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How different code-switching types modulate bilinguals' executive functions - a dual control mode perspective

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Abstract

Most existing studies on the relationship between code-switching and executive functions have focused on experimentally induced language-switching, which differs fundamentally from naturalistic code-switching. This study investigated whether and how bilinguals' code-switching practices modulate different aspects of executive functioning. Our findings suggest that existing processing models of code-switching should be extended by a dual control mode perspective, differentiating between reactive and proactive monitoring. Bilinguals engaging in code-switching types that keep languages more separate (Alternation) displayed inhibitory advantages in a flanker task inducing reactive control. Dense code-switching, which requires bilinguals to constantly monitor cross-linguistic competition, explained performance in proactive monitoring conditions. Furthermore, a correlation between Dense code-switching and response inhibition suggests that linguistic co-activation may persist during articulatory stages of language processing. Crucially, bilinguals outperformed monolinguals at those aspects of the executive system that were trained by their most frequent code-switching habits. This underlines the importance of sociolinguistic variables in bilingualism research.

Key words: bilingualism, code-switching, executive functions, response inhibition, interference suppression

1. Introduction

Language production requires speakers to use inhibition to select appropriate lemmas based on structural and socio-pragmatic requirements (Green, 1998; Levelt, Roelofs & Meyer, 1999). Bilinguals experience an increased inhibitory processing load because they manage the additional criterion of language membership (Abutalebi & Green, 2007; Green, 1986). Bilingualism has thus been hypothesised to train Executive Functions (EFs) (Bialystok, 2009; Kroll, Dussias, Bogulski, & Valdés Kroff, 2012). Although bilinguals have been found to outperform monolinguals at EF tasks (Costa, Hernandez & Sebastian-Galles, 2008), the effect of bilingualism on EFs is not always replicated, calling into question its robustness (Duñabeitia, Hernández, Antón, Macizo, Estévez, Fuentes, Carreiras, 2014; Paap & Greenberg, 2013). In this study, we take these inconsistencies in findings as an opportunity to pin-point which specific bilingualism variables modulate which aspects of EFs (Bak, 2016).

One key candidate suggested to be at the core of EF modulations in bilinguals is code-switching (Costa, Hernandez, Costa-Faidella, Sebastian-Galles, 2009; Lehtonen, Soveri, Laine, Järvenpää, de Bruin & Antfolk, 2018). Several studies on code-switching and EFs have revealed positive correlations between code-switching frequency and EFs. However, there are discrepancies regarding the specific aspect of the executive system modulated by code-switching. Whilst some studies suggest that code-switching involves inhibition (Ooi, Goh, Sorace & Bak, 2018; Rodriguez-Fornells, Kraemer, Lorenzo-Selva, Festman, Muente, 2012; Verreyt, Woumans, Vandelanotte, Szmalec & Duyck, 2016), other studies reveal effects of code-switching on monitoring (Prior & Gollan, 2011; Hartanto & Yang, 2016; Soveri, Rodriguez-Fornells, Laine, 2011). Moreover, several studies have failed to demonstrate any overlap between code-switching and EFs (Kang & Lust, 2019; Paap et al., 2017; Ying & Bialystok, 2011).

It is possible that the inconsistencies in previous studies arose from a lack of using ecologically valid methods of assessing code-switching. All existing studies have relied either on self-reports of code-switching, or on experimentally induced language-switching. Both methods have been argued to be inadequate for capturing naturalistic code-switching practices (Gardner-Chloros, 2009;

Hofweber, Marinis & Treffers-Daller, 2019). Moreover, none of the existing studies have differentiated between different types of code-switching. Code-switching is defined as the mixing of languages for socio-pragmatic optimization purposes (Bhatt & Bolonyai, 2011; Muysken, 2013). Bilinguals differ in the types of code-switching strategies they engage in as a function of a) typological differences between languages, and b) their sociolinguistic environment (Muysken, 2000). Importantly different types of code-switching may affect different aspects of the executive system (Treffers-Daller, 2009; Green & Wei, 2014; Hofweber, Marinis & Treffers-Daller, 2016). Effects of code-switching practices on EFs may therefore not be found if no distinction is made between different types of code-switching (Kang & Lust, 2019). Hence, a more fine-grained picture is needed to fully understand the relationship between code-switching and EFs.

This study explores whether and how different types of code-switching modulate EFs, and whether the modulations brought about by the different code-switching types have the potential to explain performance differences between bilinguals and monolinguals. The predictions are created by combining insights from existing processing models of code-switching (Abutalebi & Green, 2013; Green & Wei, 2014; Treffers-Daller, 2009) with a dual control perspective of EFs (Braver, 2012), thus generating a detailed model of the control processes underlying different code-switching types. The following sections will describe the rationale of our research questions and predictions.

According to the Adaptive Control Hypothesis, bilingual language control processes differ as a function of interactional contexts (Abutalebi & Green, 2013). The hypothesis predicts that speakers draw upon different aspects of EFs to adapt to the specific challenges posed by each interactional context. Whilst monolingual modes trains inhibitory control, bilingual modes train the monitoring processes required to manage linguistic co-activation. This study differentiates between interactional modes involving different forms of intra-sentential code-switching. Intra-sentential code-switching is assumed to be most challenging from a monitoring perspective because competition is greatest within the attentional window of the utterance unit.

Based on Muysken's (2000) comprehensive review of sociolinguistic corpora, this study sub-divides intra-sentential code-switching into three re-occurring patterns: *Insertion*, *Alternation* and

Dense code-switching (or *Congruent lexicalisation*). Table 1 shows examples for the language pair investigated (German-English). In Alternation, loosely connected stretches from two languages alternate, e.g. involving a switch between a main clause and a subordinate clause that does not function as a complement of another constituent. In the Alternation example in Table 1 the switch occurring at the clause boundary may, for instance, have been motivated by a change in interlocutor.

TABLE 1

In Insertion the pattern is asymmetrical (Myers-Scotton, 2006). Elements from one language (Embedded language) are inserted into the morphosyntactic frame of another language (Matrix language). In any given language pair, the relationship can go in either direction, although the Matrix language usually is bilinguals' first language (Muysken, 2013). The term Dense code-switching describes cases of language mixing in which languages remain co-activated at both the grammatical and lexical levels. This means that speakers select lexical items and structural features based on their socio-pragmatic and structural appropriateness, not based on language membership. Switching takes place more frequently in Dense code-switching than in Alternation, but switch points are hard to identify. Contrary to Insertion, it is impossible to identify a Matrix language as speakers combine structural rules from both languages. Dense code-switching primarily occurs between closely related languages.

According to Muysken (2000), different sociolinguistic environments and bilingualism profiles generate different code-switching patterns. Recent immigration contexts favour Insertion, as bilinguals slot lexical items referring to their new L2-environment into the grammatical framework of their L1. Most bilinguals use Alternation but it is most frequent in contexts where languages are associated with different socio-political identities. Dense code-switching predominantly emerges in communities with long-standing bilingual traditions. The German-English bilinguals in this study were recent immigrants to the UK, so they were predicted to engage predominantly in Insertion (of English into German) and Alternation, but rarely in Dense code-switching (Hofweber et al., 2016).

To explain cognitive control processes during code-switching, Treffers-Daller (1998, 2009) applied Green's (1986, 1998) inhibitory model of bilingual language production to code-switching.

According to her *Inhibitory Control Continuum,* the three code-switching types differ in the extent to which languages are kept separate. Language separation is achieved though inhibition, so the more a given type of code-switching separates languages, the more inhibition is recruited. Alternation is the code-switching type that keeps languages most separate, so high levels of inhibition are recruited. In Insertion the matrix language becomes permeable to the non-matrix language, but only on a lexical level, so medium-levels of inhibition apply. Dense code-switching involves minimal levels of language separation and inhibition.

Similar predictions about the effects of different code-switching types on EFs were made by the *Control Processing Model of code-switching* CPM (Green & Wei, 2014). However, the CPM groups Insertion and Alternation into a category called *Coupled control code-switching*, in which bilinguals alternate between languages using inhibition to execute language switches. Although Green & Wei (2014) acknowledge that Dense code-switching challenges processes involved in the consolidation of competing linguistic structures, they claim that it does not train inhibition because there is no separation by language membership. This prediction about Dense code-switching was recently challenged in a study suggesting that Dense code-switching does enhance inhibition under certain monitoring conditions (Hofweber et al., 2016).

This finding could be accounted for by adopting a dual control perspective, in which the monitoring of inhibition can be either *proactive* or *reactive* (Braver, 2012). Our reasoning was motivated by the Adaptive Control Hypothesis (Abutalebi & Green, 2013), which suggests that interactional contexts involving high-levels of linguistic co-activation draw upon more proactive monitoring and less reactive inhibitory control. Inhibition and monitoring are two sides of a coin (Costa et al., 2009; Morales, Yudes, Gomez-Ariza & Bajo, 2015), with monitoring referring to the high-level processes managing the de- and re-activation of inhibitory schemata (Botvinick, Carter, Braver, Barch, Cohen, 2001). In reactive control modes, inhibition is activated in reaction to an event challenging cognitive control. The reactive use of inhibition is cognitively effortful, so it is restricted to circumstances requiring the infrequent use of inhibition (De Pisapia & Braver, 2006). When events challenging inhibition occur frequently, it is more efficient to transition to a proactive control mode, which involves the sustained goal-maintenance and monitoring of inhibitory schemata.

Different types of code-switching employ inhibition with differing degrees of frequency, thus triggering different control modes. This study predicted that bilinguals would operate in a reactive mode during Alternation, because switching is infrequent. In Alternation, bilinguals stick to each language for prolonged stretches of speech. Whenever a switch does happen, the inhibitory effort to execute that switch is high because inhibitory schemata need to be re-activated. This is in line with existing models predicting Alternation to challenge inhibition most (Treffers-Daller, 2009; Green & Wei, 2014). Following Green & Wei's (2014) grouping of Insertion and Alternation into Coupled control modes, it was assumed that Insertion also involves reactive control. Dense code-switching, on the other hand, was predicted to trigger proactive monitoring because bilinguals are continuously transitioning between languages, as demonstrated in the example in Table 1. This requires a constant proactive readiness to apply inhibition as bilinguals manage the selection of co-activated, yet potentially conflicting, features from both languages.

To create an executive functions task that would tease apart the control processes employed in the different code-switching types, we manipulated the proportion of congruent-incongruent trial switching in a Flanker task. In the Flanker task, participants switch between baseline *congruent* trials and *incongruent* trials requiring the inhibitory control. The proportion of congruent and incongruent trials in Flanker tasks has been shown to modulate the nature of the monitoring processes involved (Costa et al., 2009; De Pisapia & Braver, 2006). We administered a condition aimed at inducing a *reactive* control mode, in which mostly congruent trials were interspersed with a small number of incongruent trials. This infrequent reactive use of inhibitory schemata in incongruent trials was assumed to replicate the control processes during Alternation. In the *proactive* monitoring context, on the other hand, equal numbers of congruent and incongruent trials were administered, generating a need to maintain inhibitory schemata as a goal. This proactive monitoring context mirrors the monitoring processes employed during Dense code-switching. Bilingual EF modulations have previously been shown to occur predominantly for proactive monitoring (Bialystok, Craik & Luk, 2012; Costa et al., 2009). This has been attributed to the training of monitoring skills through code-switching. In this study, we predicted that this effect will be modulated by the type of code-switching bilinguals regularly engage in. Coupled Control code-switching, particularly Alternation, trains bilinguals' reactive control skills, whilst Dense code-switching trains proactive monitoring skills.

Further predictions were made about the stage at which inhibition applies in the language production process (Levelt et al., 1999). This study differentiated between two forms of inhibition operating at different levels of processing (Luk et al., 2010): (1) *Interference suppressio*n, which takes place at the conceptual lemma level; (2) *Motor response inhibition,* which applies at stages involving articulation and phonological assembly. Some models of bilingual processing assume that language selection operates at the conceptual lemma level (Green, 1998; Green & Wei, 2014), so bilingualism has been argued to modulate interference suppression, but not response inhibition (Bialystok et al., 2009; Blumenfeld & Marian, 2014; Colzato, Bajo, v.d. Wildenberg & Paolieri, 2008; Costa et al., 2008, 2009; Martin-Rhee & Bialystok, 2008; Meltzoff & Carlson, 2008; Luk et al., 2010).

While an in-depth discussion about language selectivity in bilingual processing is beyond the scope of this paper, we argue that linguistic co-activation may persist at multiple stages of languages production. According to Kroll, Bobb and Wodniecka (2006), bilingual language production is a cascading interactive process. There is not just one locus for language selection (e.g. the lemma) but multiple loci. Thus, the authors argue that not only the conceptual level or the lemma level, but also the phonological and articulatory levels could be involved in language selection, "with the locus of eventual selection varying according to the specific manifestation of lexical competition" (Kroll et al., p. 120). Words and structures from both languages compete during language production, and a range of factors, such as language proficiency and dominance, affect the stage at which a particular language is selected. In this study, we argue that code-switching is one of these factors.

A key manifestation of the ways in which languages compete during speech production can be found in bilinguals' code-switching behaviour, but very little is known about the extent to which the type of intra-sentential code-switching practised by bilinguals affects the locus of language selection. We suggest that the stage at which language selection happens may depend on the type of code-switching in which bilinguals engage, and the scope of inhibition in the different code-switching types. Building on the available literature discussed above, the following predictions were made: Alternation involves the macro-management of languages through temporary "global inhibition" of each respective language (De Groot & Christoffels, 2006; Guo, Hongyan, Misra, Kroll, 2011; Hofweber et al., 2016). This form of language selection is predicted to happen at the conceptual lemma level through interference suppression (Green & Wei, 2014). In the case of Insertion only the grammar of the Embedded language is globally inhibited, whilst local inhibition takes place within co-activated lexical networks. We assume this also involves interference suppression rather than response inhibition as lexical selection happens at the lemma level.

Dense code-switching involves the micro-management of linguistic co-activation through local inhibition to select individual items from within co-activated linguistic networks (Hofweber et al., 2016). Hence, languages do not get inhibited globally at early stages of language production. It could therefore be argued that this type of code-switching involves simultaneous co-activation at later articulatory stages. If Dense forms of code-switching maintain linguistic co-activation throughout articulatory production stages, then this should be observable in the shape of convergence phenomena. Indeed, studies investigating the phonological properties of code-switching suggest that linguistic co-activation may persist at articulatory stages of production (Botero, Bullock, Davis & Toribio, 2004; Grosjean & Miller, 1994; Marian, Spivey & Hirsch, 2003). Hence, Dense code-switching may recruit motor response inhibition. To explore this prediction, our participants were administered a Go/No-go version of the Flanker task teasing apart performance at interference suppression and response inhibition.

To summarise, this study investigated whether different types of code-switching modulate specific aspects of EFs and whether these modulations translate into performance differences between bilinguals and monolinguals. Table 2 provides an overview of how we suggest the different aspects of EFs map onto each other with regard to their involvement in different types of code-switching: Language modes involving global forms of interference suppression trigger reactive control modes, whilst languages modes with high levels of linguistic activation draw upon proactive monitoring using local inhibition. The latter may also involve response inhibition.

TABLE 2

Our study design was thus guided by the following hypotheses:

1. The group comparison of bilingual and monolingual inhibitory performance:

Bilinguals will outperform monolinguals at those aspects of the executive system that are trained by their frequent code-switching practices. Bilinguals in this study are predicted to engage predominantly in Coupled control code-switching. Hence, inhibitory advantages should occur in the task condition mirroring Coupled control code-switching, i.e. the reactive monitoring condition. As Coupled control code-switching was predicted to involve inhibition at the conceptual lemma level, any potential bilingual advantages should occur at interference suppression, not at response inhibition.

2. The relationship between code-switching and inhibitory performance:

Coupled control code-switching will predict performance in the reactive monitoring condition, whilst Dense code-switching will predict performance in the proactive monitoring condition. Moreover, Dense code-switching will correlate with response inhibition, although this research question is exploratory because none of the existing models of code-switching incorporate response inhibition.

Importantly, code-switching was predicted to have a modulatory effect alongside other variables that have been shown to influence EFs, such as age, education and fluid intelligence. Previous research has shown that bilingualism mitigates the negative effects of age on EF performance (Bialystok et al., 2008), so we predicted age to have a stronger impact in the monolingual than in the bilingual group. Language production and comprehension have been shown to involve similar cognitive control processes (Struys, Surmont, Van de Craen, Kepinska, & Van den Noort, 2019). Hence, both the production and comprehension of code-switching should modulate EFs.

2. Methods

All tasks were created using Psychopy 1.81 and presented on a 13-inch-screen HP notebook.

2.1. Participants and control variables

Participants had no known cognitive or visual impairments. All bilinguals were German-English, so confounds from differences in typological distance between languages were avoided. The online Language history questionnaire (Li et al., 2014) was used to collect linguistic background variables (Table 3). All bilinguals (N=43) self-reported to be "native-like" speakers of German (M=6.88; 7=native-like). They all reported a late onset age of the L2 English (M=8.89), but were active L2-users living in the UK.

TABLE 3

The balance between the two languages was calculated as the difference in proficiencies (Kupisch & De Weijer, 2016). Participants reported to have similar proficiencies in both languages, although German was their L1, and English their "very advanced" L2. There was a positive correlation between Immersion (duration of stay in L2-context) and Balance [$R(1,43)$= 0.33, p=0.02], suggesting that bilinguals became more balanced through Immersion . However, a repeated-measures ANOVA with Proficiency (German, English) as the within-subject variable confirmed that German proficiency was greater than English proficiency [$F(1, 83)$=32.50, MSE=0.16, $p<0.001$, η^2=0.44], meaning that the bilinguals remained German-dominant.

The bilinguals were compared to a group of monolinguals (N=41). There was a choice of comparing the bilinguals to a monolingual baseline group in either Germany or Britain. We opted for a comparison to English-speaking monolinguals for two reasons. Firstly, it was impossible to find education-matched monolinguals in Germany. On average, the bilinguals held BA-level qualifications. Most Germans with university-level degrees are fluent in English, due to its Lingua Franca status (Seidlhofer, 2001). Secondly, EFs are shaped by experience (Bialystok, 2009), so it was more appropriate to compare the bilinguals to monolinguals living under similar circumstances, i.e. UK urban contexts.

The notions of monolingualism and bilingualism represent two extreme ends of a continuum (Luk & Bialystok, 2013). The categorisation depends on the criterion applied to distinguish between groups. Bilingual advantages have been argued to arise primarily from active language use (De Bruin & Della Sala, 2016), which was our main distinguishing criterion. To assess whether participants' language practices should be described as "monolingual" or "bilingual", participants were administered a questionnaire asking them to indicate whether they "regularly used two languages".

The monolinguals were also asked to report on their usage of regional varieties, which may modulate executive performance (Antonious, Grohmann, Kambanaros & Katsos, 2010). Most monolinguals used only one (Southern) variety of British English. Five participants originated from Scotland or Wales, but indicated using the non-Southern varieties infrequently because they had been living in South-East England for a minimum of 10 years. The monolinguals thus engaged only infrequently, if at all, in sociolinguistic practices involving the management of linguistic co-activation.

Crucially, bilinguals and monolinguals were matched on a range of variables that modulate EFs, such as Age, IQ, Working memory and Socio-Economic Status / Education (Table 4). Fluid intelligence was measured using Ravens Standard Progressive Matrices (Raven, Raven & Court, 1998). Short term (SM) and Working memory (WM) were measured using Wechsler's (1997) digit span. The two groups did not differ in any of these non-verbal control variables.

TABLE 4

2.2. Assessing the independent variable code-switching habits

A frequency judgment task was used as the primary measurement of participants' regular code-switching habits. Judgement tasks have been argued to be representative of cognitive embedding (Backus, 2014; Valk, 2014) and predict code-switching in production tasks (Hofweber, Marinis & Treffers-Daller, 2019). Participants were presented with 14 code-switches of each type: 1) Insertion English into German, 2) Insertion German into English, 3) Alternation, and 4) Dense code-switching. The stimulus sentences were matched for number of words (M=8) and syllable length (M=14). Insertions were also matched for the syntactic function of the embedded items. The stimuli were presented audio-visually in pseudo-randomized order. Stimuli were preceded by a 200ms fixation cross and presented for up to 30 seconds, during which participants rated its frequency.

Participants were instructed to imagine that they were having an informal conversation with a German-English bilingual friend and were asked to rate the frequency with which they would "encounter" utterances similar to the stimuli on a scale from 1=never to 7=all the time. Code-switching is frequently stigmatised in bilingual communities (Gardner-Chloros, 2009; Dewaele & Wei, 2014) and attitudes have been shown to modulate its acceptability ratings (Badiola, Delgado, Sande & Stefanich, 2018). Hence, we asked about "frequency" rather than "acceptability" to reduce the risk that the term "acceptability" would introduce unintended attitudinal aspects into the ratings.

Furthermore, we asked participants to report on general communication patterns in their social networks rather than on their own production of code-switches. This allowed participants to distance themselves from the reported code-switching behaviour, thus reducing the risk of socially desirable responses. We assumed that bilinguals who come across certain patterns of bilingual speech would be primed into generalising and re-using these through implicit learning processes (Bock & Griffin, 2000), resulting in the interactive alignment of code-switching (Kang & Lust, 2019). This is confirmed by a study by Hofweber et al. (2019), which found that the code-switching patterns bilinguals indicated encountering frequently in their environment were indeed the ones they produced in bilingual emails. Moreover, this paper argues that EFs should be trained through both the productive and the receptive processing of code-switching.

All code-switches were authentic utterances sourced from existing German-English corpora (Eppler, 2005; Eppler, 2010; Clyne, 2003) and from bilingual emails collected for a previous study (Hofweber et al., 2019). This corpus-based approach increased the ecological validity of the stimuli (Beatty-Martinez, Valdes Kroff & Dussias, 2018). However, Insertions of German into English occurred so rarely in the corpora that artificial stimuli needed to be created. Importantly, we used a classification method which takes into account the continuous nature of code-switching (Deuchar, Muysken & Wang, 2008). Like most other bilingualism variables (Luk & Bialystok, 2013), code-switching is a continuous variable because many real-life code-switching instances are located on a continuum between different code-witching types (Muysken, 2000).

In addition to the frequency judgement task, bilinguals filled in an extensive code-switching questionnaire. This questionnaire contained one question designed to tease apart different code-switching types. In this question, participants received a brief explanation and examples of the three different code-switching types. They were then asked to rate the frequency with which they engaged in each code-switching type. As this question was assumed to raise participants' metalinguistic awareness of code-switching, it was administered at the end of the study, so as not to affect the intuitiveness of other tasks.

2.3. Assessing the dependent variable EFs

Inhibition was measured using the Flanker task, chosen for the intuitiveness of its instructions. Participants were presented with rows of 5 arrows and instructed to indicate the direction of the central arrow as fast and accurately as possible, using the arrows key. The intuitiveness of these instructions reduced confounding working memory load, thus increasing "task purity" (Costa et al., 2008). The arrows were blue and presented centred on a white background.

In the congruent trials, all arrows faced in the same direction. In the incongruent trials, the arrows surrounding the target arrow faced in the opposite direction, which required participants to use inhibition to suppress the distractor arrows. This inhibitory cognitive load leads to an increase in RTs and a reduction in Accuracy, measured in the *Conflict effect* (performance difference between congruent and incongruent trials). A smaller Conflict effect indicated greater inhibitory skills. Each trial started with a fixation cross presented for 200ms, followed by the 1000ms stimulus presentation with a maximum of 1500ms response time. Trial intervals were jittered (Figure 1).

FIGURE 1

There were three conditions comprising 96 trials (Table 5). Crucially, the conditions differed in the proportion of congruent-incongruent trial-switching and resulting load to monitoring and inhibition (Costa et al., 2009). The reactive monitoring condition presented participants with a greater number of congruent (92%) than of incongruent trials (8%). The proactive monitoring condition contained 50% congruent and 50% incongruent trials, which required participants to maintain inhibition as a constant goal.

TABLE 5

Whilst the 50-50 condition posed the greatest load to proactive monitoring, the 92-8 condition triggered a reactive control mode. Most trials were congruent, but a minority of incongruent trials require the reactive activation of inhibition to solve the task. The 92-8 condition stress-tests participants' ability to activate inhibition most. As the 92% majority of trials were congruent, requiring no inhibition of distractor stimuli, it becomes harder for participants to activate inhibitory schemata in the remaining 8% of incongruent trials (Costa et al., 2009). The 75-25 posed medium levels of cognitive load to inhibition.

In addition, a Go/No-go version of the Flanker task was administered to test participants' response inhibition skills, i.e. their ability to suppress an automatized motor response. There were 64 Go trials (32 congruent, 32 incongruent) and 32 No-go trials. Participants were instructed to respond as fast and accurately as possible indicating the target arrow's direction, unless the target arrow was red (No-go). When the target arrow was red, they had to abstain from providing an answer. Response inhibition was measured by comparing Accuracy in the No-go trials to Accuracy in the Go trials.

3. Results

Statistical "significance" of results was established following Fisher's (1955) continuous approach. Hence, a p-value of 0.05 was taken as a rough benchmark, but not as an absolute cut-off point. P-values in the region of 0.05 will therefore be considered as "marginal" or "trending" evidence for rejecting the Null hypothesis.

3.1. Bilinguals' code-switching habits

According to the frequency judgment task, the German-English bilinguals utilised all four types of code-switching to some extent (Table 6, Figure 2).

TABLE 6

The ANOVA revealed that the main effect of Code-switching type (Insertion E > G, Insertion G > E, Alternation, Dense code-switching) was significant [$F(3,126)=124.98$, $p<0.0001$, $\eta^2=0.75$], indicating that frequency across the four types of code-switching differed. Bilinguals indicated to engage in Insertion (English into German) and Alternation significantly more frequently than in other code-switching types ($p<0.0001$). Equally low frequency was reported for Insertion (German into English) and Dense code-switching ($p>0.05$). The latter result suggests a strong preference for using German as the matrix language of Insertional code-switching.

FIGURE 2

The questionnaire confirmed the frequency judgement task results (Fig 4). The ANOVA identified a significant main effect of Code-switching type [$F(2.40, 100.67)=32.58$, $MSE=0.598$, $\eta^2=0.44$, $p<0.0001$]. Bilinguals reported to engage in Insertion and Alternation significantly more frequently than in Dense code-switching ($p=0.032$). However, Insertion of German into English was reported to be used as frequently as Insertion of English into German. This is at odds with the judgement task and with existing corpora.

FIGURE 3

Importantly, the frequency judgement task and questionnaire results converged in confirming the prediction that bilinguals in this study would engage predominantly in Coupled control code-switching (Insertion and Alternation), and that Dense code-switching would occur infrequently in 1st generation immigrants (Muysken, 2000). It is therefore likely that any potential EF enhancements will occur in tasks mirroring the inhibitory processes of Coupled control modes.

3.2. Executive performance

3.2.1 Executive performance in the Flanker task

Outlier values exceeding 3 SDs from the mean were excluded from the analysis. Due to ceiling effects, the accuracy rates were skewed, so they were assessed using non-parametric tests

(Mann-Whitney U tests for between-subject comparisons, Friedman tests for within-subject comparisons).

Accuracy. To investigate the effect of the independent variable Congruency (congruent, incongruent), Friedman tests were conducted for each Monitoring condition (cf. Table 7 for Accuracy). In the 92-8 condition, Accuracy in congruent trials was marginally greater than in incongruent trials (χ^2 (1,84)=3.19, p=0.07, V=0.19). The pattern was identical in the 75-25 condition (χ^2(1,84)=3.45, p=0.06, V=0.20). In the 50-50 condition, the effect of Congruency on Accuracy rates was strong (χ^2(1,84)=36.36, p<0.001, V=0.66). The Congruency manipulation thus appeared to lead to a reasonably robust Conflict effect. To investigate the effect of the independent variable Monitoring condition (92-8, 75-25, 50-50), Friedman tests were conducted for both congruent and incongruent trials for both groups. Monitoring condition significantly impacted Accuracy in both congruent and incongruent trials (congruent: χ^2 (2,84)=10.94, p<0.001, V=0.26; incongruent: χ^2 (2,84)=12.64, p<0.001, V=0.27). Participants performed least well in the reactive monitoring condition.

TABLE 7

Group performance (monolingual, bilingual) across the different conditions was compared using a Mann-Whitney U test producing the p-values listed in Table 7. There were no significant group differences in the 50-50 and 75-25 conditions or in congruent trials in the 92-8 conditions. However, there was a trend (Mann-W U test: p=0.06) for bilinguals to perform more accurately than monolinguals on incongruent trials in the 92-8 condition. To summarise, there was an effect of Congruency with incongruent trials generating lower Accuracy than congruent trials. The 92-8 condition triggered the lowest Accuracy rates, suggesting that inhibition was harder in reactive than in proactive monitoring contexts. Importantly, there was a trend for bilinguals to outperform monolinguals at incongruent trials in the reactive condition.

Reaction Times. A mixed-design ANOVA with Monitoring condition (92-8, 75-25, 50-50) and Congruency (congruent, incongruent) as the within-subject factors and Group (monolinguals, bilinguals) as the between-subject factor was conducted (Table 8).

TABLE 8

There was a robust Conflict effect, i.e. RTs in incongruent trials were greater than in congruent trials [$F(1,82)$= 769.521, MSE=804.75, p<0.001 η^2=0.09]. There was also a main effect of Monitoring condition [$F(1.43, 117.44)$=30.62, MSE=1235.39, p<0.001, η^2=0.27]. RTs in the 92-8 condition were significantly higher than RTs in the other conditions (p<0.001). This observation applied across both groups because there was no interaction between Group and Monitoring [$F(1.43, 117.44)$=2.00, p=0.15, η^2=0.024]. The between-subject comparison was not significant [$F(1,82)$=1.25, MSE=40002.01, p=0.27, η^2=0.02]. However, there was a significant interaction between Congruency and Group [$F(1,82)$=4.30, p=0.04, η^2=0.05], suggesting that, as predicted, the pattern differed across the two groups.

This study predicted that bilinguals would outperform monolinguals at those aspects of EFs that are modulated by the code-switching type they frequently engage in, i.e. Coupled control code-switching. Hence, the inhibitory performance difference between bilinguals and monolinguals was predicted to occur in incongruent trials in the reactive monitoring condition. To investigate this hypothesis, a planned comparison was conducted, comparing monolingual and bilingual inhibitory performance in the 92-8 condition. In line with predictions, there was a marginally significant group difference in incongruent trials in the 92-8 condition (p=0.05), in which bilinguals performed on average 32.47ms faster than monolinguals (Figure 4).

FIGURE 4

Conflict effect. The Conflict effect measures inhibitory control specifically and was computed as “Performance in incongruent - Performance in congruent trials”.

TABLE 9

For Accuracy (Table 9), the effect of Monitoring was highly significant [χ^2 $(2,84)$=19.22, p<0.001, V=*0.34*]. The Conflict effect in the 92-8 condition was greater than that in the other conditions, confirming that this condition was hardest from an inhibitory perspective. The between-subject comparison for the Conflict effect in the three Monitoring conditions revealed that bilinguals and monolinguals performed equally well in the 50-50 condition (*p*=0.61) and in the 75-25 condition (*p*=0.53). Crucially, bilinguals displayed a significantly reduced Conflict effect compared to monolinguals in the 92-8 condition (*p*=0.039). In line with trends in group differences in incongruent trials, this reveals enhanced inhibitory skills for bilinguals in the reactive condition.

TABLE 10

To assess the Conflict effect for RTs (Table 10), a mixed-design ANOVA with Monitoring condition (92-8, 75-25, 50-50) as the within-subject factor and Group (monolinguals, bilinguals) as the between-subject variable was conducted. Bilinguals (*M*=65.42ms, *SD*=23.25ms) experienced a reduced Conflict effect compared to monolinguals (*M*=75.16ms, *SD*=34.60ms) across all three conditions, but this effect was only trending [$F(1,82)=3.65$, $MSE=1637.49$, $p=0.06$, $\eta^2=0.004$]. There was a significant effect of Monitoring [($F(1.34,109.51)=35.09$, $MSE=1106.44$, $p<0.001$, $\eta^2=0.30$]. The 92-8 condition yielded a greater Conflict effect than the 75-25 and the 50-50 condition ($p<0.001$), confirming the effort involved in the reactive activation of inhibition. There was also a marginally significant interaction between Monitoring and Group [$F(1.34,109.51)=3.39$, $p=0.056$, $\eta^2=0.04$], suggesting that inhibitory performance across the conditions differed in the monolingual and the bilingual group.

It had been predicted that bilinguals would experience executive enhancements at inhibitory processes analogous to those employed by the code-switching types they regularly engaged in. The bilinguals in this study most frequently engaged in Coupled control code-switching. Hence, they were predicted to excel at inhibition in the reactive monitoring condition. Indeed, a planned comparison investigating this prediction revealed that it was in this condition that bilinguals outperformed monolinguals at the Conflict effect measuring inhibition (monolinguals: *M*=101.38ms, *SD*=59.16ms, bilinguals: *M*=79.26ms, *SD*=31.91ms, $F(1,84)=4.61$, $p=0.035$, $\eta^2=0.053$). Figure 5 illustrates the Conflict effect across the three conditions, showing a similar group performance in the 50-50 and 75-25 conditions, but a diverging performance in the 92-8 condition.

FIGURE 5

To investigate the predictors of inhibitory performance, i.e. the Conflict effect, regression analyses were conducted for each condition separately as each condition challenged different aspects of the executive system. Inhibitory performance in the 92-8 condition was of specific interest because this was the condition in which performance differences between bilinguals and monolinguals occurred. Due to the ceiling effect, the Accuracy scores displayed too little variability to conduct a multiple regression (Field, 2009). Hence, regression analyses were conducted for RTs only. We first investigated the impact of non-linguistic predictors in the two groups, before zooming in on the linguistic predictors within the bilingual group. The initial stepwise regression was based on the following non-linguistic predictor variables, which may modulate EFs: Age, Education, IQ, Short-term and Working memory. The analyses were conducted separately for monolinguals and bilinguals.

In the 92-8 condition, 34.6% of monolingual inhibitory performance variance was explained by IQ and Age [$R(1,38)=0.59$, $R^2=0.35$, adj. $R^2=0.31\%$, IQ: $B= -1.56$, $\beta= -0.45$, Age: $B=1.74$, $\beta=0.35$, Constant=216.10, *F-change*=6.91, $p<0.01$]. However, in the bilingual group none of the non-linguistic variables accounted for inhibitory performance variance. A similar picture emerged in the 50-50 and 75-25 conditions. None of the non-linguistic variables reliably predicted the Conflict effect in the bilingual group. In the monolingual group, inhibitory performance was explained by Age in both conditions [75-25 condition: $R(1,39)=0.38$, $R^2=0.144$, adj. $R^2=0.123$, *F-change*=6.58, $B=0.82$, $\beta=0.38$, Constant=36.18, $p<0.01$; 50-50 condition: $R(1,39)=0.43$, $R^2=0.18$, adj. $R^2=0.16$, *F-change*=8.62, $B=0.70$, $\beta=0.43$, Constant=36.76, $p<0.001$].

Non-linguistic variables thus explained inhibitory performance in the monolingual, but not in the bilingual group. This raised the question whether performance in the bilingual group would be explained by bilingualism-related variables, such as code-switching, prompting further regression analyses with the following linguistic predictors: Age of Onset (L2 English), frequency judgement task scores for each code-switching type (Insertion G>E, Insertion E>G, Alternation, Dense code-switching), L2 proficiency, Balance and Immersion. None of the linguistic variables explained bilinguals' inhibitory performance in either the 75-25 condition or the 50-50 condition. However, in the crucial 92-8 condition, in which performance differences between bilinguals and monolinguals had occurred, code-switching was a significant predictor: Alternation was singled out as the only predictor of inhibitory performance, explaining 27% of variance [$R(1,41)=0.52$, $R^2=0.27$, adj. $R^2=0.25$, Constant=100.00, $B= -11.50$, $\beta= -0.52$, $F\text{-}change=15.18$, $p<0.01$]. The more frequently bilinguals engaged in Alternation, the better they performed at inhibition in the reactive monitoring condition.

Additional analyses were conducted, using the self-reported code-switching scores from the questionnaire. These revealed two further results of interest to this study. Firstly, the only significant predictor of inhibitory performance in the 92-8 condition was bilinguals' frequency of Alternational code-switching [$R(1,41)=0.40$, $R^2=0.16$, adj. $R^2=0.14$, $F\text{-}change=7.68$, $B= -17.13$, $\beta= -0.40$, $p<0.01$], which provided evidence converging with the regression using frequency judgement task scores. Secondly, inhibitory performance in the 50-50 condition was predicted by self-reported Dense code-switching frequency [$R(1,41)=0.41$, $R^2=0.17$, adj. $R^2= 0.15$, $F\text{-}change=8.30$, Constant: 67.97, $B= -7.95$, $\beta= -0.41$, $p<0.01$]. Dense code-switching explained 17% of performance variance at inhibition in the 50-50 condition. Bilinguals who self-reported to frequently use Dense code-switching performed better at inhibition in the proactive monitoring condition. This suggests that Dense code-switching recruits and enhances proactive monitoring. Most Dense code-switching scores in Study 2 were low. This is because the bilinguals in this study were all recent immigrants who rarely engaged in Dense code-switching. It is possible that if there had been a greater spread of Dense code-switching scores, the relationship between Dense code-switching and inhibition would have been different. Nevertheless, the case-wise regression diagnostics did not identify any outliers, so there was no need to exclude any values.

3.2.2. Executive performance in the Go/No-go task

Accuracy. In the monolingual group, the effect of congruency was marginally significant [congruent trials: M=96.02%, SD=16.06%; incongruent trials: M=95.73%, SD=12.26; $\chi^2(1,41)=3.67$, $p=0.07$, $V=0.21$]. In the bilingual group, the difference between congruent and incongruent trials was significant [$\chi^2(1,41)=14.22$, $p<0.0001$, $V=0.41$] with bilinguals performing at ceiling in congruent trials (M=99.71%, SD=1.14%), but making slightly more errors in incongruent trials (M=97.75%, *SD*=3.82%). Descriptively, bilinguals appeared to display greater Accuracy overall, but this difference was not statistically significant (Mann-Whitney U tests: $p>0.05$).

Reaction times. To analyse RTs in the Go trials, a mixed-design ANOVA was conducted with Congruency (congruent, incongruent) as the within-subject variable and Group (monolingual, bilingual) as the between-subject variable. The Conflict effect was significant with congruent trials yielding reduced RTs (*M*=462.75ms, *SD*=5.05ms) compared to incongruent trials (*M*=505.76ms, *SD*=5.90ms) [$F(1,82)=5.14$, $MSE=386.52$, $p<0.0001$, $\eta^2=0.71$]. The overall between-subject comparison was not significant [$F(1,82)=0.63$, $MSE=1106.86$, $p=0.63$, $\eta^2=0.003$]. However, there was an interaction between Group and Congruency [$F(1,82)=5.14$, $MSE=386.52$, $p=0.03$, $\eta^2=0.06$]. To investigate this interaction, congruency effects were assessed in each group separately, and group effects were assessed for congruent and incongruent trials separately. Participants in both groups displayed shorter RTs in congruent trials (monolinguals: *M*=461.87, *SD*=49.01; bilingual: *M*=463.62, *SD*=43.60) than in incongruent trials (monolinguals: *M*=511.76, *SD*=61.57; bilingual: *M*=499.75, *SD*=45.75). Although the nature of the congruency effect was identical across both groups [monolinguals: $F(1,40)=76.72$, $MSE=665.02$, $p<0.0001$, $\eta^2=0.66$; bilinguals: $F(1,42)=231.33$, $MSE=121.28$, $p<0.0001$, $\eta^2=0.85$], the effect size in monolinguals (0.85) was larger than in bilinguals (0.66), which is likely to have led to the interaction (Figure 6). In the group comparison bilinguals and monolinguals performed equally well on congruent trials [$F(1,83)=0.03$, $MSE=2145.44$, $p=0.86$, $\eta^2=0.00$]. In incongruent trials, bilinguals were on average 12.02ms quicker than monolinguals, but this difference was not statistically significant [$F(1,83)=1.04$, $MSE=2921.50$, $p=0.31$, $\eta^2=0.01$].

FIGURE 6

Interference suppression and response inhibition. Bilinguals engaging predominantly in Coupled control code-switching had been hypothesised to outperform monolinguals at the interference suppression aspect of inhibition. To investigate this, an ANOVA was conducted with Group (monolingual, bilingual) as the between-subject variable and the Conflict effect for RTs in the Go trials as the dependent variable. Bilinguals displayed a reduced Conflict effect (*M*=36.12ms, *SD*=15.57ms) compared to monolinguals (*M*=49.89ms, *SD*=36.47ms). This turned out to be a small

(13.77ms), yet significant difference [$F(1,82)=5.14$, $MSE=3976.85$, $p=0.03$, $\eta^2=0.06$]. Bilinguals thus outperformed monolinguals at interference suppression.

Performance at No-go trials measured response inhibition. This can only be measured in error rates, because, by definition, correct responses in No-go trials do not have RTs. Friedman tests were conducted for each group separately to assess whether Accuracy in No-go trials differed from accuracy in Go trials. Group performance in No-go trials was compared in Mann-Whitney U tests. In congruent trials, monolinguals performed significantly [$\chi^2(1,41)=4.57$, $p=0.03$, $V=0.23$] less accurately in No-go ($M=94.34\%$, $SD=15.86\%$) compared to Go trials ($M=96.02\%$, $SD=16.06\%$). The same can be said for bilinguals who performed nearly at ceiling on congruent Go trials, but slightly less well at No-go trials [Go: $M=99.71\%$, $SD=1.14\%$, No-go: $M=97.82\%$, $SD=4.70\%$, $\chi^2(1,43)=4.56$, $p=0.04$, $V=0.23$]. In incongruent trials, the pattern was different. Monolinguals performed equally well in Go and No-go trials [Go: $M=95.73\%$, $SD=1.22\%$, No-go: $M=95.58\%$, $SD=12.36\%$, $\chi^2(1,41)=1.63$, $p=0.20$, $V=0.14$]. Bilinguals on the other hand performed significantly better on No-go compared to Go trials [Go: $M=97.75\%$, $SD=3.82\%$, No-go: $M=98.69\%$, $SD=3.49\%$, $\chi^2(1,43)=4.55$, $p=0.03$, $V=0.23$]. There were no group differences in No-Go trials (Mann-Whitney U tests: $p>0.05$).

To summarise, participants performed more accurately in Go than in No-go trials when the trials were congruent. In incongruent trials, this effect was reversed in the bilingual group and disappeared in the monolingual group. How can this performance pattern reversal be explained? Firstly, it is possible that incongruent trials are less automated because the increased inhibitory effort requires some form of processing, triggering a “thinking pause” (increased RTs). It is possible that this response delay in incongruent trials facilitated response inhibition, which would explain why the No-go effect was cancelled out. A reversal of patterns is also possible if the heightened levels of inhibition in incongruent trials transferred to the response inhibition aspect of the task. Importantly, the group comparisons suggest a bilingual advantage for interference suppression, but not for response inhibition.

To compare predictors of performance in bilinguals and monolinguals, separate regression analyses were conducted for the two groups, and for congruent and incongruent trials in the Go and

No-go conditions. Firstly, none of the non-linguistic predictors explained Accuracy in any of the conditions in either group. For RTs, Age explained 53.6% of variance at congruent RTs [$R(1,39)$=0.73, R^2=0.54, adj. R^2=0.52, *F-change*=45.09, Constant=358.97, B=3.04, β=0.73, p<0.0001] and 31.6% of variance at incongruent RTs [$R(1,39)$=0.56, R^2=0.32, adj. R^2=0.30, *F-change*=18.02, Constant=412.52, B=2.93, β=0.56, p<0.0001] in the monolingual group. Older monolinguals had slower RTs. This age effect was absent in the bilingual group. Variance at the Conflict effect was explained by Short-term memory in the bilingual group [$R(1,41)$=0.32, R^2=0.10, adj. R^2=0.08, *F-change*=4.68, Constant=75.84, B= -6.21, β= -0.32, p=0.04], but not in the monolingual group.

The regression analysis using linguistic variables provided limited insights. None of the predictor variables explained RT performance in Go trials. As for Accuracy, a complex picture emerged. None of the linguistic variables predicted Accuracy in the congruent Go trials or in the incongruent Go and No-go trials. However, in the No-go trials (congruent) Dense code-switching explained 11.4% of performance variance [$R(1,40)$=0.34, R^2=0.11, adj. R^2=0.09, *F-change*=5.12, Constant=1.03, B= -0.02, β= -0.34, p=0.03], so there was a negative correlation between response inhibition skills and Dense code-switching. Frequent Dense code-switchers performed less well at response inhibition.

To summarise, bilinguals outperformed monolinguals in interference suppression, but not in response inhibition. Linguistic variables did feature as significant predictors of response inhibition. There was a significant negative relationship between the frequency of Dense code-switching and response inhibition, suggesting that the Dense code-switchers are less good at supressing an automated motor response.

4. Discussion

This study investigated whether and how different code-switching types (Muysken, 2000) modulate EFs, and whether code-switching explains executive performance differences between bilinguals and monolinguals. The predictions were based on existing processing models of code-switching (Treffers-

Daller, 2009; Abutalebi & Green, 2013; Green & Wei, 2014), which were extended by a dual control perspective of EFs (Braver, 2012). The results revealed selective executive performance modulations in bilinguals, which can be explained in a model differentiating between different code-switching types and control modes.

Although bilinguals and monolinguals performed on a par in most conditions, there was a selective inhibitory advantage for bilinguals in the reactive monitoring condition. This suggests that the effect of bilingualism on inhibitory performance is modulated by monitoring, as suggested by previous studies (Costa et al., 2009; Morales et al., 2015). Crucially, the bilingual performance modulation occurred in the condition mirroring the control processes employed in bilinguals' most frequent code-switching habits. It was a type of Coupled control code-switching, Alternation, that accounted for bilingual advantages at inhibition.

Importantly, the observed relationships provide novel insights into the nature of the overlap between code-switching and EFs, suggesting that processing models of code-switching should differentiate between reactive and proactive monitoring (Braver, 2012). Whilst Alternation draws upon reactive control forms, Dense code-switching requires proactive monitoring. The inhibitory processes called upon in the reactive monitoring condition are akin to what is required to globally inhibit languages for prolonged periods of time during Alternation, because the de- and re-activation of inhibition happens less frequently. The proactive monitoring context on the other hand challenges the continued maintenance of inhibition, thus replicating the need to manage a constant state of cross-linguistic competition during Dense code-switching. Inhibitory performance variance in the reactive monitoring condition was indeed explained by Alternation, whilst performance in the proactive monitoring condition was explained by Dense code-switching.

Our study converged with and differed from previous studies in several points. The positive correlation between Dense code-switching and inhibitory performance in the proactive monitoring condition was coherent with Hofweber et al. (2016). Hence, there is converging evidence suggesting that Dense code-switching trains the ability to manage inhibition proactively. However, the effect of Dense code-switching did not translate into performance differences between bilinguals and monolinguals in this study. This is also inconsistent with Costa et al. (2009) who found bilinguals to outperform monolinguals in a 50-50 version of the flanker task. We hypothesise that the observed divergence in results is due to differences in participants' code-switching patterns. It is possible that the Spanish-Catalan bilinguals in Costa et al. (2009) engaged in Dense code-switching because they were living in communities with long-standing bilingual traditions. The recent bilinguals in this study, by contrast, engaged in Dense code-switched too infrequently for group differences to occur. Hence, the divergence in results may be due to a threshold effect.

The results of this study also revealed that inhibitory performance was predicted by different variables in the bilingual and monolingual groups. A large percentage of inhibitory performance variance was predicted by the non-linguistic variables Age and IQ in monolinguals, but not in bilinguals. The fact that Age and IQ predicted executive performance amongst the monolinguals was unsurprising. Reaction times commonly increase with Age (Bialystok, Craik, & Luk, 2008; Goral, Campanelli & Spiro, 2015; Weissberger, Wierenga, Bondi & Gollan, 2012), and IQ is well known to correlate with a wide range of cognitive abilities (Raven & Court, 1998). Surprisingly, these influential variables did not impact inhibitory performance in the bilingual group. This observation is coherent with the notion that bilingualism generates neural adaptations re-shaping executive networks, leading to a fundamentally different modus operandi of executive control (Bialystok et al., 2005; Abutalebi & Green, 2007). The absence of an age effect is also in line with previous studies showing that bilingualism has the potential to reduce the age-related decline of EFs (Bialystok et al., 2008). However, this study only tested middle-aged participants, so future research is needed to systematically investigate the interaction between code-switching and aging effects.

The response inhibition task produced another selective group difference: Bilinguals outperformed monolinguals at interference suppression, but not at response inhibition. This was in line with previous studies (Bialystok, 2009). It was also consistent with the fact that the bilinguals in this study engaged primarily in Coupled control mode code-switching, thus training primarily interference suppression. However, there was evidence of a relationship between response inhibition and code-switching. In line with predictions, bilinguals' response inhibition performance correlated with Dense code-switching frequency. Contrary to predictions, the nature of this relationship was negative. The more frequently bilinguals engaged in Dense code-switching, the less well they performed at response inhibition.

This raises a chicken and egg question. Is it more intuitive to say that Dense code-switching makes bilinguals worse at response inhibition or that less strong response inhibition abilities increase the likelihood of Dense code-switching? The answer to this question impacts the direction of causality implied in the relationship between code-switching and EFs. Bilinguals' EF abilities could influence their code-switching behaviour. Most likely, the relationship between code-switching and EFs is mutual, making it hard to tease apart cause and effect. The correlational design of this study cannot provide a definite answer to this question. Future research should address the issue of causality using longitudinal study designs (Woumans & Duyck, 2015).

Both interpretations of causality are nevertheless in line with the hypothesis that during Dense code-switching languages remain co-activated beyond the conceptual level (Botero et al., 2004). Interestingly, Alternation and Insertion did not correlate with the response inhibition measure, indicating that they are unrelated to response inhibition. This suggests that Coupled control code-switching involves global language selection at conceptual processing stages, whilst Dense code-switching involves linguistic co-activation at articulatory stages and is managed through local forms of language selection (Hofweber et al., 2016). Future research could test this hypothesis by comparing the nature of phonological transition processes in the different code-switching types.

The following sections will discuss some of the limitations of this study and how they could be addressed in future research. Firstly, this study assessed executive performance using purely behavioural methods. To identify the neural correlates of different language modes and interactional contexts, future research could use direct measures of neural activity (Van Hell, Fernandez, Kootstra, Litkofsky & Ting, 2018; Ruigendijk, Hentschel, & Zeller, 2016). Furthermore, this study explored the predictions about the dual control modes involved in different code-switching types using a correlational design. Additional insights could be obtained by comparing bilinguals who display opposite usage frequency of Alternational code-switching, as it was done for Dense code-switching (Hofweber et al., 2016).

The results from this study suggest that code-switching has a moderate modulatory impact on EFs. Hence, findings from this project do not contradict the notion that individuals' EFs are partially shaped by genetic pre-disposition (Friedman, Miyake, Young, DeFries, Corley & Hewitt, 2008) or by life experiences other than bilingualism (Bialystok, 2009). They merely capture the specific modulatory impact of code-switching on EFs. Moreover, the data do not contrast with studies suggesting that code-switching may not be more effortful than monolingual modes (Gardner-Chloros, McEntee-Atalianis, & Paraskeva, 2013; Kleinmann & Gollan, 2016). Rather, the data suggest a trade-off of dual control mechanisms (Braver, 2012) and global and local control (Hofweber et al., 2016). The "total" executive effort may be equal across all language modes, but language modes differ in their specific demands to reactive and proactive inhibitory mechanisms (Ooi et al., 2018). This is in line with Abutalebi & Green's (2013) Adaptive Control Hypothesis, which suggests that the interplay of proactive and reactive control differs as a function of interactional contexts. Coupled control code-switching challenges reactive but not proactive monitoring, whilst the pattern of "executive effort" is the opposite for Dense code-switching.

A trade-off could also be hypothesised for the balance between executive and linguistic efforts, i.e. between the inhibitory effort used to suppress non-target languages and the linguistic effort used to consolidate competing linguistic structures. The Adaptive Control Hypothesis (Abutalebi & Green, 2013) suggests that intra-sentential code-switching challenges the temporal processes responsible for syntactic processing. However, traditional models of syntactic processing suggest that speakers minimise effort during planning by using whatever linguistic item is most accessible. Syntactic priming paradigms show that speakers reuse structures previously used by their interlocutors (Bock & Griffin, 2000), and construct utterances around frequent or visually salient referents (Gleitman, January, Nappa, Trueswell, 2007). This raises the question if code-switching is driven by such accessibility criteria, i.e. whether there is something more accessible about the language-not-in-use that prompts a speaker to switch. Lexical frequency effects have for instance been shown to affect the pattern of insertional code-switching (Khakimov, 2014). This implies that code-switching relieves the burden of syntactic planning and is less effortful from a linguistic perspective, but it does not necessarily mean it is less effortful for EFs.

Accessibility may indeed dominate language selection in Dense code-switching in which the gates are "open" and speakers are free to select linguistic items from either language (Green & Wei, 2014). However, even in the open control mode there will be a cost to proactive monitoring and local inhibition (Abutalebi & Green, 2013; Green & Wei, 2014; Hofweber et al., 2016). Speakers need to consolidate competing linguistic structures. In the Dense code-switching example in Table 1 for instance the speaker opted for a calque translation of the English idiomatic expression "to make friends". Whilst this term may have been lexically more accessible, its usage in a bilingual sentence involved the consolidation of incongruent word orders from German and English.

Moreover, accessibility criteria may be overwritten by sociolinguistic conventions. In bilingual communities with strong traditions of language separation speakers may avoid code-switching, even if it is linguistically less effortful. The impact of accessibility criteria may also be mitigated when the situational context requires speakers to inhibit a language. This study did not specifically investigate the impact of accessibility criteria on code-switching patterns, but an investigation of the interaction of linguistic accessibility and EFs in code-switching would be an interesting avenue for future research. Bilinguals' selective attention abilities may for instance modulate the extent to which they utilise the visual saliency of referents when constructing utterances (Gleitman et al., 2007).

Another important avenue for further research is to investigate the relationship between EFs and code-switching patterns in sociolinguistic communities in which Dense code-switching is widely practised, such as Singapore. Code-switching in those communities may not require (global) inhibition to the same extent as it draws on the open control mode (Kang & Lust, 2019). Future research on the relationship between code-switching and EFs should consider the subtle differences in community-wide code-switching practices. Communities, in which topics or activities are language-specific, and thus code-switching is less commonly practised (e.g. Brussels, Treffers-Daller, 1992), are different from communities in which topics and activities are covered equally by both languages and code-switching is widely found (e.g. Singapore, Kang & Lust, 2019). A more in-depth analysis of the actual distribution of languages across a range of topics and activities in the communities under study is therefore needed. Such analyses could, for example, make use of Grosjean's (2016) Complementarity Index, which measures the degree of overlap between the use of languages across topics and activities. This could shed light on fine-grained within-group and between-group differences in language use patterns (including code-switching practices) that may affect EFs.

To summarise, the results of this study suggest that code-switching involves EFs. Moreover, the answer to the question whether code-switching brings about modulations that translate into performance differences between bilinguals and monolinguals was affirmative. The nature of differences depended on the type of code-switching bilinguals regularly engaged in. In this study, bilinguals engaged predominantly in Coupled control code-switching, so group differences occurred in task conditions challenging the EFs involved in Coupled control code-switching. Bilinguals with different code-switching habits would probably display other EF modulations. This highlights the importance of assessing sociolinguistic variables in explaining inconsistent findings in bilingualism research (Bak, 2016). A lack of assessing bilinguals' sociolinguistic habits is likely to result in a lack of sensitivity of the administered EF tasks when it comes to replicating the cognitive processes trained by bilinguals' practices.

5. Conclusion

This study investigated the effects of different types of code-switching, as distinguished by Muysken (2000), on different aspects of the executive system. The study also explored whether EF modulations through code-switching would translate into performance differences between bilinguals and monolinguals. Based on processing models of code-switching (Treffers-Daller, 2009; Green & Wei, 2014; Braver, 2012), Coupled control code-switching (Alternation, Insertion) was predicted to train reactive control modes. Dense code-switching was predicted to train proactive control modes because the prolonged linguistic co-activation in this code-switching type requires a constant readiness to use inhibition. The results confirmed the predicted interactions between code-switching and EFs. Moreover, the training effect of code-switching translated into "bilingual advantages". Bilinguals outperformed monolinguals in the task conditions mirroring the EFs employed by the type of code-switching they frequently engaged in.

The results also indicated that different code-switching strategies involve language selection processes taking place at different stages in language production (Kroll et al., 2006). A correlation between Dense code-switching and response inhibition performance suggested that Dense code-switching involves linguistic co-activation at articulatory stages of language production, whilst in Coupled control code-switching selection happens at the conceptual lemma level. The findings of this study thus provided novel insights into the interaction of EFs with code-switching. They also suggested that the observed complexity of the relationship between code-switching and EFs necessitates the use of more bespoke assessment methods of code-switching in bilingualism research to explain performance differences between bilinguals and monolinguals.

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Tables

Table 1 German-English code-switching examples for each code-switching type (Muysken, 2000)

Code-switching type	**Example**
(1) Alternation	*Ich kann heute nicht kommen* BECAUSE I'M ILL. *I can today not come* BECAUSE I'M ILL. *I cannot come today BECAUSE I'M ILL.*
(2) Insertion E > G	*Wir suchen noch* VOLUNTEERS *fuer das Projekt*. *We search still* VOLUNTEERS *for the project*. *We are still looking for VOLUNTEERS for the project.*
(3) Insertion G > E	*We didn't bring* SCHUHWERK *for hiking*. *We didn't bring* SHOES *for hiking*. *We didn't bring SHOES for hiking.*
(4) Dense	*Wir haben* FRIENDS *gemacht mit'm* SHOP OWNER. *We have* FRIENDS *made with th'* SHOP OWNER. *We have made FRIENDS with th' SHOP OWNER.*

Table 2 Inhibitory control processes involved in different code-switching types

Framework	**Alternation**	**Insertion**	**Dense**
Inhibitory control continuum (Treffers-Daller, 2009)	High inhibitory load	Medium inhibitory load	Low inhibitory load
CPM control mode (Green & Wei, 2014)	Inhibitory load	Inhibitory load	No inhibitory load
Dual control mode (Braver, 2012)	Reactive monitoring	Reactive monitoring	Proactive monitoring
Scope (Hofweber et al., 2016)	Global inhibition	Global for grammar, Local for lexicon	Local inhibition
Processing stage	Conceptual stage: Interference suppression	Conceptual stage: Interference suppression	Conceptual & Articulatory stage: Interference suppression & Response inhibition

Table 3 Linguistic background variables bilinguals

Variable		**Bilinguals**
German Proficiency	M	6.88
	SD	0.27
	Range	5.50 - 7.00
English Proficiency	M	6.38
	SD	0.60
	Range	4.25 - 7.00
Balance	M	0.56
	SD	0.94
	Range	0.00 - 5.06
Age of Onset English (in years)	M	8.84
	SD	4.36
	Range	0.00 - 27.00
Immersion (in years)	M	9.33
	SD	9.04
	Range	1.00 - 48.00

Table 4 Non-linguistic background variables

Variable		**Monolinguals**	**Bilinguals**	**F-value**	**df**	**p-value**
Age	M	33.83	32.14	0.52	1, 82	0.47
	SD	11.80	9.57			
	Range	18.00 - 69.00	19.00 - 71.00			
Education	M	4.12	4.21	0.16	1, 82	0.69
	SD	0.87	1.10			
	Range	3.00 - 6.00	1.00 - 6.00			
IQ Non-verbal	M	41.88	44.09	2.58	1, 82	0.11
	SD	7.24	5.28			
	Range	27.00 – 58.00	29.00 – 57.00			
SM	M	6.22	6.40	0.77	1, 82	0.38
	SD	1.07	0.80			
	Range	5.00 - 9.00	5.00 - 9.00			
WM	M	4.48	4.53	0.05	1, 82	0.82
	SD	1.21	0.84			
	Range	3.00 - 9.00	3.00 - 7.00			

Table 5 Experimental conditions in the Flanker task

Condition	**Congruent trials**	**Incongruent trials**	**Monitoring**	**Inhibitory Load**
92-8	92%	8%	Reactive	High
75-25	75%	25%	Medium	Medium
50-50	50%	50%	Proactive	Low

Table 6 Frequency judgement task scores (scale 1-7)

Code-switching type		Bilinguals
Insertion	M	5.01
E > G	SD	1.39
	Range	1.90 - 6.86
Insertion	M	2.32
G > E	SD	1.06
	Range	1.00 - 5.07
Alternation	M	3.85
	SD	1.44
	Range	1.00 - 6.50
Dense	M	2.52
	SD	0.78
	Range	1.00 - 6.50

Table 7 Accuracy rates in the Flanker task

Accuracy in % Condition		Monolinguals	Bilinguals	Mann-Whitney U	df	p-value
92-8	M	99.40	99.37	777.00	1, 84	0.27
Congruent	SD	1.50	0.83			
	Range	91.00 - 100.00	98.00 - 100.00			
92-8	M	90.28	95.35	701.50	1, 84	0.06
Incongruent	SD	12.96	7.73			
	Range	50.00 - 100.00	75.00 - 100.00			
75-25	M	98.12	99.13	780.00	1, 84	0.22
Congruent	SD	3.72	1.94			
	Range	83.00 - 100.00	92.00 - 100.00			
75-25	M	98.15	98.75	838.50	1, 84	0.67
Incongruent	SD	4.02	1.77			
	Range	75.00 - 100.00	91.00 - 100.00			
50-50	M	99.48	99.81	809.00	1, 84	0.27
Congruent	SD	1.38	0.61			
	Range	94.00 - 100.00	98.00 - 100.00			
50-50	M	96.51	97.87	865.00	1, 84	0.88
Incongruent	SD	8.70	2.55			
	Range	46.00 - 100.00	88.00 - 100.00			

Table 8 RTs in the flanker task

RTs in ms **Condition**		**Monolinguals**	**Bilinguals**	**F-value**	**df**	**p-value**
92-8	M	463.64	454.41	0.89	1, 82	0.35
Congruent	SD	55.11	32.33			
	Range	370.85 - 619.72	381.80 - 525.25			
92-8	M	565.02	532.55	3.94	1, 82	0.05
Incongruent	SD	96.45	45.90			
	Range	407.27 - 813.41	434.77 - 631.80			
75-25	M	452.47	444.29	1.01	1, 82	0.32
Congruent	SD	44.05	29.65			
	Range	370.49 - 583.41	390.48 - 518.06			
75-25	M	516.93	506.21	1.13	1, 82	0.29
Incongruent	SD	53.20	38.13			
	Range	407.09 - 662.60	430.49 - 605.00			
50-50	M	459.33	452.37	0.77	1, 82	0.38
Congruent	SD	41.36	30.83			
	Range	372.65 - 537.03	405.44 - 528.35			
50-50	M	519.59	506.96	1.80	1, 82	0.18
Incongruent	SD	49.96	35.32			
	Range	428.46 - 666.22	442.39 - 607.31			

Table 9 Conflict effect (Accuracy) by Monitoring condition

Accuracy in % **Condition**		**Monolinguals**	**Bilinguals**	**F-value**	**df**	**p-value**
92-8	M	9.12	4.02		1, 84	*0.04
	SD	13.13	7.73			
	Range					
75-25	M	-0.03	0.37		1, 84	0.53
	SD	5.18	2.71			
	Range					
50-50	M	2.97	1.94		1, 84	0.61
	SD	8.11	2.59			
	Range					

Table 10 Conflict effect (RTs) by monitoring condition

Conflict effect in ms **Condition**		**Monolinguals**	**Bilinguals**	**F-value**	**df**	**p-value**
92-8	M	101.38	79.26	4.61	1, 84	*0.03
	SD	59.16	31.91			
	Range	2.61 - 306.43	11.35 - 154.11			
75-25	M	63.84	62.32	0.08	1, 84	0.78
	SD	25.38	23.81			
	Range	0.00 - 117.34	10.51 - 117.32			
50-50	M	60.26	54.69	2.31	1, 84	0.13
	SD	19.26	14.03			

Range	20.12 - 129.19	21.12 - 84.82

Figures

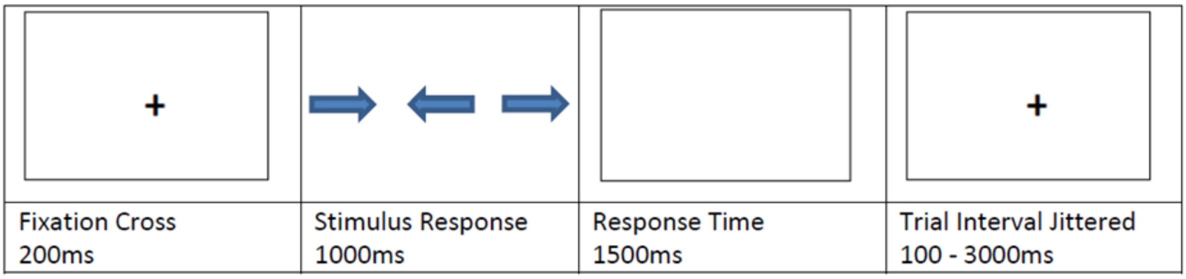

Figure 1 Flanker task stimulus presentation

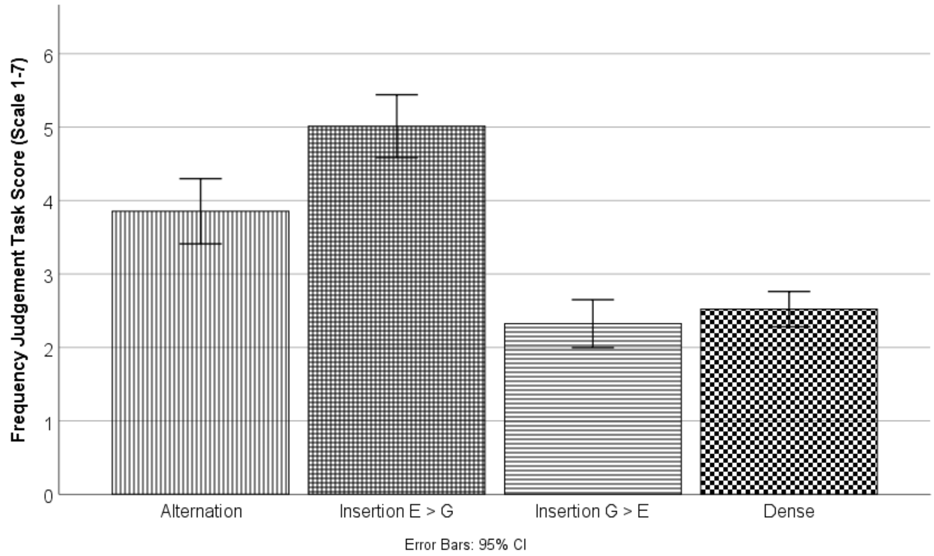

Figure 2 Frequency judgement task scores

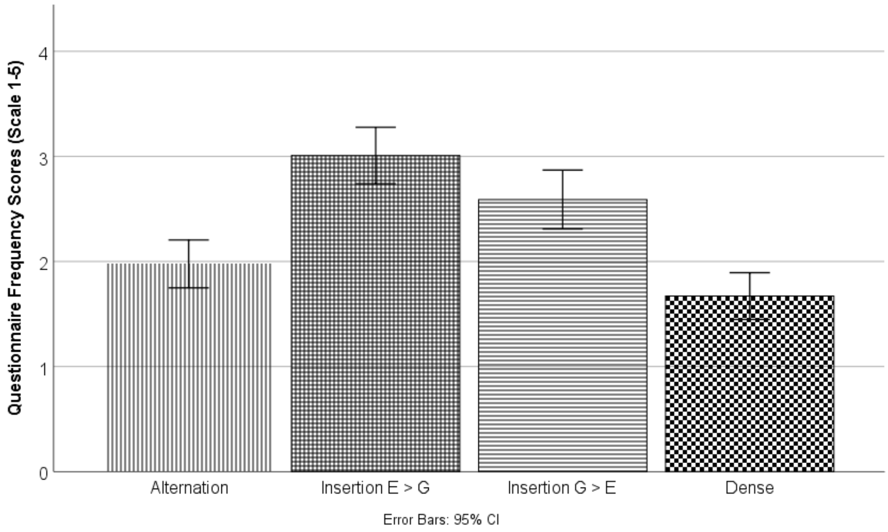

Figure 3 Code-switching questionnaire scores

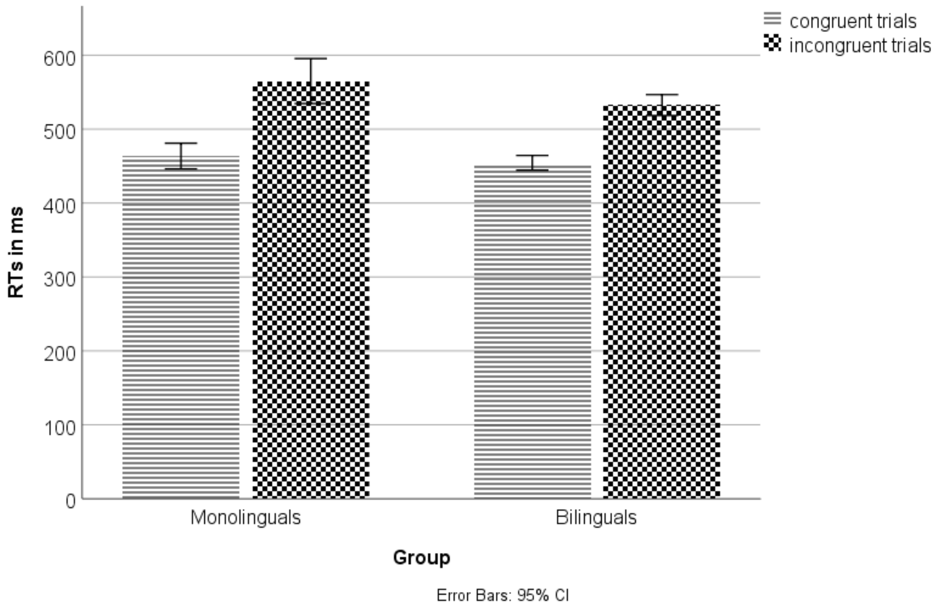

Figure 4 RTs in reactive monitoring condition

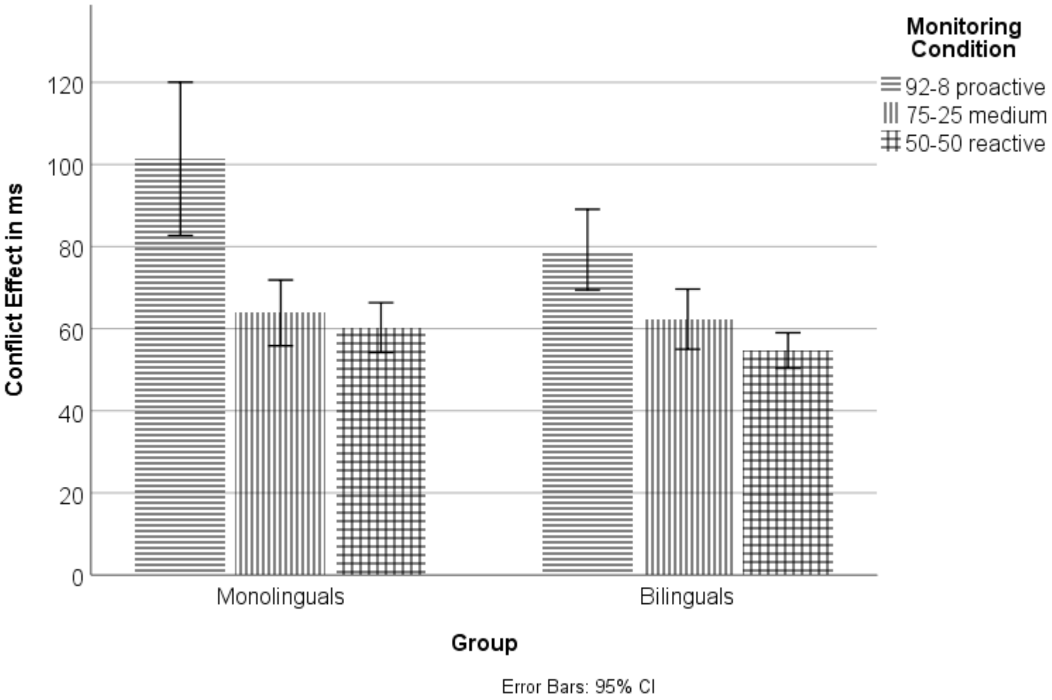

Figure 5 Conflict effect in RTs by group and monitoring condition

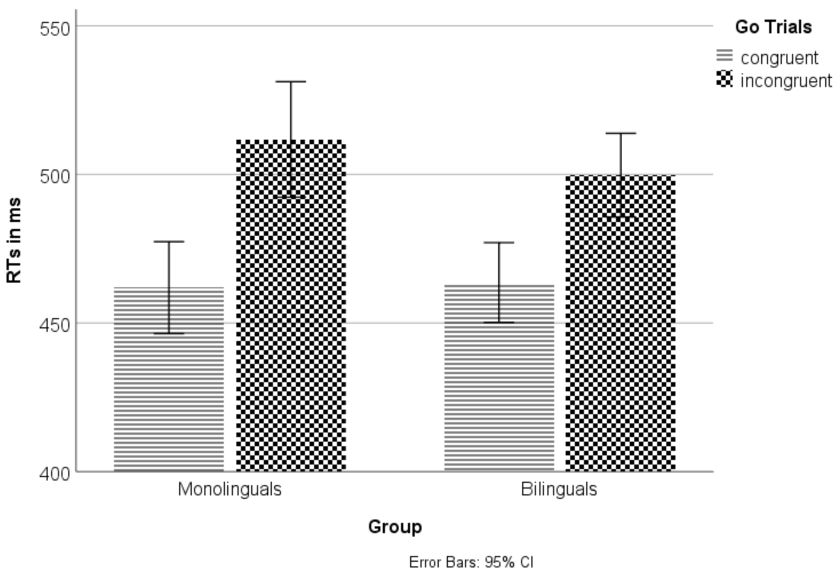

Figure 6 RTs in Go trials by grou