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Comprehension-based language switching between newly learned languages: The role of individual differences

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ABSTRACT

The Adaptive Control hypothesis and relevant empirical evidence in bilingualism literature have revealed the adaptive nature of bilingual language control in skilled languages, while the language control processes at the very initial stage of new language learning have not been examined. The present study investigated how the individual differences in inhibition ability and language switching experience influence the controlling process of newly learned languages, using event related potentials (ERPs) technology. We first assessed the language switching frequency and inhibition ability of Chinese-English bilinguals on Day 1. Then, all bilinguals learned words from new languages (namely German and Japanese words) during the next six days and completed a comprehension-based language switching task between the newly learned languages on Day 8. Results of mixed-effects models on the behavioral data showed that there were no switching costs (i.e., derived by contrasting switch trials with repeat trials) and no predictive effect of individual difference on the language switching between newly learned languages. However, the ERPs results revealed switching costs and individual difference effects in N2 and LPC. The language switching frequency significantly predicted the variability of the N2 and LPC, and the inhibition ability modulated the switch effect in Japanese as showed in the LPC. These findings suggest that individual differences predict comprehension-based language control between the newly learned languages, providing new evidence for the adaptability of language control from a language comprehension perspective.

1. Introduction

Previous research has found that non-target language is often activated automatically in bilinguals, producing interference for the target language during language switching (Kroll, Bobb, & Wodniecka, 2006; Marian & Spivey, 2003). A series of studies have been conducted trying to figure out the mechanism that makes it possible to successfully select the target language in the intrusive situation (Baus, Branzi, & Costa, 2015; Bobb & Wodniecka, 2013; Kroll, Bobb, Misra, & Guo, 2008). Some studies revealed that individual differences (such as external language switching behavior and internal inhibition ability) play a critical role in controlling the skilled languages of bilinguals (Green, 1998; Green & Abutalebi, 2013; Liu, Liang, Dunlap, Fan, & Chen, 2016). However, relevant studies mainly focused on the control processes of skilled languages in bilinguals, little attention has been paid to the language control

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processes between newly learned languages.

From a developmental perspective, language experience should be viewed as a continuum (DeLuca, Rothman, Bialystok, & Pliatsikas, 2019), along which not only vocabulary knowledge, proficiency and so on are constantly changing, but the language control efficiency also increases from newly learned stage to a skilled stage. In consideration of the Adaptive Control hypothesis (Green & Abutalebi, 2013) and Inhibitory Control (IC) model (Green, 1998), language control processes in the context of newly learned languages may recruit different control mechanisms compared with the skilled language context. Moreover, given the close relationship between inhibition ability and new language learning (Kapa & Colombo, 2014), it is possible that the individual differences of bilinguals predict the language switching pattern between newly learned languages. But, the Bilingual Interactive Activation (BIA) model (Dijkstra & van Heuven, 2002) proposes that inhibitory control process is within the lexicon and not governed by domain-general inhibition ability. This model leaves open the possibility that differences in domain-general inhibition ability may not directly work on comprehension-based language control processes. Given these inconsistent assumptions around language switching of newly learned languages, the present study used a training paradigm and examined how individual differences in bilinguals (namely inhibition ability and language switching experience) predict language control processes in the context of understanding newly learned languages.

1.1. Language switching processes in bilinguals

To investigate the language control process during language comprehension, previous studies always combined visually presented words with language switching task. For instance, Mosca and de Bot (2017) combined language switching task with a lexical decision task; Philipp and Huestegge (2015) with a picture-sentence matching task; and Macizo and colleagues with a semantic category judgment task (Macizo, Bajo, & Paolieri, 2012). The language switching task consists of two types of trials, namely repeat trials (repeating the same language in two subsequent trials) and switch trials (switching from one language to the other). Regarding the control process of comprehension-based language switching task, switching cost is a commonly used indicator which is always reflected by the difference between switch trials and repeat trials in behavioral performance (e.g., RTs) and brain response (e.g., N2) (Liu, de Bruin, Jiao, Li, & Wang, 2021; Liu, Timmer, Jiao, & Wang, 2020). In general, more cognitive resources are needed to switch to another language, leading to longer RTs in switch trials than repeat trials (Green, 1998; Liu et al., 2019). However, some behavioral studies found an absence of switching costs during comprehension-based language switching (Declerck, Koch, Duñabeitia, Grainger, & Stephan, 2019). Thus, the processes of comprehension-based language switching deserve more attention.

In bilingualism literature, there are also studies taking advantage of the high-temporal resolution feature of EEG/ERPs technology to examine how bilinguals control their two languages during language switching. Therefore, besides behavioral performance, ERPs components like N2 and late positive component (LPC) can also serve as indicators of switching costs. Specifically, compared with repeat trials, switch trials may elicit a different tendency in N2/LPC amplitude, and the difference in amplitude between the repeat and switch trials is usually used as a measurement of switching costs (Jackson, Swainson, Cunnington, & Jackson, 2001; Jiao, Liu, de Bruin, & Chen, 2020; Liu, Rossi, Zhou, & Chen, 2014). Thus, the present study investigated comprehension-based language switching processes by combining language switching task and picture-word matching task using both behavioral and ERPs measurements.

1.2. Individual differences and language switching between skilled languages

In order to clearly reveal the mechanism of language switching processes, lots of studies in bilingualism literature have been conducted from two perspectives, namely the internal executive control ability and the external language switching experience (Green, 1998; Green & Abutalebi, 2013; Liu et al., 2016). First, one line of research has investigated whether individual's executive control ability, especially inhibition ability, influences bilingual language control, as indicated by the switching costs. The theoretical motivation for investigating the relationship between inhibition and language control in bilingualism literature is mainly based on the IC model (Green, 1998). The IC model emphasizes that two or more languages would be activated simultaneously in bilinguals, leading to competition between them. The degree of inhibition of a language is proportional to the activation strength or proficiency of that language. Then, given the critical role of inhibition processes in controlling two languages, Liu and colleagues selected two groups of bilinguals with high-IC and low-IC through Simon task and asked these two groups to perform a language switching task. The ERPs results revealed a different pattern of language switching between the two groups in the LPC, suggesting that domain-general inhibition ability influenced language control between skilled languages (Liu et al., 2014). Moreover, a training study further investigated the effect of inhibition training on bilingual language control and revealed that inhibition training increased the efficiency of language switching for low-IC bilinguals, especially during the lexical selection response phase reflected in the LPC (Liu et al., 2016). Another line of reasoning is based on the BIA model, a model of bilingual word recognition, which proposed that lexical access operates within the lexicon and the lexical activation/lexical access is not influenced by the domain-general inhibition ability (Dijkstra & van Heuven, 2002; Jylkkä et al., 2018). However, both BIA model and IC model focused on skilled languages in bilinguals, leaving open the role of inhibition in controlling newly learned languages.

The other line of research focused on language switching experience, another aspect of individual differences. The Language-mode Continuum framework (Grosjean, 2013) and the Adaptive Control hypothesis (Green & Abutalebi, 2013) both emphasize the adaptive feature of language control processes in bilinguals. The empirical evidence supported the effect of language switching training on the controlling of skilled languages (Kang, Ma, & Guo, 2018). In Kang et al. (2018) study, two groups of unbalanced bilinguals performed a picture naming task in pre- and post-test sessions. The experimental group received a 8-day language switching training while the other control group received no training. ERPs results revealed a training effect on the N2 component of picture naming task only for the experimental group, suggesting that language switching experience could influence language control processes, especially at the language task schema phase reflected in the N2 effect.

Overall, bilingual's inhibition ability and language switching experience have been speculated to impact language control processes, as indicated by switching costs in a series of researches. However, existing studies about the effects of individual differences on language control mainly centered on skilled languages. Few studies examined how these individual differences (i.e., inhibition ability and language switching experience) impact the language control processes between newly learned languages.

1.3. Individual differences and newly learned languages

Regarding the role of individual differences in newly learned languages, the available evidence shows that individuals' language control experience and inhibition ability may predict the learning outcomes when bilinguals learn new languages (Bartolotti, Marian, Schroeder, & Shook, 2011; Weiss, Gerfen, & Mitchel, 2010). For example, Kapa and Colombo (2014) used Simon task to measure individual's inhibition ability and found a predictive effect of inhibition ability on artificial language learning performance for adult bilinguals, suggesting a close relationship between general inhibition ability and new language learning. Moreover, Liu and colleagues examined the effect of inhibition training on language control processes between L1 (Chinese) and newly learned language (Korean) in a pre-post training design (Liu, Dunlap, Liang, & Chen, 2018). The results showed that for low-IC individuals, the inhibition training affected the pattern of their switching costs between L1 and the new language, especially in the LPC amplitude reflecting the lexical selection processes in the target language. These findings suggest that the individual difference in domain-general inhibition ability is associated with the language control/learning processes (Jiao, Liu, Schwieter, & Chen, 2021; Liu et al., 2018). Even though Liu et al. (2018) examined language switching processes using a new language, they only trained one language (i.e., Korean) and focused on the language switching between L1 and the new language. Therefore, it is still unclear about the language switching processes between two new languages and the role of inhibition in controlling two new languages.

In addition, some studies have discussed the relationship of language control experience (i.e., another aspect of individual differences) and newly learned language during the initial stage of language learning. For instance, one functional magnetic resonance imaging (fMRI) study examined the cognitive control mechanism at the initial stage of learning new words by comparing monolingual and bilingual groups. Results showed that the experience in managing multiple languages differentiates the neural mechanisms of cognitive control between monolinguals and bilinguals (Bradley, King, & Hernandez, 2013). Furthermore, Bogulski, Bice, and Kroll (2019) examined the bilingual advantage in vocabulary learning and pointed out the key role of L1 regulation, suggesting learning via the L1 allowed learners to engage the language regulation skills to facilitate learning outcome. These studies involving new language learning indicate the potential influence of language control experience on newly learned language.

Based on the above research results, it is not hard to find that at the initial stage of learning new languages, a bilingual's language control experience and inhibition ability may have an impact on the learning performance. However, so far, few studies have directly explored whether the above two factors that affect the learning performance of new languages predict the controlling processes of understanding newly learned languages in bilinguals.

1.4. The present study

In the present study, we used a training design to investigate how individual differences in language switching experience and inhibition ability predict comprehension-based language switching between newly learned languages in bilinguals. In the pre-test session, we assessed the language switching frequency and inhibition ability of a group of Chinese-English bilinguals; then, these participants received a 6-day training to learn German/Japanese words. After training, the participants completed a comprehension-based language switching task between new words. We used the bilingual switching questionnaire (BSWQ), Stroop task, and comprehension-based language switching task (i.e., picture-word matching task) to tap into language switching frequency, inhibition ability, and language control processes, respectively.

The EEG technology with high temporal resolution allows for sensitive analysis on the language control processes and gives us the opportunity to measure the two phases during language switching, i.e., the phase of language task schema competition and the phase of lexical selection response (Jackson et al., 2001; Liu et al., 2016). Thus, in consideration of previous studies and the theoretical interests of the present study, we also focused on the N2 and LPC components in the comprehension-based language switching task, besides behavioral RTs (Kang, Ma, Li, Kroll, & Guo, 2020; Liu et al., 2016). N2 is a negative-going ERP component which peaks at approximately 200–350 ms post-stimulus and has a scalp distribution located at the fronto-central electrode sites (Jackson et al., 2001; Liu et al., 2016). The LPC is a positive-going ERP component with a scalp distribution in the parietal region, reflecting a different pattern of inhibition from the N2 effect. Specifically, during the language switching task, the suppression of language task schema competition is reflected by the N2 effect, and the inhibition function during the later lexical selection response phase may be reflected by the LPC effect (e.g., Declerck, Philipp, & Koch, 2013; Liu et al., 2016; Misra, Guo, Bobb, & Kroll, 2012).

There are some predictions for the present study. First, for the language control processes, we expect to observe switching costs between switch trials and repeat trials. Specifically, compared to the repeat trials, the switch trials will elicit differences in behavioral performance or brain response, such as longer RTs in switch trials. Then, for the role of individual differences, we expect predictive effects of language switching experience and inhibition ability on language control processes reflected by RTs or N2/LPC amplitudes, supporting the IC model. Specifically, individuals with less language switching experience (i.e., low BSWQ score) may perform poorly in controlling the newly learned language, with larger switching costs in RTs or N2/LPC components. Similarly, individuals with low inhibition ability (i.e., large Stroop effect) may have a worse performance in controlling newly learned languages, accompanied with larger switching costs in RTs or N2/LPC components. There is another possibility that there is no evidence of individual differences on the language switching control of newly learned languages, which would support the BIA model from the new language perspective.

2. Method

2.1. Participants

The participant group comprised of 22 Chinese-English bilinguals. Three participants were excluded, one of whom did not complete the language learning session. The other two participants had excessive EEG artifacts. Thus, the final sample consisted of 19 participants (12 female) from the age of 18–25 years old (mean = 21, SD = 1.9). All participants confirmed that they had no migration experience or overseas education, and they only learned English as the second language in a classroom setting, and they all had no knowledge of German or Japanese words. All participants completed a self-rating questionnaire of language background and a bilingual switching questionnaire (BSWQ). As shown in Table 1, all participants were unbalanced bilinguals with Chinese as the dominant language ($ps < 0.001$) and learned English at the age of 8 years old (SD = 2.5). All participants were right handed and they all signed written informed consent and confirmed that they had normal or correct-to-normal vision and hearing. None of them had neurological or psychological impairments.

2.2. Materials

The images used in the German-Japanese language switching task included 30 black-and-white drawings, selected from the dataset of Snodgrass and Vanderwart (1980), which has been standardized by Zhang and Yang (2003). Therefore, there were 30 German words and 30 translation equivalents in Japanese in total in the present study and the sound of these new words were recorded by a male speaker in a soundproof room.

2.3. Procedure

The present study was approved by the Committee of Protection of Subjects at Beijing Normal University. Participants in the present study completed three parts (Fig. 1). They first completed a language background questionnaire, a bilingual switching questionnaire (BSWQ) and a Stroop task on day 1. Then during the next six days, participants learned German and Japanese words in a non-lab environment (e.g., school dormitory, classroom) via pictures and sounds, with learning sessions lasting at least 15 min per day. Contact with the participants was maintained via various communication tools, such as e-mail, chatting software. Finally, they performed a comprehension-based language switching task (i.e., picture-word matching task) on the eighth day and the EEG data was collected. Before entering the EEG experiment, a picture-word matching task in single language (only German or Japanese words) was used to check the learning outcome of new words. The learning test showed that the mean accuracy in the picture-word matching task was 93% (German = 94%, Japanese = 92%, $t(18) = 2.28$, $p < 0.05$), suggesting that participants have mastered the novel words (i.e., established an association of sounds and semantics), especially in German words.

Stroop task. Participant's inhibition ability was measured by a color-word Stroop task. In the Stroop task, three colors (green, red, and blue) were chosen as target colors and only those three colors were presented in Chinese words. Participants were asked to press the response keys to identify the target color of a given word. Each target word was presented randomly congruent or incongruent with

Table 1
The characteristics of the participants.

	Mean	Standard Deviation (SD)	Range
L1 proficiency	5.08	0.42	4.50–6.00
L1 listening	5.68	0.48	5–6
L1 speaking	5.21	0.42	5–6
L1 reading	4.84	0.76	4–6
L1 writing	4.58	0.77	4–6
L2 proficiency	3.17	1.12	1.00–5.25
L2 listening	3.63	1.30	1–6
L2 speaking	3.21	1.18	1–5
L2 reading	2.84	1.12	1–5
L2 writing	3.00	1.49	1–5
BSWQ	2.43	0.68	1.50–3.33
L1S	3.25	0.81	2.00–4.67
L2S	2.21	0.74	1.00–3.67
CS	2.44	1.04	1.00–4.00
US	1.84	0.53	1.00–3.00

Note: L1 proficiency and L2 proficiency were measured on a six-point Likert scale, consisting of listening, speaking, reading, and writing. The higher score of L1/L2 proficiency denotes highly proficient in the language. BSWQ, a bilingual switching questionnaire, was measured on a five-point scale consisting of L1S, L2S, CS, and US. The higher the score of BSWQ, the higher frequency of language switching.

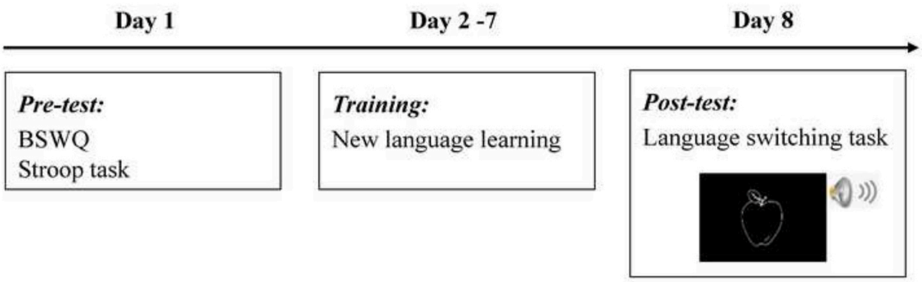

Fig. 1. Schematic overview of training and test task and example of stimuli in language switching task.

their color, e.g., for congruent trial, "red" was presented in red color; for incongruent trial, "red" was presented in green/blue color (MacLeod, 1991). The whole task consisted of three blocks and each block consisted of 72 trials presented in a pseudo-random order. In each trial, a fixation appeared at the center of the computer screen for 500 ms; then a colored word was presented and remained there until the participants pressed the response key or for a maximum duration of 2000 ms; finally, an inter-trial interval of 500 ms occurred. Only behavioral data was collected for Stroop task. Compared with the congruent trails, the response time is usually longer in the incongruent trials. This difference value is defined as Stroop effect indexing inhibition ability (Bialystok, Craik, & Luk, 2008).

BSWQ. The frequency of language switching between Chinese and English was measured by BSWQ (Rodríguez-Fornells, Krämer, Lorenzo-Seva, Festman, & Münte, 2012), which has been standardized by Jiao and colleague (Jiao, Wang, Liu, & Shen, 2016) for Chinese-English bilinguals. The questionnaire, consisting of twelve items, decomposed language switching behavior into four constructs: the tendency to switch to L1 (L1S), the tendency to switch to L2 (L2S), the contextual switching (CS), and the unintended switching (US). L1S and L2S mainly reflect the language switching frequency caused by linguistic factors; CS reflects language switching frequency caused by sociolinguistic factors (e.g., conversation partner); US reflects unconsciousness, unexpected language switching frequency (Jiao, Zhang, Plummer, Liu, & Chen, 2019). Each item was rated on a five-point scale. The higher the score of BSWQ, the higher frequency of language switching between Chinese and English was in bilinguals.

The comprehension-based language switching task. An auditory picture-word matching task was selected to measure the language switching processes in comprehension. All participants were presented with 8 practice trials to get familiar with the procedure and the whole experiment included four conditions defined by language (German and Japanese) and trial type (switch and repeat) variables. In switch trials, the target language in the current trial is different from that of the previous trial; in repeat trials, the target language in the current trial and the previous trial are same. The whole task consisted of 3 blocks and the order of the three blocks was counterbalanced. There were 61 trials in each block, including one filler trial and 60 formal trials. Therefore, each participant performed 90 switch trials and 90 repeat trials across German and Japanese words. All trials were presented pseudo-randomly to make the number of trials in each condition equal. The practice and formal experiments followed the same procedure. Each trial started with a fixation for 500 ms. Then a picture was presented at the center of the computer screen accompanied with a sound through headphone. Participants were required to identify whether the picture and sound matched by pressing the left or right

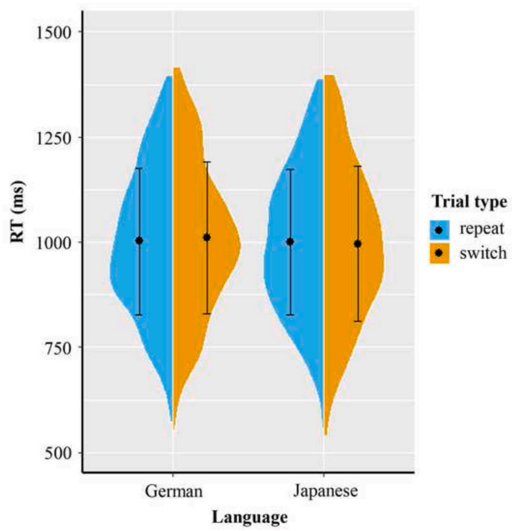

Fig. 2. Split violin plots showing the RT of the comprehension-based language switching task between new-learned German and Japanese. The black dot represents the mean value, while the thin vertical black line represents the standard deviation.

response key (Jiao et al., 2020). The picture stimulus remained on the screen until the participant pressed the response key or for a maximum duration of 2000 ms. After the picture and sound disappeared, a blank screen was presented for 1000 ms prior to the next trial. The difference between switch and repeat trials is defined as switching costs, which reflects the control processes of language switching (Meuter & Allport, 1999).

2.4. EEG data recording and pre-processing

While participants were performing the language switching task, their EEGs were recorded from 64 Ag/AgCl electrodes placed according to the extended 10–20 positioning system. The signal was recorded at a sampling rate of 1 k Hz and referenced online to the tip of the nose. Electroencephalographic activity was filtered online with a bandpass between 0.05 and 100 Hz. Impedances were maintained below 5 kΩ. During offline data pre-processing, the trials with error response and filler trials were removed. Then, the EEGs were re-filtered with a 30 Hz low-pass (24dB/Oct), re-referenced to the average of bilateral mastoid (M1 and M2).

For language switching task, the continuous signals were cut into epochs ranging from −200 ms to 800 ms relative to picture stimuli. Baseline correction was performed in reference to the pre-stimulus activity (Jiao et al., 2021). The epoch with voltages exceeding ±80 μV were automatically discarded. Based on the recording of eye movements, eye blinks were corrected for each subject by a regression-based algorithm (Semlitsch, Anderer, Schuster, & Presslich, 1986). For EEG data, trials with error response and trials that were contaminated with movement artifacts were excluded, which took up 9.6%, 10.5%, 11.1%, and 13.2% of the data for German-repeat, German-switch, Japanese-repeat, and Japanese-switch conditions. In the language switching task, the time windows for ERPs components of interest were first determined by visual inspection of the grand average waveforms (Fig. 3). Then, combined with previous relevant studies (Liu et al., 2016), two ERPs components were analyzed in time windows typically used to examine the N2 (200–300 ms) and late positive component (LPC, 400–600 ms). We analyzed the mean amplitude of the waveform across the selected time windows of N2 (FZ, FCZ, CZ) and LPC (CZ, CPZ, PZ) (Jiao et al., 2021; Kang et al., 2018; Timmer, Christoffels, & Costa, 2019).

2.5. Data analysis

In R environment (lme4 package), we used a linear mixed-effects model analysis to investigate the potential prediction of language switching frequency and inhibition ability on the language control between newly learned languages (Bates, Maechler, Bolker, & Walker, 2014). The language control processes between German and Japanese were measured by RTs, N2, and LPC amplitudes. The inhibition ability was indexed by the Stroop effect in RTs; the language switching frequency was reflected by the score of BSWQ. Moreover, given the divergent effect of each dimension of BSWQ (LS, CS, and US) in the executive control domain (Jylkkä et al., 2017), we further examined the scores of LS, CS, and US subscales. LS score was the mean value of L1S and L2S subscales, reflecting the language switching behavior caused by linguistic factors.

The model included random intercepts for participants and items and slopes for all within-participants/items predictors (Barr, Levy, Scheepers, & Tily, 2013). If the full models did not converge, we would first remove all correlations between the random slopes

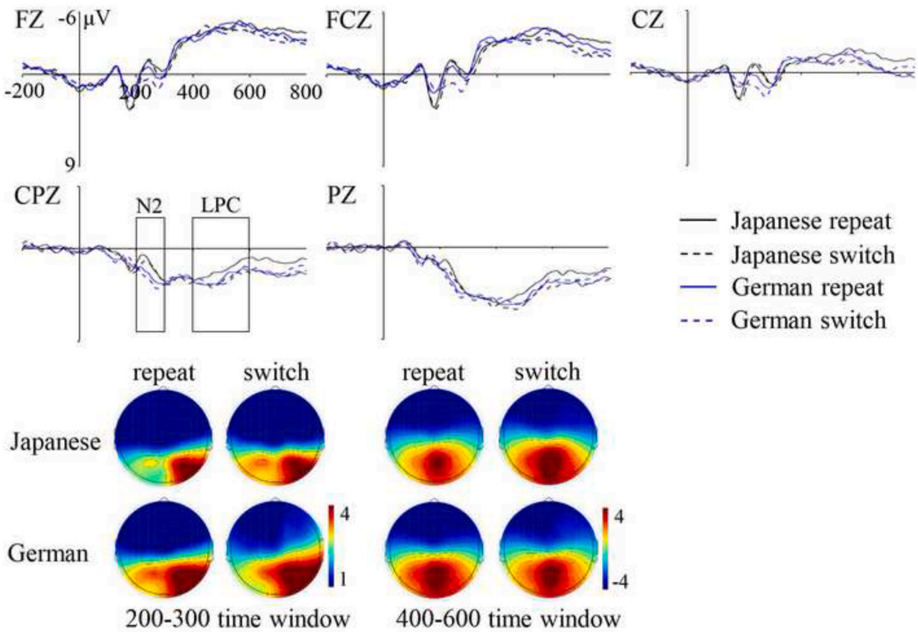

Fig. 3. Grand average waveforms (upper panel) and topographic maps (lower panel) of language switching task for per language and trial type.

and the random intercepts (Barr et al., 2013). Then, if the model still failed to converge, we used a backward way to build down the random effects structure until convergence was reached (Jevtović, Duñabeitia, & de Bruin, 2020). Finally, we assessed the contribution of each random slope to each model using likelihood-ratio chi-square test in order to find the best fitting model. For fixed effects, the models included language, trial type, and their interaction to examine language control processes. In addition, given the aim of the present study was to explore the potential prediction of language switching experience and inhibition ability on the language control processes between new languages, we included language switching frequency (i.e., BSWQ score) and Stroop effect as fixed effects and allowed switching frequency and Stroop effect to interact with language and trial type. All continuous fixed effects were z-scored to reduce collinearity (Jiao et al., 2019). The two-level categorical factors were coded as −0.5 and 0.5 (i.e., −0.5 for German and 0.5 for Japanese; −0.5 for repeat trial and 0.5 for switch trial). The collinearity between factors was checked by Variance Inflation factors (VIFs) and all were below 2.

3. Results

3.1. Stroop task

All trials with error response (6.3%), RTs beyond Mean ± 2 SD (4.1%) or less than 150 ms (0.02%) were excluded. The Stroop effect for each participant was calculated by subtracting the RT in congruent trials from that in incongruent trials. The result of paired-sample *t*-test showed a significant slower response in incongruent trials (M = 613 ms, SD = 103) than congruent trials (M = 545 ms, SD = 69), $t(18) = -5.91$, $p < 0.001$. The differences between congruent and incongruent trials reflected the cost to inhibit interference information (the mean value of Stroop effect = 68 ms, SD = 50, ranging from −7 to 188). The smaller the Stroop effect, the better the inhibition ability is.

3.2. Behavioral results of the language switching task

Before analyzing RTs of the language switching task, all data with error responses (6.7%), RTs beyond Mean ± 2 SD (1.9%) or longer than 1500 ms (5.0%) were removed. RTs were log transformed as dependent variable. Fig. 2 shows the RTs in the language switching task in each language and trial type. For the behavioral performance of language switching task, there was no significant main effect of language, with similar response speed between German (M = 1005 ms) and Japanese (M = 998 ms), Estimate = −0.005, SE = 0.018, $t = -0.28$, $p = 0.78$. In addition, the main effect of trial type was not significant (repeat = 1000 ms, switch = 1002 ms; Estimate = −0.001, SE = 0.006, $t = -0.18$, $p = 0.85$). For the role of switching frequency and inhibition ability, there was no significant effect of BSWQ score (Estimate = −0.005, SE = 0.022, $t = -0.22$, $p = 0.82$) or Stroop effect (Estimate = 0.017, SE = 0.021, $t = 0.81$, $p = 0.42$) on the language control processes between newly learned languages. Neither interaction reached significance.

Then, in order to fully understand the potential effects of different subscales of BSWQ on German-Japanese switching control processes, we constructed three models in consideration of the score of LS (i.e., the switching caused by linguistic factors), CS (i.e.,

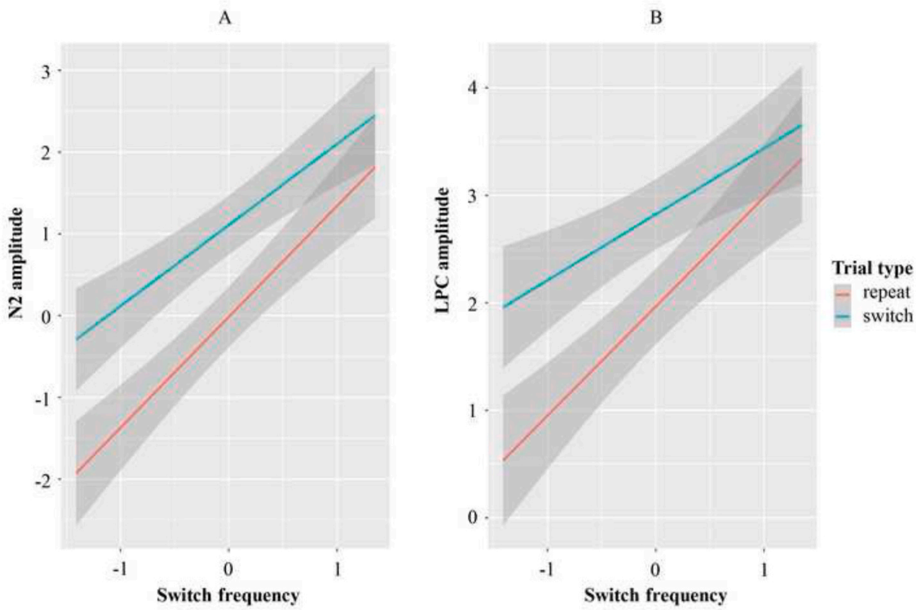

Fig. 4. Mean amplitude (panel A for N2; panel B for LPC) as a function of trial type and switching frequency (i.e., the BSWQ score). Error band shows 95% confidence intervals.

contextual switching), and US (i.e., unintended switching), respectively. The results of these three models revealed that neither the effect of language switching frequency (LS: Estimate = −0.001, SE = 0.022, t = −0.06, p = 0.95; CS: Estimate = 0.006, SE = 0.021, t = 0.29, p = 0.77; US: Estimate = −0.038, SE = 0.021, t = −1.84, p = 0.08), nor other effects reached significance level. In sum, the results of the subscales of BSWQ were consistent with the above findings from the full score of BSWQ.

3.3. N2 of the language switching task

Fig. 3 shows the grand average event-related potential waveforms elicited by the language switching task in comprehension. The mixed-effects model with stimulus-locked N2 mean amplitude as dependent variable included the participants and items as random intercepts. The significant main effects of trial type (Estimate = 1.15, SE = 0.26, t = 4.42, $p < 0.001$), language (Estimate = −0.86, SE = 0.28, t = −3.02, p = 0.003), and the interaction between language and trial type (Estimate = −1.16, SE = 0.52, t = −2.23, p = 0.02) showed that the switching costs to German were larger than the costs to Japanese. In addition, there was a main effect of switching frequency (Estimate = 1.17, SE = 0.53, t = 2.19, p = 0.04), showing a larger N2 amplitude with the increases of BSWQ score. The marginally significant interaction between switching frequency and trial type (Estimate = −0.43, SE = 0.26, t = −1.65, p = 0.09) showed that participants with a higher language switching frequency in daily life (i.e., the higher BSWQ score) had smaller switching costs at a marginally significant level (see Fig. 4). However, neither the main effect of Stroop effect (Estimate = 0.16, SE = 0.52, t = 0.3, p = 0.76), nor other interactions reached significance ($p > 0.1$) in N2 amplitude.

Then, in line with the RTs analysis, we further constructed three models to examine the separate effects of LS, CS, and US subscales. Consistent with the findings from the full score of BSWQ, the effect of switching frequency has been revealed in the US subscale (Estimate = 1.25, SE = 0.56, t = 2.23, p = 0.04) at a conventionally significant level, but in the LS subscale (Estimate = 1.08, SE = 0.55, t = 1.95, p = 0.06) and the CS subscale (Estimate = 1.01, SE = 0.54, t = 1.86, p = 0.08) at a marginally significant level. Moreover, the model for the LS subscale and the US subscale revealed a marginally significant interaction between switching frequency and trial type (LS: Estimate = −0.42, SE = 0.26, t = −1.61, p = 0.10; US: Estimate = −0.51, SE = 0.27, t = −1.92, p = 0.05), which was consistent with the full score of BSWQ. For the model with CS score, the interaction between CS score and trial type failed to reach significance (Estimate = −0.30, SE = 0.25, t = −1.19, p = 0.23), but the tendency between switching frequency and trial type was consistent with the model for full BSWQ. In a word, regarding the N2 amplitude, the results from the score of BSWQ subscales were relatively consistent with the results from a full score of BSWQ.

3.4. LPC of the language switching task

The mixed-effects model with LPC mean amplitude as dependent variable included random intercepts of participants and items. The main effect of trial type showed that switch trials elicited a larger LPC amplitude than repeat trials (Estimate = 0.73, SE = 0.25, t = 2.91, p = 0.004). Then, in line with N2 amplitude, the significant interaction between switching frequency and trial type (Estimate = −0.50, SE = 0.24, t = −2.0, p = 0.04) showed smaller switching costs for participants with a higher switching frequency in daily life (see Fig. 4). In addition, there was a significant prediction of Stroop effect on LPC amplitude (Estimate = 0.82, SE = 0.26, t = 3.15, p =

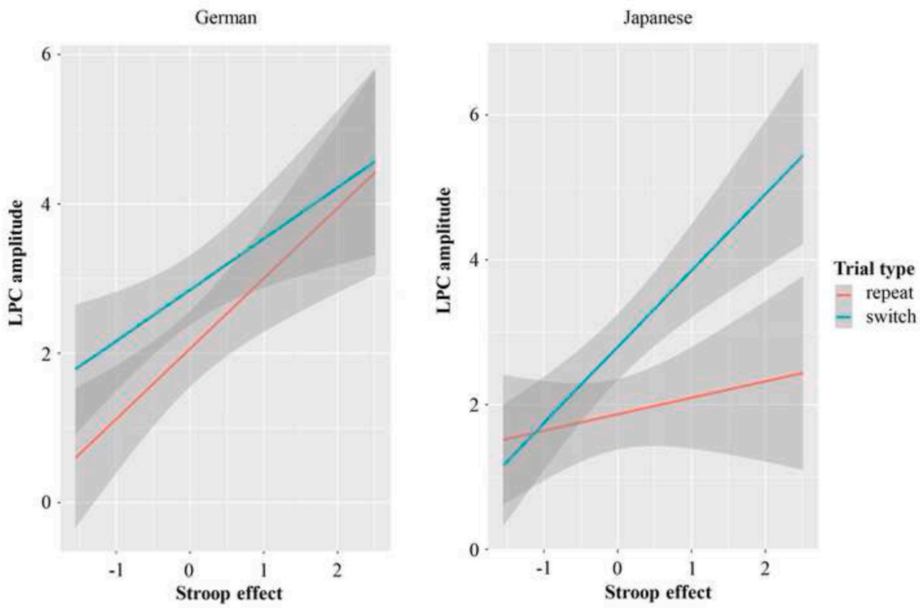

Fig. 5. LPC mean amplitude as a function of trial type and inhibition ability (i.e., the Stroop effect). Error band shows 95% confidence intervals.

0.02), accompanied with a marginally significant three-way interaction of language × trial type × Stroop effect (Estimate = 0.95, SE = 0.48, $t = 1.98$, $p = 0.05$). Follow-up analysis for each language showed that the two-way interaction of trial type × Stroop effect was significant for Japanese (Estimate = 0.79, SE = 0.33, $t = 2.40$, $p = 0.01$), but not for German (Estimate = −0.23, SE = 0.33, $t = -0.69$, $p = 0.49$). As shown in Fig. 5, participants who performed better in inhibition (i.e., smaller Stroop effect) showed smaller switching costs in Japanese, but no Stroop effect on language control processes in German.

In addition, we also examined the effect of LS, CS, and US score separately. In line with the interaction between switching frequency and trial type revealed by the model with the full score of BSWQ, the model with US score showed this interaction at a conventionally significant level (Estimate = −0.50, SE = 0.25, $t = -2.02$, $p = 0.04$), but the models with LS and CS scores showed such interaction at a marginally significant level (LS: Estimate = −0.43, SE = 0.24, $t = -1.79$, $p = 0.07$; CS: Estimate = −0.40, SE = 0.23, $t = -1.73$, $p = 0.08$). Moreover, differing from the model for the full score of BSWQ, the model with US subscale showed a significant interaction between US score and language (Estimate = −0.54, SE = 0.25, $t = -2.16$, $p = 0.03$), indicating that the increase of US score was associated with larger LPC amplitude whose tendency was consistent with the effect of full BSWQ score, while the effect of US score was more significant for German.

4. Discussion

The present study investigated the potential prediction of individual differences (namely language switching frequency and inhibition ability) on the language control processes between newly learned languages in bilinguals. The BSWQ and color-word Stroop task were adopted to measure individual's language switching frequency and inhibition ability, respectively. All bilinguals learned German and Japanese words during training and performed comprehension-based language switching task in the post-learning session. Even though neither language switching frequency nor inhibition ability affects language switching processes in behavioral performance, ERPs results showed that BSWQ score significantly predicted the amplitudes of the stimulus-locked N2 and LPC switch effects; the Stroop effect only predicated the LPC switch effect in Japanese.

While previous studies have examined the relationship between individual differences and language control of skilled languages (Kang et al., 2020; Liu et al., 2016), whether the comprehension-based language control of newly learned languages could also be predicted by individual inhibition ability and switching frequency remains unclear. Based on the Adaptive Control hypothesis (Green & Abutalebi, 2013), the present study examined the language control processes in the context of newly learned languages, thus enriching the bilingualism literature by focusing on the initial stage of language learning.

4.1. The role of individual differences in the language control of newly learned languages

A main finding of the present study is that the comprehension-based switching costs of newly learned languages could be predicted by individual differences. Specifically, both external language switching frequency and internal inhibition ability play a role in controlling newly learned languages, reflected by the switching costs of ERPs components.

Regarding the role of language switching frequency, both N2 and LPC amplitudes showed the main effect of BSWQ score and its interaction with trial type, suggesting that the higher the language switching frequency in daily life, the smaller costs during language switching are. This finding is in line with previous studies showing that short-term language switching training could improve the efficiency of language control processes (Kang et al., 2018). In the study of Kang et al. (2018), unbalanced Chinese-English bilinguals performed picture naming task before and after language switching training sessions. The training effect was indicated by the N2 component, suggesting that the language control processes of skilled language were modulated by language switching experience.

Consistent with the language switching training in Kang et al. (2018), the BSWQ score in the present study also reflects individual's language switching frequency, the effect of which showed that language switching experience influences the efficiency to establish target language task schema, as indicated by our finding that the increase of N2 amplitude was accompanied with a higher switching frequency. Moreover, for controlling newly learned languages, switch trials that elicited a larger LPC amplitude than repeat trials interacted with language switching frequency, suggesting smaller switching costs for participants with a higher switching frequency in daily life. Moreover, our findings were consistent with the study conducted by Christoffels, Firk, and Schiller (2007), which required unbalanced bilinguals to complete a language switching task and found that participants with frequent language switching experience showed symmetric switching costs between skilled languages, indicating a correlation between switching frequency and language control processes. From the developmental perspective, our findings extended the effect of switching frequency observed in skilled languages to newly learned languages.

Considering all the findings regarding switching frequency, it is not difficult to find that the effects of both LS score (including L1S and L2S reflecting the language switching caused by linguistic factors) and CS score were consistent with the full score of BSWQ. However, the score of US subscale interacted with language variable in the LPC analysis, but no such interaction was found for LS, CS, or the full score of BSWQ. For the greater influence of unintended switching on German, it is possible that participants who learned German better may automatically activate German during German-Japanese switching. Given that German and Japanese learning lasted for only six days in the present study, the potential role of unintended switching needs further investigation in future studies.

The individual differences in inhibition ability also play a role in the language control of newly learned languages. In detail, a higher inhibition ability (i.e., the smaller Stroop effect) is accompanied with smaller switching costs in the LPC amplitude under Japanese context. The predictive effect of domain-general inhibition ability on the lexical access of word comprehension is inconsistent with the BIA model which proposes that inhibitory process is within the lexicon (Dijkstra & van Heuven, 2002), but this effect is in line with previous studies about the effect of domain-general inhibition ability on the language control between skilled languages (Kang et al., 2020; Liu et al., 2014, 2016, 2018). For example, in the study of Liu et al. (2016), they employed two groups of bilinguals, one group with high inhibition ability and the other with low inhibition ability, measured by the Simon task. The comparison results between the two groups in language switching task showed in LPC amplitude, high inhibition group suppressed the interference more efficiently than the other group when inhibiting the non-target language. However, once the inhibition ability of the low-level group was improved through inhibition-related training, the training effect could be transferred to language switching and the efficiency of language switching could increase significantly. As for language switching involving newly learned languages, Liu et al. (2018) divided unbalanced Chinese-English bilinguals into high-IC group and low-IC group and both learned some new Korean words. After performing the language switching task between L1 and the new language, the low-IC group received inhibition training. Then, both groups performed the language switching task again and the results indicated that inhibition ability training benefits language switching between L1 and newly learned language for the low-IC group.

In line with these results, the present study found that inhibition ability could affect the language control processes of understanding newly learned languages and play a key role in the lexical selection response phase as indicated by the LPC. But, in the present study, the predictive effect of inhibition ability only occurred in Japanese switching effect, not in German. According to the viewpoint of the IC model (Green, 1998), the degree of inhibition for language is positively correlated with language proficiency, so the different inhibition effects on German and Japanese may be related to language proficiency. Based on the scores of the learning test prior to the language switching task, we found participants learned German better than Japanese. Thus, when switching to the less-proficient Japanese words, participants may need more effort to inhibit more-proficient German words, thus triggering the involvement of domain-general inhibition.

However, some studies emphasized the association between comprehension-based language switching and domain-general monitoring ability, not the inhibition ability. For example, Struys and colleagues used a categorization task and a Simon task to assess the comprehension-based switching costs and the domain-general control ability, respectively. They found a significant correlation between the switching costs (from L1 to L2) of categorization task and the global response times of Simon task which reflects monitoring ability (Struys, Woumans, Nour, Kepinska, & Van den Noort, 2019). Moreover, Jiao et al. (2021) employed a cross-task-adaption paradigm and revealed that the language switching between newly learned languages affected the domain-general executive control reflected by the global performance of flanker task, suggesting a correlation between domain-general monitoring control and language switching of new languages. It is not surprising that the previous findings are not the same with the present study. The possible reason is related to the proficiency of target languages. For instance, the present study examined the language switching between newly learned languages at a low proficiency level, while Struys et al. (2019) investigated the skilled languages of Dutch-French bilinguals with high proficiency. Despite that inhibition and monitoring abilities are both a part of domain-general executive control, it is still an open question about the association between comprehension-based language switching and inhibition/monitoring ability.

4.2. Switching costs in comprehension-based language control processes

Regarding the processes of bilingual language comprehension, some previous studies discussed whether switch trials result in a cost during comprehension-based language switching task (Declerck et al., 2019; Declerck & Philipp, 2018). For the newly learned languages, the present study examined the switching costs of comprehension-based control processes in both behavioral performance and EEG data.

Some studies failed to find switching costs in comprehension-based language switching task and speculated that the absence of comprehension-based language switching costs may be due to processing speed, which is quite fast during language comprehension tasks (Declerck et al., 2019). However, in the present study, even though we did not find switching costs in behavioral performance, the N2 and LPC amplitudes in ERPs results revealed switching costs between repeat and switch trials. Given the high temporal resolution of ERPs technique, one possible explanation for these inconsistent findings about comprehension-based switching costs may be related to the constraints of the RT indicator itself. That is, the behavioral indicator represents an aggregation of various cognitive processes, while the time-sensitive ERPs allow a separation of various stages of processing via specific components (Guo, Misra, Tam, & Kroll, 2012; Kang et al., 2020).

Another possible explanation for these inconsistent results may be related to the language processing context. According to the Adaptive Control hypothesis (Green & Abutalebi, 2013), language context plays a key role in bilingual language control. For example, Liu et al. (2020) revealed that the degree of switching costs flexibly changes with the processing context. In the present study, participants may be able to directly access concept for familiar words in L1/L2 language context. However, in the newly learned language context, they may have to rely on their native language to access the concept of unfamiliar words, thus slowing down the processing speed. Taken together, in terms of the existence of switching costs in comprehension-based control processes, more potential factors should be considered, such as language context, the sensitivity of indicators, etc.

4.3. Limitation and future directions

Results from the present study showed that in the newly learned language context, both external language switching experience and internal inhibition ability effectively predict language control process. We acknowledge, however, that our findings are limited to the unbalanced bilingual group and may not be extended to balanced bilinguals. Generally speaking, along with the development of second language, bilinguals will be more experienced in language switching and control. Thus, we cannot rule out the possibility that balanced bilinguals will show a different pattern in controlling newly learned languages, which is a question worthy of further investigation. Moreover, another limitation of present study is the failure to find switching costs and the individual differences effect in behavioral data. One possible reason may be related to the relatively small sample size in the present study. Future studies interested in the effect of individual differences should consider testing a larger sample size. Finally, following previous research, the present study adopted the BSWQ to test the language switching frequency between Chinese and English (e.g., Jiao et al., 2019, 2016; Sulpizio, Del Maschio, Del Mauro, Fedeli, & Abutalebi, 2020). Even though the psychometric qualities of this questionnaire were good in the study of Rodríguez-Fornells et al. (2012) and it has been widely used, the stability of this questionnaire still requires further confirmation. By using self-reporting, it is not clear whether bilinguals could figure out the different types of language switching and how well they could precisely estimate their switching frequency. Therefore, future studies focusing on language switching frequency may consider employing a voluntary language switching task and measure an individual's actual language switching frequency.

5. Conclusion

The present study focused on the initial stage of new language learning and found that the degree of comprehension-based switching costs varied with individual differences in controlling newly learned languages. Compared with individuals with less switching experience, individuals with higher switching frequency had more efficient comprehension-based language switching processes in newly learned languages. Moreover, individual's inhibition ability also affected the switching costs of less-proficient newly-learned words. Therefore, the findings of the present study suggest that at the initial stage of new language learning, individual differences might play a role in the language switching between two new languages.

Credit author statement

Lu Jiao: Conceptualization, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Funding acquisition. **Xiaoting Duan:** Writing - original draft, Writing - review & editing. **Cong Liu:** Formal analysis, Writing - review & editing. **Baoguo Chen:** Conceptualization, Writing - review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

No potential conflict of interest was reported by the authors.

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