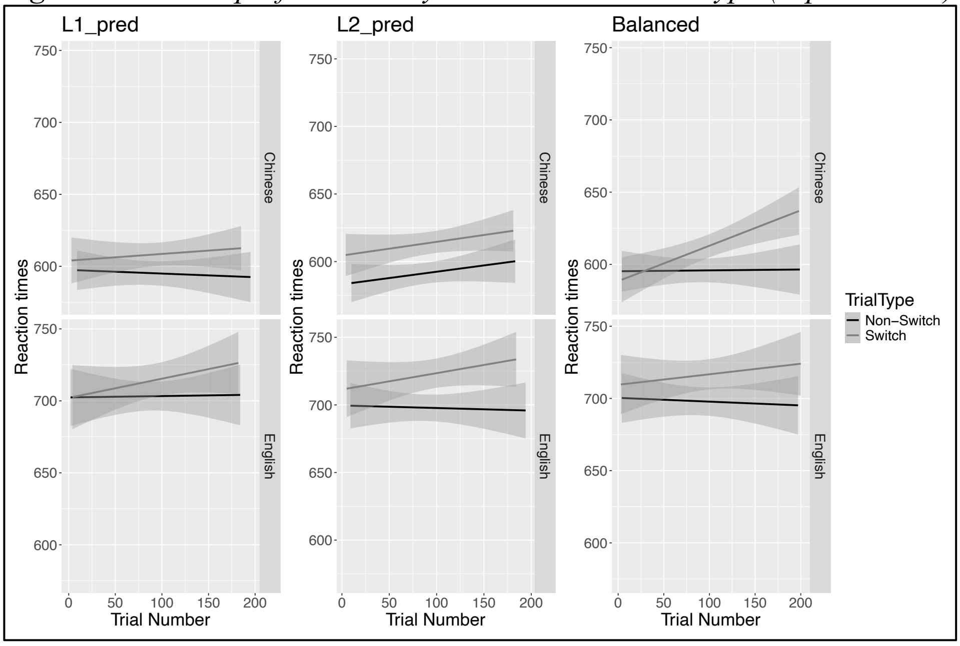


Table 5.1. Mean and standard deviations of stimulus information

		English		Chinese	
	Set	Mean	SD	Mean	SD
H-statistic	1	0.133	0.255	0.252	0.305
	2	0.175	0.233	0.276	0.256
	3	0.170	0.317	0.304	0.317
	4	0.143	0.233	0.253	0.252
	5	0.194	0.236	0.312	0.269
	6	0.259	0.340	0.386	0.335
Zipf	1	4.187	0.532	4.020	0.636
	2	4.143	0.297	3.939	0.402

Appendix A

	Set	English Mean	English SD	Chinese Mean	Chinese SD
	3	4.162	0.329	3.824	0.597
	4	4.082	0.669	3.910	0.605
	5	4.133	0.698	3.958	0.434
	6	4.088	0.676	3.727	0.775
Number of syllables	1	1.680	0.852	2.080	0.493
	2	1.760	0.879	2.160	0.374
	3	1.880	0.781	2.080	0.493
	4	1.760	0.831	2.120	0.440
	5	1.680	0.748	2.080	0.493
	6	1.640	0.810	2.040	0.539
Number of phonemes	1	4.480	1.759	5.160	1.748
	2	4.960	2.031	5.920	1.706
	3	4.960	1.744	5.720	1.926
	4	4.760	1.921	5.760	1.562
	5	4.520	1.531	5.560	1.583
	6	4.560	1.660	5.520	1.828

Note: H-statistics refers to name of agreement of the pictures (retrieved from Multipic, Duñabeitia et al., 2022). Zipf law refers to word frequency. We also included number of syllables and phonemes (*p*-values across sets are > .49).

Appendix B. Supplementary materials for Chapter 3

Table 5.2. Participants' language background

	Variable	Mean	SD
Non-Chinese Home Use and Proficiency	Language used with Grandparents	1.30	1.72
	Language used in infancy	0.39	0.86
	Code switching with family	1.13	1.11
	Non-Chinese understanding proficiency	73.48	17.79
	Non-Chinese language speaking proficiency	73.48	17.79
	Language used with other relatives	0.72	1.13
	Language used in preschool	0.43	0.81
	Language used with parents	0.28	0.62
	Non-Chinese language listening frequency	2.57	0.91
	Non-Chinese language speaking frequency	2.50	0.96
	Language used at home	0.87	1.22
	Language used in primary school	0.72	0.66
	Language used for religious activities	3.59	1.96
	Language used with siblings	0.65	1.34
	Chinese listening frequency	2.98	0.93
	Language used for praying	3.54	2.02
	Language used in high school	0.93	0.90
	Chinese speaking frequency	2.91	0.94
Non-Chinese Social Use	Language used at work	3.24	1.25
	Language used at school	2.04	1.83
	Language used for health care, banks, government services	3.33	1.19
	Language used for shopping, restaurants, commercial services	3.13	1.02
	Language used for social activities	2.04	0.89
	Language used for e-mailing	2.72	0.83
	Language used with friends	1.78	0.96
	Language used for extracurricular activities	2.85	1.21
	Language used with roommates	2.61	1.94
	Language used for texting	2.07	0.80
	Language used on social media	1.96	0.70
	Language used for watching movies	2.50	0.94
	Language used for browsing the internet	2.02	0.71
	Code switching on social media	1.85	0.92
	Language used with neighbours	2.85	1.58
	Language used for watching TV/listening to radio	2.13	0.83
	Language used for writing lists	2.09	1.05
	Language used for reading	1.83	0.80
	Language used with partner	2.00	1.78
	Code switching with friends	2.02	0.95
	Composite scores (degree of bilingualism)	14.94	5.35

Appendix B

Accuracy analysis by context

Context L1

In Context L1, the results showed a main effect on trial type (β = .66, SE = .25, z = 2.61, p = .008), but a marginal effect on language (β = .56, SE = .30, z = 1.88, p = .060). This indicates that there was an accuracy cost and that participants were more accurate on non-switch trials than on switch trials. There was no two-way interaction between the two predictors (p = .733).

Context L2

In Context L2, the results showed a main effect on trial type (β = .89, SE = .23, z = 3.89, $p < .001$), but not on language (β = -0.26, SE = .26, z = -1.02, p = .309). Participants were more accurate on non-switch trials than switch trials. No interactions were found (p = .131).

Reaction times analysis by context

Context L1

In Context L1, there was a main effect on trial type (β = -64.84, SE = 9.89, $t(46.96)$ = -6.55, $p < .001$) but not on language (β = -5.36, SE = 14.46, $t(65.02)$ = -0.37, p = .712), showing that participants were faster in non-switch trials than in switch trials. Moreover, this predictor also interacted with language (β = -41.20, SE = 19.23, $t(43.62)$ = -2.14, p = .037), meaning switch cost pattern was asymmetrical.

Appendix B

Context L2

In Context L2, there was a main effect on trial type (β = -53.32, SE = 8.08, $t(47.59) = -6.60$, $p < .001$) but not on language (β = 2.56, SE = 17.34, $t(61.25) = .14$, $p = .883$). This means that participants were faster on non-switch trials than switch trials. There was no interaction between the two predictors ($p = .189$), indicating switch cost pattern was symmetrical in this context.

Appendix C. Supplementary materials for Chapter 4

Table 5.3. Participants' language background

	Variable	Mean	SD
Non-Chinese Home Use and Proficiency	Language used with Grandparents	0.55	0.58
	Language used in infancy	0.4	0.32
	Code switching with family	0.85	0.84
	Non-Chinese understanding proficiency	73	72.65
	Non-Chinese language speaking proficiency	69.5	69.98
	Language used with other relatives	0.32	0.33
	Language used in preschool	0.65	0.58
	Language used with parents	0.35	0.37
	Non-Chinese language listening frequency	2.15	2.16
	Non-Chinese language speaking frequency	2.1	2.16
	Language used at home	0.6	0.63
	Language used in primary school	1	1.05
	Language used for religious activities	NA	NA
	Language used with siblings	1.05	1.1
	Chinese listening frequency	3.15	3.21
	Language used for praying	NA	NA
	Language used in high school	0.9	0.95
	Chinese speaking frequency	3.2	3.21
Non-Chinese Social Use	Language used at work	1.6	1.68
	Language used at school	1.95	1.95
	Language used for health care, banks, government services	2.05	2.1
	Language used for shopping, restaurants, commercial services	1.95	2
	Language used for social activities	1.45	1.47
	Language used for e-mailing	2.7	2.69
	Language used with friends	1.3	1.27
	Language used for extracurricular activities	1.45	1.42
	Language used with roommates	1.35	1.42
	Language used for texting	1.6	1.58
	Language used on social media	1.4	1.37
	Language used for watching movies	2.05	2.1
	Language used for browsing the internet	1.85	1.89
	Code switching on social media	1.9	1.9
	Language used with neighbours	1.15	1.21
	Language used for watching TV/listening to radio	1.75	1.79
	Language used for writing lists	2	2
	Language used for reading	1.8	1.79
	Language used with partner	0.8	0.84
	Code switching with friends	2	2.05
	Composite scores	21.99	5.75

Appendix C

Accuracy analysis by context

Context L1

There was a main effect of language, meaning participants were more accurate in L1 than in L2 ($\beta = 1.36$, SE = .62, $z = 2.22$, $p = .027$). No other effects nor interactions were found ($p > .344$).

Context L2

There were no effects nor interactions found ($p > .140$).

Reaction times analysis by context

Context L1

There was a main effect of trial type, meaning participants were faster in non-switch trials than switch trials ($\beta = -47.42$, SE = 19.95, $t(18.6) = -2.38$, $p = .028$). No other effects nor interactions were found ($p > .244$).

Context L2

Context L2 yielded a main effect of trial type, meaning participants were faster in non-switch trials than switch trials ($\beta = -70.32$, SE = 17.54, $t(18.12) = -4.00$, $p < .001$). No other effects nor interactions were found ($p > .714$).

ERP analyses by context

Appendix C

CNV

Context L1

Context L1 yielded an effect of trial type, meaning switch trials elicited more negative amplitudes than non-switch trials (F(1, 19) = 15.51, SE = 3.12, $p < .001$). This also interacted with language, which switching to L2 showed a greater CNV effect than switching to L1 (β = 2.90, SE = .64, $t(19) = 4.47$, $p < .001$).

Context L2

We found an effect of trial type in Context L2 (F(1, 19) = 8.30, SE = 3.65, $p < .010$). However, this did not interact with language (F(1, 19) = .42, SE = 4.82, $p = .523$).

N200

Context L1

Context L1 only yielded a marginal effect of language (F(1, 19) = 3.31, SE = 4.49, $p = .084$). No other effects nor interactions were found ($p > .387$).

Context L2

There was a marginal effect of trial type (F(1, 19) = 3.41, SE = 1.57, $p = .080$). No other effects nor interactions were found ($p > .254$).

N400

Appendix C

Context L1

Context L1 yielded significant effect of language (F(1, 19) = 12.98, SE = 6.19, *p* = .002), meaning L1 yielded more negative amplitudes than L2 (β = -2.01, SE = .56, *t*(19) = -3.60, *p* = .002). No other effects nor interactions were found (*p* > .226).

Context L2

Context L2 yielded significant effect of language (F(1, 19) = 6.64, SE = 3.53, *p* = .018), meaning L1 yielded more negative amplitudes than L2 (β = -1.08, SE = .42, *t*(19) = -2.58, *p* = .180). There was also an effect of trial type (F(1, 19) = 8.65, SE = .88, *p* = .008), showing switch trials yielded more negative amplitudes than non-switch trials (β = .62, SE = .21, *t*(19) = 2.94, *p* = .008). However, no interactions were found (*p* > .698).

LPC (see Figure 5.9)

Context L1

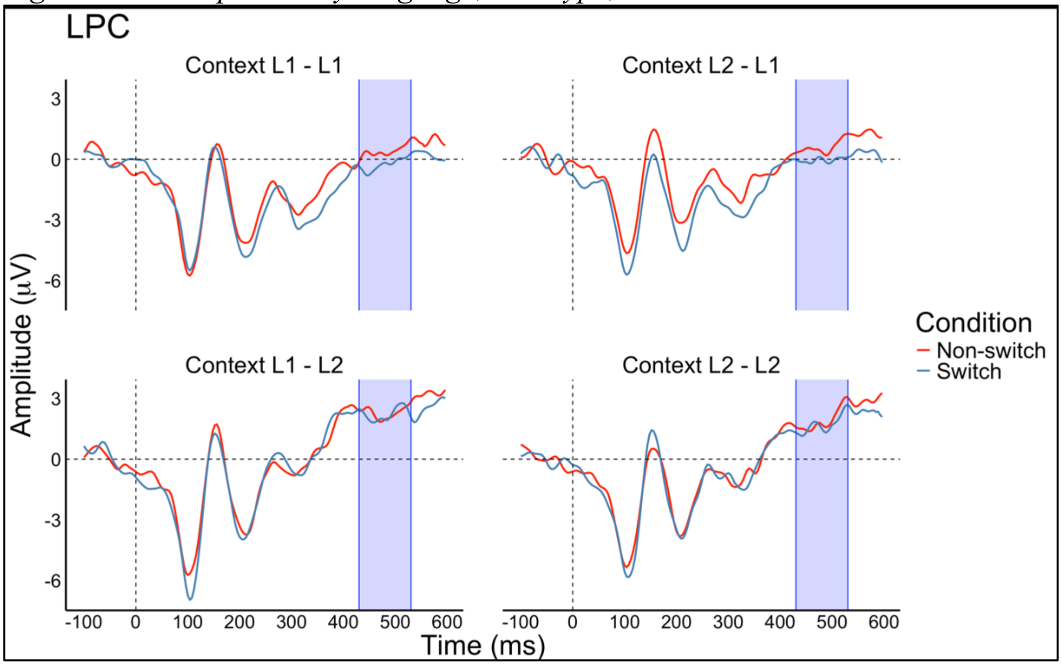
There was an effect of language (F(1, 19) = 17.49, SE = 5.17, *p* < .001), indicating L1 yielded greater positivity than L2. No other effects nor interactions were found (*p* > .336).

Context L2

There was an effect of language (F(1, 19) = 10.18, SE = 3.45, *p* = .005), indicating L1 yielded greater positivity than L2. No other effects nor interactions were found (*p* > .158).

Appendix C

Figure 5.9. LPC pattern by language, trial type, and context



Note: Upper left: L1 in Context L1, Bottom left: L2 in Context L1,

Upper right: L1 in Context L2, Bottom right: L2 in Context L2