コードスイッチングが実行機能メカニズムに与える影響：日英早期バイリンガルと後期バイリンガルの比較
The effect of code-switching experience on dual mechanisms of cognitive control: comparison between early and late Japanese-English bilinguals

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Abstract
There is a controversial debate as to whether bilingualism enhances cognitive control performance. This study aims to gain novel insight into the mechanisms that underlie the bilingual advantage in cognitive control and investigate the effect of code-switching experience in daily life, rather than language proficiency, on the mechanisms that underlie the bilingual advantage in cognitive control. We compared the performances of early and late Japanese-English bilinguals on the AX-Continuous Performance Task (AX-CPT). We found early bilinguals and late bilinguals show different cognitive control mechanisms to cope with interference: with the late bilinguals, the more frequently they switched languages in their L1 environment, the better they performed in the proactive control tasks. In contrast, with the early bilinguals who are generally more proficient, the frequency of code-switching did not modulate their dual mechanism of cognitive control (DMC) any better, showing little correlation with the ability of proactive control. These findings verify the role of switching frequency in the development of cognitive control and suggest a better understanding of the nature of mechanisms regulating early and late bilinguals' brains.

Keywords — Executive Function, Bilingualism, Language Switching, Dual Mechanisms of Control, Second Language Proficiency, Cognitive Control

I. Background
There is a controversial debate as to whether bilingualism enhances cognitive abilities. Over the past two decades, researchers have reported that bilingual individuals demonstrate cognitive advantages compared to monolingual peers on both linguistic and non-linguistic measures. However, it is still unclear whether such advantages are equally present in all types of bilinguals, or what cognitive and neural modules underlie them. There has been a tendency to overemphasize bilingual language proficiency, while failing to address the effect of code-switching experience. A recent neuroimaging study (Chen et al., 2021) has demonstrated that language switching training modulates the neural interaction of domain-general cognitive control, which gives the critical implication for future studies to continue exploring how the code-switching behaviors influence the mechanism of bilinguals' cognitive control.

II. Objective
In the current study, we examine the effect of code-switching experience on cognitive control abilities in young Japanese-English bilinguals.

In the previous studies, relatively few researchers have examined the effect of code-switching frequency on cognitive control. Among rare studies to explore the relationship between the performance of non-linguistic task-switching and the experience of language switching, Prior and Gollan (2011) compared the performance of Spanish–English bilinguals and Mandarin–English bilinguals in task-switching and language-switching paradigms. In their study, Spanish–English bilinguals showed a higher frequency of switching languages in daily life; however, Mandarin–English bilinguals switch languages less frequently. The results showed that bilinguals who regularly switch between languages performed with smaller task-switching costs, which suggested the relationship between language switching and bilingual task-switching benefits. Similar findings have been reported by Hartanto and Yang's (2016) that bilinguals within the dual-language context showed smaller switch costs than bilinguals within the single-language context. They applied diffusion-model analysis on subjects and verified that code-switching experience benefits from task-set reconfiguration rather than proactive interference.

Based on previous research experience, it can be concluded that switching between different languages, relative fluency of the languages they can speak, and experience in terms of years they have been code-switching will lead to differences in cognitive control. Therefore, this study will focus on two types of young Japanese-English bilinguals: early bilinguals and late bilinguals. Early bilinguals will mainly have acquired both Japanese and English naturally by pre-school age. Hence, early bilinguals would show excellent fluency in both two languages and are used to adapting to code-switching behaviors in daily life, which could offer much more frequency of code-switching. In contrast, we define late bilinguals as those who have acquired the second language as a foreign language after the age of puberty (i.e., 12 years or later). In our research, late bilinguals refer to native Japanese speakers who learned English as a second language. They do not switch languages as skillfully or as frequently as early bilinguals and there is a great imbalance between the two languages. To sum, it is the differences in relative fluency and experience in terms of years they have been code-switching that lead to the differences in cognitive control performance between the two groups and also the different mechanisms under the performances, which is the focus of this paper.

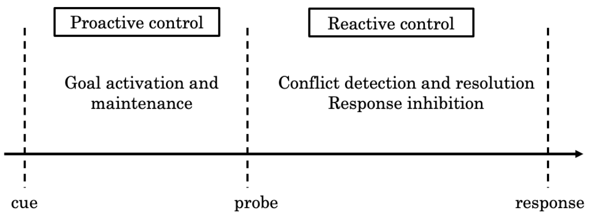

Figure 1 the dual mechanism of cognitive control(DMC) framework

In this study, we chose to use the AX-CPT tasks to examine the effect of code-switching experience on the dual mechanism of cognitive control (DMC, Braver et al., 2012, see Figure 1). In recent years, some researchers have tried to apply a dual mechanism of cognitive control (DMC) to explain cognitive advantage of bilingualism. The main principle of the dual mechanism of cognitive control (DMC) was first put forward by Braver and his colleagues (2007). They proposed that there are two qualitatively distinct control modes to uncover and combine the mechanisms enabling cognitive control. The dynamic combination of proactive and reactive control is made up of DMC. The proactive control happens ahead of cognitively demanding events, regarded as the form of "early selection" or the act of anticipating; in contrast, reactive control is viewed as "late correction", which happens after the onset of demanding events. In previous studies, researchers pointed out that bilingual advantage should not be explained only by a single process but may be illustrated by the combination of monitoring and inhibition, which are DMC frameworks (Bialystok, Craik, & Luk, 2012; Costa et al., 2009). Specifically, bilinguals need to first monitor the conversation's context and then select the appropriate language to communicate. During this process, proactive control may assist bilinguals in regulating context processing and suppressing unnecessary interference before the complicated communication starts. The results of the behavioral experiment and the ERP experiment using a highly demanding version of the AX-CPT found that bilingualism may modulate the dual mechanism of cognitive control (Morales et al., 2013, Morales et al, 2015). Therefore, in the current study, we chose this more comprehensive DMC framework, rather than a single process model, to evaluate the features of early and late bilingual's cognitive control ability.

In short, the purpose of this study is to compare and contrast the DMC functions between early and late bilinguals. We hypothesized that the early bilinguals would outperform in the DMC because they are more likely to be proficient in code-switching owing to their longer experience compared to that the late bilinguals.

III. Methods

Participants

Fifty-five Japanese-English bilingual young adults (21 female, 34 male, $M_{age} = 20.64$, $SD_{age} = 1.53$, age range = 18 - 24 years) were recruited from Waseda University in Japan. All participants were Japanese native speakers who can also speak English.

Participants completed a language background questionnaire (LBQ) that asked for details about each language they knew, including AoA, proficiency, and frequency of use (see Language Background Measures).

Table 1 Demographics, mean score, and standard deviation on language background measures

	Early Bilingual Group (EBG) N = 30	Late Bilingual Group (LBG) N = 25
Male/female	17/13	17/8
Age (years)	20.52 (1.33)	20.64 (1.66)
Japanese		
AoA[a]	0.00 (0.00)	0.00 (0.00)
Proficiency[b]	9.68 (0.53)	9.84 (0.42)
Usage[c]	0.55 (0.15)	0.81 (0.15)
English		
AoA[a]	4.21 (2.19)	11.4 (1.55)
Proficiency[b]	8.59 (1.02)	6.61 (0.95)
Usage[c]	0.45 (0.15)	0.19 (0.15)
Language-switching[d]	21.72 (3.06)	16.54 (4.94)

[a] AoA = Age of Acquisition
[b] Average of self-reported proficiency in Japanese and English language comprehension, speaking, reading and writing, ranging from 1 = not proficient to 10 = very proficient.
[c]Self-reported proportion of current language use weekly in various contexts (e.g., if a participant reported using a language 40% of the time weekly, the usage score would be 0.40 for this language.)
[d]Total score of 7 questions on the frequency of language-switching, ranging from 1 = never to 5= always.

Based on the answers of LBQ, we classified the participants into two groups: (i) the early bilingual group (EBG) consisting of 30 early bilinguals who had acquired English before 4.5 years old and (ii) the late bilingual group (LBG) consisting of 25 late bilinguals who had acquired English at about 12 years old.

Early bilingual group (EBG) learned both English and Japanese simultaneously before the age of 4.5 (English: M_{AoA} = 4.21 years, SD = 2.19, Japanese: M_{AoA} = 0.00 years, SD = 0.00). Most participants acquired the languages both at home and in school. They also reported English and Japanese as the two most-used languages in their present daily life; the average weekly use of English and Japanese was 45% and 55% respectively.

<u>Cognitive Control Task: AX-CPT task</u>

The AX-CPT tasks (Braver et al., 2012, see Figure2) were used to measure the proactive and reactive cognitive control. In the AX-CPT tasks, each trial began with a plus sign ("+") for fixation, followed by a cue. The cue was an alphabetic letter (excluding X, K, or Y) presented in the center of the screen for 1000 ms, followed by a blank screen as an inter-stimulus interval (ISI) of 1000 ms. After the ISI, the probe appeared. The probe was also an alphabetic letter (excluding A, K, or Y) presented in the center of the screen for 500 ms. According to the instruction, when participants observed an A cue followed by an X probe (i.e., A-X trials), they should press the "Yes" button with the left index finger as quickly as possible. For all the other trials where the cue and probe consisted of letter combinations other than A-S, they had to press the "No" key with the right index finger as quickly as possible. In the English keyboard of a laptop computer, the "c" key was used to indicate "yes" and the "n" key was used to indicate "no". In the experiments, each key was labeled "yes" and "no" as reminders. The participants were instructed to respond only after they have observed the second letter in the pair (i.e., the probe). Responses to the probe stimuli were recorded with a time limit of 1500 ms.

Also, there were four types of trials that conform to the AX-CPT tasks, as used in the study by Braver et al. (2012, Table.2). In each task block, AX pairs took up 70% of the trials, and AY pairs (an A followed by a letter other than X) took up 10% of the trials. BX trials (a letter other than A followed by an X) and BY trials (a letter other than A followed by a letter other than X) both respectively took up 10% of the trials. All the letters except A and X are pseudo-randomly selected. Trials within each block were presented randomly. Based on this proportion, since AX pairs occur at a very high frequency (70% of the trials),

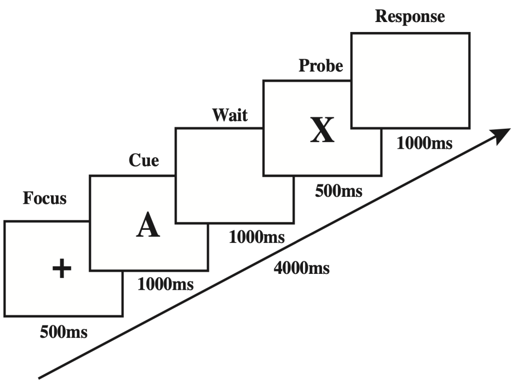

Figure 2 Schematic representation of the AX-CPT procedure

participants prepare to respond Yes after seeing an A cue appearing, motivated by proactive control mechanisms. On the contrary, BX pair's errors was led by the failure in reactive control because X probe induces Yes response. There were two blocks, each consisting of 50 trials in the experiment, resulting in the total of 100 trials for each participant. The reaction time (RT) and the error rate (in %) were collected and used in the data analysis.

Table 2 The four types of trails that conform the task (Braver et al., 2009)

Cue	Probe	%	Response	Condition
A	X	70	Yes	Target Trials
A	Y*	10	No	Errors due to proactive control
B*	X	10	No	Errors due to reactive control
B*	Y*	10	No	Control trials

**B&Y here mean any letter except X, K or Y*

Experiments were administered individually in a quiet room at Waseda University. The experiment has been approved based on the assessment of the Ethics Review Committee on Research with Human Subjects of Waseda University. All participants voluntarily participated in the experiments and provided informed consent before participating in the study. Participants completed the language background questionnaire, followed by completing the AX-CPT task on the computer.

Language Background Measures

Four sections consist of language background questionnaires, including language background, past and current language usage, and the frequency of language-switching.

In the first section of the language background, the age they were first exposed to and the proficiency in each of the languages they know were asked. Participants were asked to self-rate their language proficiency in four aspects on a 10-point scale where 1 is not proficient and 10 is very proficient. We also asked participants to recall their English language score as the reference to ensure the correctness of self-rated reported proficiency. The second and third sections aimed to learn about past language use, including the period of living abroad other than living in Japan (past language usage) and obtain usage for each language in Japan nowadays (current language usage). Also, participants have to use percentages to calculate how often they communicate with people in different contexts in a typical week and rate the share they use in each language in each of these contexts. The usage of the different languages in the various contexts would add up to 100%. For instance, students living with their families always claim 50% to communicate with their family members and 50% for others. In 50% with their families, 100% in Japanese represents they all use Japanese at home; In another 50%, English was the frequent answer on campus and in classes. A higher usage level in one language means a lower usage level in the other language(s).

In addition, to study the effect of code-switching experience on early bilinguals and late bilinguals in cognitive control, we used the score of the fourth section of language background questionnaires which focuses on language-switching behaviors. This section has seven questions to identify the language switching patterns in Japanese and English. The participants had to rate each situation on a scale ranging from 0 (=never) to 5 (=always). Based on all participants' language-switching performance (M_{score} = 19.49, SD = 5.49), higher scores indicating higher tendency to switch between languages (referred to the questions created by Rodriguez-Fornells et al., 2012; Yow, W. Q., & Li, X.,2015).

IV. Results and Discussions

Focusing on the RTs (Figure.3) and the proportion of errors (Figure.4) of the AX-CPT tasks, we applied the general linear model (a repeated-measures ANOVA) on the permanence of both groups in four conditions (AX, AY, BX, BY trials), and in "no" responses (AY, BX, BY trials), with the language group as a between-subject variable and the trial type as a within-subject variable. The main effect of trial types and the interaction effect between language groups and trial types reached significance in both the RTs and error rates. However, there was no statistically significant difference in either the RTs or errors between the two language groups.

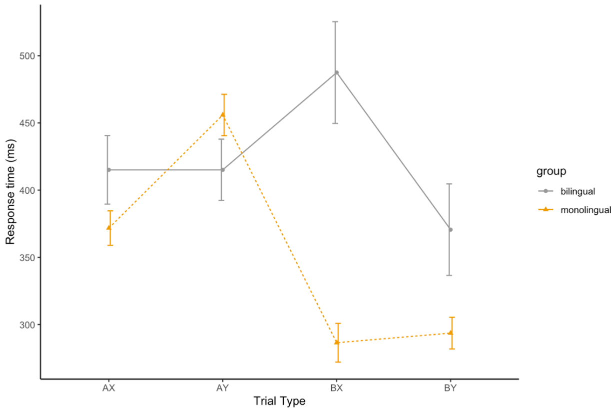

Figure 3 Average response times in the AX-CPT as a function of trial type and task condition

In addition, we also applied a Pearson correlation coefficient to assess the linear relationship between the frequency of language-switching behaviors and the Proactive Behavioral Index (PBI index) for each language group respectively. PBI index is calculated as (AY − BX) / (AY + BX) and measures the relative balance of interference between AY and BX trials: A

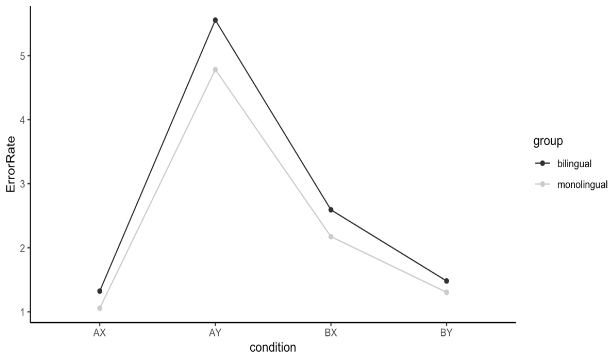

Figure 4 Average error rates in the AX-CPT as a function of trial type and task condition

positive PBI index indicates the active engagement of proactive control, and a negative PBI index indicates the active engagement of reactive control (Braver et al., 2009). We were surprised to find a positive correlation only in the late bilinguals' group (see Figure.5), which indicates that if late bilinguals switch their languages more frequently in their daily life, they will tend to employ the proactive control more. Unlike late bilinguals, there were no statistically significant correlations in the early bilinguals' group, which shows even though the frequency of code-switching behaviors increases, this increasing will not work on the proactive control obviously.

Based on the standard of grouping, early and late bilinguals participating in the present study showed disparate features in the aspect of English proficiency, AoA (age of English acquisition), frequency of use of English in daily life, and the frequency of language-switching. This means that even though the participants are all Japanese native speakers and living in a Japanese-dominant context environment, their language environments were vastly different. For late bilinguals, switching languages is only possible when communicating with foreign friends and taking English classes on the university campus. They need to be consciously reminded themselves to switch languages and are not used to these language-switching behaviors. Also, according to the answers of section 3-3 in the language background questionnaire, all late bilinguals claimed that whether they speak English or Japanese, they think in Japanese. Thus, English for late bilinguals is not a common behavior, which means when they have to use English, they need to think in Japanese and then translate it into English. However, it was this conscious language switching behavior that led to better performance on proactive control. As the frequency of this unusual language-switching behavior increases, the capacity of better regulation of context processing and suppression of inappropriate responses were trained in daily life, which leads to performing well in the AX-CPT tasks and achieving a higher score in the PBI index.

Different from late bilinguals group, early bilinguals are used to conduct language-switching behavior in their daily life. They tend to switch the context of their thinking automatically and unconsciously according to the different language environment: when they use English, they think in English; When they use Japanese, they think in Japanese. This natural and familiar language-switching behavior does not confer a definite advantage to cognitive control, explained by the no-significance in the correlation between the PBI index in response times and the frequency of language-switching behaviors. Another possibility is that being bilingual may have an advantage in reactive control. For early bilinguals, there is no need to consciously anticipate, monitor, and prepare for the language they will use before the conversation occurs because they are already skilled enough to cope with such challenges. However, when the speaker begins to speak in a particular language, bilinguals automatically switch language channels in their brain to the corresponding language. Such transformation and adjustment are a manifestation of reactive control, but it may be because such transformation is too skilled and fast, and the intentional weakness in reactive control is not reflected in this experiment. Or it is also possible that early bilinguals did not use DMC mechanisms but had other mechanisms to regulate their cognitive mechanisms. Therefore, based on our findings, early bilinguals and late bilinguals may be using different strategies for different conditions.

To conclude, this study provides evidence for a multi-component perspective that the code-switching behaviors influence the mechanism of bilinguals' cognitive control. The analysis of both the AX-CPT task and the frequency of language-switching behaviors allows us to claim that early and late bilinguals are using different strategies for different conditions, modulated by the dual mechanism of cognitive control and also affected by the frequency of code-switching behaviors.

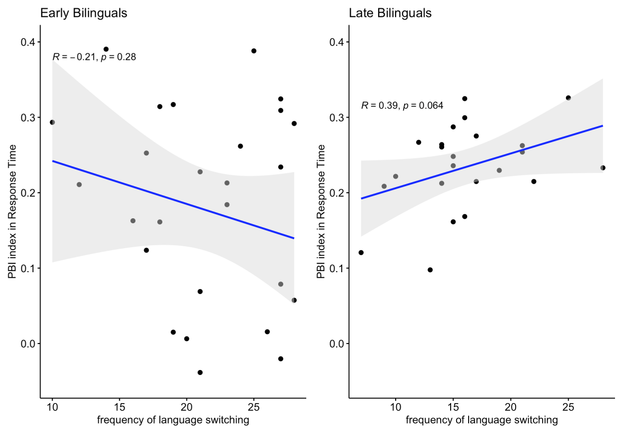

Figure 5 Scatterplots for the correlation between the frequency of language switching and PBI index in Response Time in the early bilinguals' group and late bilinguals' group

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