

## Bilingual Control Mechanisms and Influencing Factors in Autonomous Language Switching

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### Abstract

Voluntary language switching refers to the spontaneous language switching produced by bilinguals. Compared with cued language switching, voluntary language switching under conditions of high lexical accessibility and high linguistic freedom induces significantly reduced switching costs, even tending to disappear. Neuroimaging studies have shown that voluntary language switching elicits lower activation of the inhibitory control network, while additionally recruiting brain mechanisms related to volition and spontaneous behavior. The bilingual control mechanisms in voluntary switching are closely associated with L2 proficiency, context, and individuals' executive control ability. Future research should integrate individual and environmental factors to construct more refined dynamic models; combine real-world behavioral patterns with laboratory measurements to deepen exploration of neural mechanisms; conduct longitudinal tracking studies and focus on production-comprehension interaction, to facilitate the translation of voluntary language switching into cognitive advantages, communicative functions, and learning efficiency.

### Full Text

## Bilingual Control Mechanisms and Influencing Factors in Voluntary Language Switching

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## Abstract

Voluntary language switching refers to the spontaneous language shifts that bilinguals produce. Compared with forced language switching, the switching costs associated with voluntary switching are significantly reduced—and may even disappear—when lexical access is high and language choice is unconstrained. Neuroimaging research indicates that voluntary switching engages the inhibitory control network less strongly while additionally recruiting brain mechanisms related to self-generated intentions and spontaneous behavior. The bilingual control mechanisms underlying voluntary switching are closely linked to second language proficiency, contextual factors, and individual executive control abilities. Future research should integrate individual and environmental factors to construct more refined dynamic models, combine real-world behavioral patterns with laboratory measures to deepen exploration of the neural mechanisms, and conduct longitudinal studies while attending to the interaction between production and comprehension. Such efforts may help translate voluntary language switching into cognitive advantages, communicative functions, and learning efficiency.

**Keywords:** voluntary language switching, forced language switching, inhibitory control, context, executive control

Bilinguals must select a language to express themselves, and in bilingual contexts, they also need to switch languages to communicate with interlocutors from different linguistic backgrounds. Forced language switching is guided by external cues (such as the interlocutor), whereas voluntary language switching is spontaneously generated by bilinguals themselves. Although both represent common patterns in bilingual life, research has predominantly focused on forced language switching, employing language cues (e.g., colors, shapes, flags, face images) to instruct bilinguals to respond in a designated language. Decades of research have revealed that forced language switching in both bilingual production (e.g., Costa & Santesteban, 2004; Ma et al., 2016; Zhuang et al., 2023) and comprehension (e.g., Declerck & Grainger, 2017; Olson, 2017) consistently incurs switching costs. Switching costs refer to longer naming latencies or lower accuracy rates associated with language switching compared with language repetition.

The Inhibitory Control Model (Green, 1998) and the BIA+ Model (Bilingual Interactive Activation Plus Model; Dijkstra & van Heuven, 2002) posit that both target and non-target languages are activated during bilingual language processing, and that bilinguals must inhibit the non-target language to accurately and efficiently select lexical items in the target language. Switching costs thus reflect a top-down inhibitory control mechanism that bilinguals employ to resolve language conflict (Christoffels et al., 2007; Green, 1998; Ma et al., 2016). Numerous studies have also found that switching costs between a bilingual's two languages are typically asymmetrical for non-balanced bilinguals: switching from the more proficient language (usually the first language, L1) to the less

proficient language (usually the second language, L2) incurs smaller costs (in reaction time or accuracy) than switching from L2 to L1 (Costa & Santesteban, 2004; Meuter & Allport, 1999). The Inhibitory Control Model explains this by proposing that the proficient language (L1) has a higher default activation level in non-balanced bilinguals, thus requiring stronger inhibitory mechanisms to control its automatic activation during L2 naming; when bilinguals subsequently switch back to L1, reactivating the previously more strongly inhibited L1 takes longer, resulting in larger switching costs.

Forced language switching tasks have made substantial contributions to our understanding of bilingual language switching mechanisms. However, voluntary language switching that bilinguals spontaneously produce in natural communication clearly differs from forced switching based on explicit language cues. This article systematically integrates recent advances in voluntary language switching research, elucidates the unique characteristics of voluntary switching in bilingual control mechanisms, and emphasizes the complex modulatory roles of individual and contextual factors. Exploring these issues can not only deepen scholarly understanding of the cognitive and neural mechanisms underlying language switching but also help advance the development of bilingual processing and related cognitive models.

## 1.1 Experimental Paradigms for Voluntary Language Switching

In bilingual language switching research, previous studies have typically employed forced language switching tasks—such as picture or digit naming tasks (Costa & Santesteban, 2004; Ma et al., 2016; Meuter & Allport, 1999), phrase naming tasks (Blanco-Elorrieta et al., 2018), and sentence reading tasks (Gollan & Goldrick, 2018; Li et al., 2024)—to investigate bilingual language control mechanisms. Bilinguals must select the designated language based on language cues provided by the task (e.g., the color of a shape, flags, or face images), meaning that language selection is determined by external factors. This paradigm simulates scenarios where bilinguals switch languages in response to interlocutors with different linguistic backgrounds, selecting the appropriate language according to the interlocutor’s linguistic abilities. To examine how linguistic and cultural backgrounds influence bilingual switching, some researchers have further modified the task format by adding racial faces or specific cultural items that are either congruent or incongruent with the naming language (Li et al., 2013; Liu et al., 2021; Zhuang et al., 2023). Although this experimental paradigm incorporates cues from natural contexts and enhances the ecological validity of language switching, it does not alter the fundamental nature of forced language switching tasks.

In contrast to forced language switching tasks, voluntary switching tasks typically either (1) provide no cues and instruct participants through task directives that they may freely choose the naming language, or (2) simultaneously present bilingual cues representing both languages before the to-be-named picture stim-

ulus, requiring bilinguals to freely select their intended language on any given trial (Blanco-Elorrieta & Pylkkänen, 2017; de Bruin et al., 2018; de Bruin & Martin, 2022; Kleinman & Gollan, 2016; Zhu et al., 2022). This paradigm simulates the spontaneous language switching behavior that bilinguals produce when unconstrained by interlocutors—that is, when both conversation partners share the same bilingual background and can freely alternate between their two languages (Myers-Scotton & Lake, 2020; Poplack, 1980) without relying on external language cues. For example, Blanco-Elorrieta and Pylkkänen (2017) created a free bilingual dialogue environment in which participants first viewed an image of a video call with an interlocutor and then performed a picture naming task. Prior to the experiment, participants were explicitly informed that the interlocutor was bilingual in Arabic and English. Given this bilingual background of the interlocutor, participants could freely choose between Arabic and English for naming. The results showed that proficient Arabic-English bilinguals exhibited no switching costs during naming. Clearly, voluntary language switching differs from forced language switching.

## 1.2 Language Switching Costs in Voluntary Language Switching

Gollan and Ferreira (2009) conducted the first study on voluntary language switching in bilinguals. This research introduced the voluntary task-switching paradigm (Arrington & Logan, 2004) into language switching research for the first time, requiring Spanish-English bilinguals to complete picture naming under instructions to choose either language freely, and examined whether voluntary language switching would produce switching costs or benefits. The study found that voluntary language switching incurred switching costs for both young and older bilinguals. Unlike the cost patterns observed in forced language switching, voluntary switching costs were symmetrical across the two languages and were not modulated by participants' L2 proficiency. Additionally, Kleinman and Gollan (2016) created a bottom-up voluntary language switching block by simultaneously presenting flags representing Spanish and English. Participants freely chose which language to use for naming when a picture was first presented and continued using that initially selected language when the same picture reappeared later. The results showed that Spanish-English bilinguals did not exhibit significant switching costs in this bottom-up voluntary switching task, suggesting that consistently selecting more accessible lexical items in voluntary language switching incurs no cost.

To further elucidate the unique characteristics of bilingual control mechanisms in voluntary switching, several recent studies have directly compared the patterns and costs of voluntary and forced language switching. For example, Jevtović et al. (2020) incorporated both voluntary and forced language switching tasks in their study to investigate the mechanisms of voluntary switching in highly proficient Spanish-Basque bilinguals. The experimental results showed that switching costs persisted in the voluntary switching task alone; however, when volun-

tary and forced switching occurred concurrently, the cost of switching to Basque was smaller in the voluntary condition compared with the forced condition, and overall response times were shorter in voluntary switching. Therefore, although many studies have reported switching costs in voluntary language switching, voluntary switching imposes a smaller cognitive load on bilinguals than forced switching, as evidenced by reduced switching costs. Furthermore, task settings may influence the difficulty of lexical access in voluntary language switching, thereby further modulating voluntary switching costs.

### 1.3 Theoretical Explanations for Voluntary Language Switching Costs

The Inhibitory Control Model provides a theoretical basis for language switching costs: because bilinguals activate both languages simultaneously during processing, they must inhibit the non-target language when selecting the target language. When bilinguals subsequently switch back to a previously inhibited language, overcoming this inhibition requires additional time—this constitutes the switching cost. However, numerous studies reporting switching costs have employed forced switching tasks where language is specified by cues (Christoffels et al., 2007; Declerck & Philipp, 2015; Ma et al., 2016; Meuter & Allport, 1999; Zhuang et al., 2023). Many studies have found that forced language switching triggers significant switching costs (de Bruin et al., 2018; Gollan et al., 2014; Jevtović et al., 2020; Liu et al., 2020; Mooijman et al., 2024; Sánchez et al., 2022; but see Mosca et al., 2022), whereas these costs are significantly reduced or even completely eliminated in voluntary language switching (Blanco-Elorrieta & Pylkkänen, 2017; Jevtović et al., 2020; Kleinman & Gollan, 2016; Zhu et al., 2022; but see Geng et al., 2024; Zhang et al., 2024).

Why does voluntary language switching exhibit this differential pattern? Many studies suggest that the Adaptive Control Hypothesis (Green & Abutalebi, 2013) and its distinction among switching contexts (single-language context, dual-language context, and dense code-switching context) can provide insight (de Bruin et al., 2018; Jiang et al., 2024; Lai & O'Brien, 2020). In single-language and dual-language contexts, bilinguals typically select the appropriate language based on their interlocutor's linguistic background (for example, flexibly switching languages when communicating with monolingual colleagues or family members who use different languages). To effectively avoid interference from the non-target language, bilinguals must strengthen language control mechanisms, placing higher demands on cognitive processes such as interference suppression, goal maintenance, and conflict monitoring. In contrast, in dense code-switching contexts, bilinguals usually interact with interlocutors who are also bilingual and can seamlessly alternate between languages. Therefore, compared with the first two contexts, bilinguals in this situation engage in timely language planning but involve fewer complex cognitive control processes such as conflict monitoring and interference suppression. Clearly, voluntary language switching tasks closely resemble the dense code-switching context described in

the Adaptive Control Hypothesis, whereas forced language switching tasks more closely approximate dual-language contexts (de Bruin et al., 2018; Jevtović et al., 2020; Jiang et al., 2024). In dual-language contexts, forced mixing of two languages increases production difficulty, whereas in dense code-switching contexts, free mixing of two languages actually makes language production more fluent (de Bruin et al., 2018; de Bruin & Xu, 2023).

According to the Adaptive Control Hypothesis, language control demands in dense code-switching contexts are not only lower than in dual-language contexts but also lower than in single-language contexts where language switching occurs infrequently. This difference is reflected in the mixing cost metric (i.e., poorer performance on repeat trials in mixed-language blocks compared with single-language trials in single-language blocks). Mixing costs frequently appear in forced language switching, reflecting higher control demands in dual-language contexts relative to single-language contexts (Ma et al., 2016). However, many studies have found that in voluntary language switching, bilinguals name pictures faster on repeat trials in mixed-language blocks than on single-language trials in single-language blocks, demonstrating a mixing benefit (de Bruin et al., 2020; de Bruin & Xu, 2023; Jevtović et al., 2020). This suggests that freely mixing two languages may be even easier than consistently using one language.

#### 1.4 Cognitive and Neural Mechanisms of Voluntary Language Switching

Recent electrophysiological and neuroimaging studies have provided further neural-level evidence for the cognitive control mechanisms underlying voluntary language switching. Some research has found that voluntary language switching activates the inhibitory control network very similarly to forced language switching (Geng et al., 2024; Jiao et al., 2022b). Both elicit activation in brain regions related to language control (such as bilateral caudate nuclei and left supramarginal gyrus) and electrophysiological components (N2 and LPC, late positive component), with the difference being that voluntary language switching shows lower levels of brain activation and neural response. However, other evidence indicates that the cognitive and neural mechanisms of voluntary language switching exhibit specificity, particularly during the language selection stage. For instance, Zhang et al. (2024) found that language selection under voluntary switching conditions was associated with bilateral frontoparietal activation, which may involve bilinguals' naming intentions and regulation of spontaneous behavior (Desmurget et al., 2009; Lau et al., 2004), whereas language selection in forced language switching activated left frontal regions associated with inhibitory control.

Similarly, Reverberi et al. (2018) used multivariate pattern analysis to investigate neural activity during both the language selection and naming execution stages of voluntary language switching. The results showed that encoding of the target language during the language selection stage activated the medial prefrontal cortex, a brain region closely linked to free choice and decision-making

processes. The language control network activated during naming execution, however, showed substantial overlap with the neural mechanisms of forced language switching (Reverberi et al., 2015), primarily including left inferior frontal regions, basal ganglia, bilateral angular gyri, and inferior parietal lobules. These regions collectively participate in cognitive control processes such as target language selection and non-target language inhibition. Therefore, voluntary switching may recruit additional neural modules related to self-generated intentions and goal-directed behavior on top of the inhibitory control network.

In summary, although many voluntary language switching studies have reported switching costs similar to those in forced language switching, neural evidence suggests that voluntary and forced language switching may differ in both the stage at which inhibitory control occurs and the intensity of neural activity. Compared with forced language switching, voluntary language switching shows lower activation in brain regions related to language control, with this reduced activation primarily manifested during the later naming execution stage. During the initial language selection stage, the brain mechanisms of voluntary language switching more strongly reflect free decision-making and self-intention regulation. These findings suggest that previous bilingual control models may have overestimated the universality of inhibitory networks, whereas bilateral frontoparietal regions and the medial prefrontal cortex may play a central role in intention formation (rather than inhibitory control). Free choice may involve more intention generation and proactive planning than reactive inhibition.

## **1.5 Dual Advantages of Voluntary Language Switching: From Inhibitory Control to Lexical Access**

### **(1) Voluntary Language Switching Relies Less on Top-Down Inhibitory Control Mechanisms**

According to the Adaptive Control Hypothesis, language selection in dense code-switching contexts or situations with high language freedom depends less on control processes such as conflict monitoring and interference suppression. This suggests that inhibitory control demands may be lower in voluntary language switching contexts than in forced switching. In voluntary language switching tasks, participants can spontaneously choose to use either language at any time without needing to memorize language cues. This task design eliminates the process of checking whether lexical items match the expected language, thereby reducing reliance on top-down control (such as inhibiting the dominant language or activating the non-dominant language) (Kleinman & Gollan, 2016). The findings of Blanco-Elorrieta and Pykkänen (2017) also support this hypothesis. Their study examined brain activation patterns related to language control in bilingual production and comprehension across interactive contexts with varying ecological validity. The results showed that under forced language switching conditions with the lowest ecological validity, prefrontal and anterior cingulate control networks were significantly activated. However, when bilinguals engaged

in completely spontaneous language switching, these language control-related brain regions did not show comparable activation levels in either production or comprehension. These findings suggest that language switching triggered by external instructions may impose additional neural resource demands.

Moreover, imposing additional inhibitory control in voluntary language switching tasks may actually produce switching costs. Liu et al. (2020) applied transcranial direct current stimulation (tDCS) to the right dorsolateral prefrontal cortex, which is responsible for inhibitory control, to observe whether behavioral or neural switching costs would emerge during voluntary language switching in non-balanced Chinese-English bilinguals. Behavioral results showed that switching costs appeared under both anodal stimulation (which accelerates neural information transmission) and cathodal stimulation (which slows neural information transmission), but not under sham stimulation (no stimulation to the inhibitory control brain region). EEG data revealed that only cathodal stimulation elicited language switching costs, specifically manifesting as larger LPCs when switching to L2 compared with switching to L1. These findings indicate that inhibitory control is not necessarily beneficial in voluntary language switching and may instead trigger switching costs. A plausible explanation is that inhibitory control may interfere with the bottom-up lexical access process in voluntary language switching, hindering bilinguals' free choice between their two languages. Therefore, voluntary language switching may rely less on inhibitory control.

## (2) Faster Lexical Access in Voluntary Language Switching

Beyond top-down inhibitory control, another crucial factor influencing switching costs is the level of bottom-up lexical access. Lexical access levels affect bilinguals' language preferences (de Bruin et al., 2018; Gross & Kaushanskaya, 2015): the more accessible a lexical item is in a given language, the more likely bilinguals are to select that language. When language switching is entirely driven by lexical access levels, switching costs disappear (Kleinman & Gollan, 2016; Zhu et al., 2022). In voluntary language switching tasks, lexical access levels can be manipulated through task-driven language selection. Completely voluntary language switching requires participants to randomly select a language on each trial, and such tasks often reveal significant switching costs (Gollan et al., 2014; de Bruin et al., 2018). In contrast, when tasks require participants to select a preferred language for each picture and maintain that language choice throughout the naming task, switching costs tend to decrease or even disappear.

Similarly, Kleinman and Gollan (2016) compared whether completely voluntary language switching and bottom-up language switching differed in switching costs. The bottom-up switching task required bilinguals to choose a preferred language for each picture and consistently use that language throughout the naming task. The results showed that this type of language switching produced no costs because bilinguals' language switching costs were offset by the lexical access advantage of their preferred language, thereby eliminating switching

costs. In completely voluntary switching tasks, however, participants needed to evaluate which language would be easier to use on each trial and decide whether to switch languages or repeat the same language based on this assessment. This higher-level decision-making process means that language switching is not entirely driven by bottom-up lexical access but is significantly influenced by top-down decision processes (Gollan & Ferreira, 2009). Additionally, because no one-to-one correspondence is established between languages and lexical items, using different languages to name the same picture may reduce differences in lexical access difficulty across languages, thereby eliciting switching costs. Therefore, whether the task design permits consistent use of the same language may be a critical factor triggering voluntary language switching costs. Fixed language selection (driven by lexical access levels) can reduce inhibitory demands, whereas unpredictable cross-language competition in free switching may trigger top-down control mechanisms.

Zhu et al. (2022) cleverly used stimulus materials with inherent language biases in a voluntary language switching task, such as pictures of “DNA” and “shuttlecock.” These stimuli had much higher lexical access levels in their corresponding languages than their translation equivalents, naturally creating a voluntary switching context that reduced the control load of task-driven language selection. The results showed that in this voluntary language switching context, language switching did not elicit switching costs or activate brain regions related to language control. In contrast, in a control forced language switching task where participants produced lexical items without language bias, language switching not only triggered significant switching costs but also showed stronger activation in the right inferior frontal gyrus. The natural switching context not only eliminated switching costs but also reduced mixing costs and decreased prefrontal neural activity. This demonstrates that lexical access-driven word selection, combined with language congruency, collaboratively reduces cognitive load. Laboratory task settings (such as random language cues and switching instructions) may overestimate bilingual control demands in real-world scenarios.

## 2.1 Second Language Proficiency

In forced language switching tasks, bilinguals’ second language proficiency is widely considered an important factor influencing switching costs (Bonfieni et al., 2019; Green, 1998; Meuter & Allport, 1999). Differences in proficiency between L1 and L2 are typically reflected in the asymmetry of language switching costs. Among non-balanced bilinguals, researchers frequently observe asymmetrical switching costs, with higher costs when switching from L1 to L2 than from L2 to L1. In contrast, balanced bilinguals with comparable proficiency in both languages tend to show symmetrical switching costs (Calabria et al., 2012; Costa & Santesteban, 2004). However, despite the fact that L2 proficiency affects L2 lexical access speed, voluntary language switching studies less frequently report asymmetrical switching costs, regardless of whether participants are balanced or non-balanced bilinguals (de Bruin et al., 2018, 2020; Gollan et al., 2014;

Gollan & Ferreira, 2009; Gross & Kaushanskaya, 2015; Jevtović et al., 2020; cf. Mooijman et al., 2024). Unlike forced language switching, L2 proficiency in voluntary language switching modulates bilinguals' language selection preferences, which may influence proactive language control exerted at the global language level. Proactive control typically manifests as language mixing costs or reversed language dominance effects (Declerck, 2020) and functions to inhibit activation of the non-target language (e.g., the dominant language) at the global level, thereby reducing cross-language interference.

Gross and Kaushanskaya (2015) examined voluntary language switching in English-Spanish bilingual children and found that objects selected for naming in the non-dominant language were often those with high frequency in both languages, early acquisition, and lack of alternative names. Similarly, Gollan and Ferreira (2009) found that non-balanced English-Spanish bilinguals tended to select the non-dominant language (Spanish) when naming low-difficulty pictures and the dominant language (English) when naming higher-difficulty pictures. This flexible language selection reduced the difficulty of using the non-dominant language in mixed-language tasks, resulting in a mixing benefit effect for English in non-balanced bilinguals. In contrast, balanced bilinguals did not show mixing benefits but instead experienced mixing costs between their two languages. Voluntary language switching allows non-balanced bilinguals to leverage their bilingual advantage to avoid weak-language lexical items, for example, by selecting the most easily retrievable words from either L1 or L2 to reduce retrieval difficulty. This strategy reduces the need to inhibit L2 and avoids the cognitive load of continuously suppressing L1, leading to faster naming in mixed-language conditions than in single-language conditions (mixing benefits). As L2 proficiency increases and lexical access levels in both languages converge, decision conflicts may instead arise. Even when lexical access levels are relatively balanced, the act of selecting a language itself may require additional cognitive resources (such as inhibiting the current language or monitoring the target language), thereby producing mixing costs.

Mooijman et al. (2024) further validated the modulatory role of L2 proficiency, particularly self-rated proficiency, on proactive control. The study found that non-balanced Dutch-English bilinguals with higher L2 proficiency exerted stronger proactive control over their dominant language during voluntary switching tasks. Compared with participants with lower self-rated L2 proficiency, those with higher self-rated proficiency were more inclined to name pictures in English. To maintain consistent English production, they applied greater inhibition to the stronger Dutch language, resulting in a reversed language dominance effect—that is, overall naming times in Dutch were longer relative to English. This phenomenon reveals the proactive control mechanisms underlying voluntary language switching in non-balanced bilinguals. Individuals with high self-assessment are more likely to actively use L2 but require more resources to maintain language balance, leading to mixing costs; conversely, those with low self-assessment may underestimate their L2 abilities and actually rely more on L1, thereby reducing mixing costs.

Thus, although high L2 proficiency enhances lexical access efficiency and reduces lexical search time, the additional decisions required in voluntary switching may be independent of language ability, such as choosing whether to switch and when to switch (Kleinman & Gollan, 2016). Mooijman et al. (2024) found that self-rated proficiency influences switching frequency through metacognitive strategies; for example, increased proficiency may enhance language confidence and motivation to use L2 but does not necessarily reduce the speed and complexity of individual decisions, such as evaluating lexical items and avoiding difficulties. Consequently, its impact on local-level switching costs is relatively small. The dissociation between voluntary language switching costs and proficiency reveals the limitations of inhibitory control theory: switching costs may stem not only from inhibiting conflicting languages but also reflect the cognitive load of intentional decision-making. This aligns with neuroimaging evidence for voluntary switching, which shows that voluntary switching involves not only language competition but also intention formation and self-behavior regulation (Zhang et al., 2024).

## 2.2 Context

In addition to bilinguals' own L2 proficiency, context represents another important factor influencing bilingual control in voluntary language switching. Research has found that bilingual control mechanisms in voluntary switching undergo adaptive changes and adjustments at both global and local levels, whether in non-linguistic contexts (e.g., interlocutor context) or linguistic contexts (e.g., sentence context) (Blanco-Elorrieta & Pyllkkänen, 2017; de Bruin & Martin, 2022; Kapiley & Mishra, 2024; Sánchez et al., 2022). Interlocutor context is typically presented through non-linguistic cues (e.g., avatars, flags) in experiments and is therefore categorized as a non-linguistic cue-based context, distinct from linguistic contexts that provide direct cues through language content (e.g., sentence text).

The Adaptive Control Hypothesis (Green & Abutalebi, 2013) emphasizes that bilinguals' language control mechanisms adapt dynamically according to communicative context. In interactive situations, the frequency and costs of bilinguals' voluntary language switching are modulated by interlocutor characteristics (such as language production patterns and proficiency levels). For example, in a picture description dialogue task, Kootstra et al. (2020) found that Dutch-English bilinguals' language switching behavior converged with that of their interlocutors. During turn-taking picture descriptions, if the interlocutor had just switched languages, participants tended to spontaneously switch languages in the subsequent turn. Kapiley and Mishra (2024) further discovered that both the interlocutor's and the bilingual's own language backgrounds influence lexical selection and language control mechanisms in voluntary switching. High-proficiency Telugu-English bilinguals experienced L2 switching benefits (i.e., switching to L2 was faster than repeating L1) when interacting with high-proficiency interlocutors who appeared frequently; when lower-proficiency

interlocutors appeared more frequently, they showed L1 switching benefits (i.e., switching to L1 was faster than repeating L2). Unlike high-proficiency participants, low-proficiency participants showed symmetrical switching costs across different interlocutor contexts. Thus, bilinguals with higher L2 proficiency can more effectively predict interlocutor frequency and flexibly adjust the activation states of their two languages according to interlocutor proficiency levels, making language switching more fluent. Bilinguals dynamically adjust language selection based on interlocutor proficiency, suggesting that language switching is not only goal-driven but also involves real-time social intention inference, such as assessing speakers' language habits and abilities. This supports the language activation selection model proposed by Blanco-Elorrieta and Caramazza (2021), which posits that language selection is guided by lexical activation levels and depends on dynamic integration of contextual cues rather than unidirectional inhibitory control.

Beyond interlocutor-centered interactive contexts, the conceptual framework of Hasson et al. (2018) further broadens the notion of context, noting that natural language processing involves complex interactions among different types of contexts, including communicative-social context (e.g., interlocutor background characteristics), personal context (e.g., one's own emotional state or beliefs), and prior discourse context (linguistic context). Jiang et al. (2024) examined voluntary language switching performance in Chinese-English bilinguals under neutral, negative, and positive emotional states and found that emotional states affect proactive control at the global language level, manifested in reversed language dominance effects. Negative emotional states impaired proactive control (reduced reversed language dominance effects and longer overall naming times), whereas positive states improved proactive control (shorter overall naming times). Emotion may influence language switching strategies and efficiency, and these findings reflect the complex adaptability of bilingual control across different emotional contexts, supplementing the Adaptive Control Hypothesis's classification of communicative contexts by highlighting the role of emotional context.

Furthermore, bilingual control mechanisms in voluntary language switching are also modulated by sentence context. Sentence context provides bilinguals with more naturalistic situations and more ample preparation time (Declerck & Philipp, 2015), which may facilitate language switching. Sánchez et al. (2022) used an image path description paradigm requiring Spanish-English bilinguals to describe in sentences the trajectory of a red dot traveling through a network of eight pictures. The results revealed that switching costs disappeared when bilinguals voluntarily switched to L1, suggesting that contexts more closely approximating natural communication may substantially reduce language control demands. However, de Bruin and Shiron (2024) found different switching cost patterns in picture naming with sentence context. Compared with the no-context condition, Bulgarian-English bilinguals showed significantly reduced voluntary language switching frequency in sentence contexts, with correspondingly increased switching costs. Additionally, high-predictability sentence contexts

elicited fewer language switches than low-predictability contexts. This may be because non-target language activation is lower in high-predictability sentence contexts, thereby increasing the difficulty of switching to the non-target language. The authors propose that sentence context may suppress co-activation of both languages (Coumel et al., 2024; Van Hell & de Groot, 2008), consequently leading to increased switching costs and reduced switching frequency. These findings suggest that sentence context may exert a dual modulatory effect on voluntary language switching. Context is closely related to dynamic allocation of language resources and integration of semantic expectations. Although not constituting the core meaning of lexical items, contextual features serve as important components of conceptual information that constrain lexical selection (Blanco-Elorrieta & Caramazza, 2021). For example, in highly predictable sentences, semantic expectations may reduce competition through top-down processing, meaning that lexical selection may not rely solely on inhibitory mechanisms, challenging traditional inhibitory models (Green, 1998).

### 3 Bilingual Control Mechanisms in Voluntary Language Switching and Domain-General Executive Control

A substantial body of research indicates that bilinguals' language switching behavior is closely linked to domain-general executive control abilities, with long-term language switching experience contributing to enhanced executive control (DeLuca et al., 2020; Han et al., 2022; Gosselin & Sabourin, 2023; Yao et al., 2025). However, research on language switching and executive control over the past three decades has predominantly used forced language switching tasks (e.g., Declerck et al., 2017; Hernandez, 2009; Jiao et al., 2022a; Jylkkä et al., 2021; for a review see Tao et al., 2021). For example, Declerck et al. (2021) found that switching costs elicited by forced language switching and task switching showed high similarity in both response time and EEG measures. However, such experimentally manipulated language switching does not perfectly map onto bilinguals' self-directed language switching phenomena. In recent years, some studies have begun using voluntary language switching tasks that more closely approximate bilinguals' spontaneous switching behavior to investigate the relationship between language switching and domain-general executive control.

Gollan et al. (2014) compared Spanish-English bilinguals' performance on voluntary language switching and non-linguistic task switching (reading vs. addition tasks), finding significant switching costs in both language and task switching. Moreover, bilinguals who switched frequently in language switching tasks also tended to switch frequently in non-linguistic tasks. This finding suggests that when bilinguals spontaneously switch languages, they employ cognitive mechanisms similar to those used in non-linguistic switching. de Bruin and Samuel (2020) found that voluntary language switching elicited switching costs in both young and older Basque-Spanish bilinguals. Although voluntary switching reduces external interference and allows more flexible resource allocation, it still

requires executive control resources to inhibit the non-target language. Notably, older bilinguals showed larger voluntary switching costs than younger bilinguals, possibly due to cognitive aging leading to deficits in inhibitory release mechanisms that make it difficult to eliminate within-language interference. However, these studies primarily relied on laboratory tasks, neglecting the complex diversity of spontaneous switching behavior in natural contexts.

To further investigate voluntary language switching behavior and its control mechanisms in real-world scenarios, recent researchers have expanded the association between bilingual control and cognitive control in voluntary switching by using task designs that more closely approximate natural language use, refining language switching types, and incorporating individual factors such as language use environment and switching frequency. For example, López-Penadés et al. (2020) categorized bilinguals' language switching experiences into conscious switching (e.g., actively switching from L1 to L2), context-driven switching, and unconscious switching, and found for the first time that active L2 switching was positively correlated with working memory updating and task-switching efficiency, whereas unconscious switching was associated with poorer interference control, revealing the complex adaptability of language control. Han et al. (2024) moved beyond lexical-level task designs and used natural conversation and story narration tasks to observe voluntary language switching behavior in Chinese-English bilinguals, finding a significant positive correlation between higher-frequency intrasentential insertion-type language switching and domain-general inhibitory control performance (spatial Stroop task), manifested as shorter response times on incongruent trials. Similarly, Lai and O'Brien (2020) found that intersentential switching ability in natural dialogue tasks was positively correlated with goal maintenance and conflict monitoring efficiency in English-Chinese bilinguals. However, the authors argue that the static classification of the Adaptive Control Hypothesis cannot fully explain actual language behavior in multilingual societies because real language use involves contextual overlap and dynamic switching—for instance, the same conversation may involve both intersentential switching and intrasentential mixing, which cannot be strictly categorized as a single context.

Overall, this evidence suggests that voluntary language switching is closely linked to multiple components of domain-general executive control, including inhibitory control, working memory, and conflict monitoring. Different types of voluntary language switching (e.g., conscious vs. unconscious switching; intrasentential vs. intersentential switching) may rely on different cognitive control mechanisms, and individual difference factors such as age and language use patterns significantly affect this relationship. Therefore, the Adaptive Control Model requires further refinement and adjustment by incorporating dynamic contextual factors (such as individual language use habits, sociocultural norms, language policies, etc.) to accommodate real-world complexity. Meanwhile, current research on voluntary language switching in natural contexts has focused primarily on the behavioral level, with insufficient exploration at the neuroscience level. Consequently, future research urgently needs more neuroscientific

evidence to investigate whether bilingual control mechanisms in natural contexts share the same brain mechanisms as domain-general executive control and to reveal how voluntary switching experience shapes executive control abilities.

## 4 Summary and Outlook

Voluntary language switching research focuses on bilinguals' spontaneous language switching behavior in daily life. Such research reflects the self-driven language switching mechanisms in bilinguals' natural communication and reveals how bilinguals efficiently manage and control their two languages without external coercion. Research on voluntary language switching continues to advance, with more nuanced understanding of switching costs, increasingly refined delineation of neural mechanisms, and more systematic investigation of relevant influencing factors. Recent studies demonstrate that voluntary language switching does not necessarily entail high cognitive load; under specific conditions (e.g., contexts driven by lexical access), switching costs can be significantly reduced or even completely eliminated. Neuroimaging research has preliminarily revealed that voluntary language switching exhibits specific patterns of brain activation, involving not only regions related to inhibitory control (e.g., right inferior frontal gyrus) but also additionally recruiting brain areas associated with self-selection processes (e.g., medial prefrontal cortex). In natural contexts, voluntary language switching may rely less on inhibitory control, thereby promoting efficient allocation of neural resources. Furthermore, the efficiency, frequency, and patterns of voluntary language switching are subject to complex modulation by individual difference factors (language proficiency, switching experience, executive control ability, etc.) and multiple environmental factors (interlocutor background, emotion, and contextual cues, etc.), highlighting the adaptability and flexibility of the bilingual control system. These advances are driving theoretical evolution from a single mechanism centered on inhibition to a comprehensive framework encompassing multi-factor dynamic interactions.

The multiple influencing factors of voluntary language switching pose new requirements for theoretical model construction. Building upon the Inhibitory Control Model (Green, 1998), bilinguals' language selection and use are not only the result of controlling the non-target language based on proficiency but also depend on speakers' integration of multidimensional information in conversational contexts, such as recent language use patterns, conceptual information, and interactive contexts (Blanco-Elorrieta & Caramazza, 2021; Hasson et al., 2018). The Adaptive Control Model (Green & Abutalebi, 2013) provides a basic theoretical framework for the adaptability of bilingual control to different interactive contexts but has not integrated individual differences, sociocultural, and emotional factors. Its classification struggles to explain differences in language switching patterns, frequencies, and social functions across different cultural backgrounds and sociolinguistic environments. Therefore, existing theoretical models need to incorporate individual difference factors (language use habits, emotional states, executive control ability, etc.) and expand to

more fine-grained context classifications while constructing multi-level control frameworks that distinguish bottom-level control mechanisms related to lexical selection from higher-level regulation associated with social intentions and semantic expectations.

Although current research has preliminarily explored bilingual control mechanisms and influencing factors in voluntary language switching, future studies require further innovative expansion in research approaches and methodologies. Recent voluntary language switching research has begun employing natural dialogue and narration tasks that more closely approximate real interactive scenarios (e.g., Han et al., 2024), improving upon the ecological validity limitations of traditional laboratory research. Future studies can also leverage technological advantages in cognitive neuroscience to deeply investigate the cognitive and neural mechanisms of voluntary language switching. For example, combining near-infrared spectroscopy with online dialogue analysis to probe bilingual control mechanisms and patterns of cognitive control resource recruitment during real peer interactions. Using VR technology to construct multimodal dialogue scenarios (e.g., simulating test situations or conversations with authority figures) and combining physiological measures such as EEG to explore the neural coupling mechanisms between emotion and bilingual control networks, capturing the multiple modulatory effects of interactive contexts and individual factors (e.g., language proficiency and emotional states) on bilingual control.

Additionally, although existing research has revealed associations between bilingual control mechanisms in voluntary language switching and domain-general executive control, its role as bilingual experience shaping cognitive development and brain structure and function awaits verification through longitudinal studies, particularly in bilingual children undergoing brain development and older adults experiencing cognitive decline. Future research could collect voluntary language switching data from bilinguals in social networks, use speech recognition and semantic analysis tools (such as BERT, GPT large language models) for annotation and classification, and employ portable devices (e.g., eye-tracking and EEG) to capture voluntary switching behavior and neurophysiological indicators in more naturalistic environments. By combining complex behavioral patterns in social contexts with standardized laboratory measurements, future studies can parse the essence of bilingual control in voluntary language switching, reveal the mutual facilitation between bilingual control and domain-general executive control functions such as memory, switching, and interference suppression, and explore the long-term adaptability of cognitive resources.

Finally, current voluntary language switching research has focused primarily on the language production dimension, while the bilingual control mechanisms underlying comprehension of voluntary language switching and their relationship with production remain underexplored. Natural language comprehension and production recruit similar brain regions and share linguistic representations (Patel et al., 2023; Wu et al., 2022). Future research needs to compare similarities and differences in bilingual control mechanisms between comprehension and pro-

duction of voluntary language switching and explore their synergistic shaping effects on cognitive control. Investigating the interaction mechanisms between comprehension and production in voluntary language switching may also provide insights for second language learning and bilingual education. Previous research has found that the coupling strength between speakers' and listeners' brain activity is proportional to communication quality (Zada et al., 2024). During conversation, reduced production and comprehension costs of voluntary language switching for both communication partners may lower mutual understanding and communication costs. For instance, comprehending frequently occurring language switches in natural contexts imposes minimal burden on bilinguals (Salig et al., 2024). In classroom teaching or group communication contexts, allowing speakers to voluntarily switch languages according to expressive needs may not only enhance their language fluency but also reduce learners' cognitive load, thereby improving learning effectiveness. Under the trend of interdisciplinary and technological integration, future voluntary language switching research should combine theories and approaches from education and neuroscience to enhance the applied value of research findings.

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