



Cognitive control in Russian–German bilinguals

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Bilingual speakers are faced with the problem to keep their languages apart, but do so with interindividually varying success. Cognitive control abilities might be an important factor to explain such interindividual differences. Here we compare two late, balanced and highly proficient bilingual groups (mean age 24 years, L1 Russian, L2 German) which were established according to their language control abilities on a bilingual picture-naming task. One group had difficulties to remain in the instructed target language and switched unintentionally to the non-target language (“switchers”), whereas the other group rarely switched unintentionally (“non-switchers”). This group-specific behavior could not be explained by language background, socio-cultural, or demographic variables. Rather, the non-switchers also demonstrated a faster and better performance on four cognitive control tests (Tower of Hanoi, Ruff Figural Fluency Test, Divided Attention, Go/Nogo). Here, we focus on two additional executive function tasks, the Wisconsin Card Sorting Test (WCST) and the Flanker task requiring conflict monitoring and conflict resolution. Non-switchers outperformed switchers with regard to speed and accuracy, and were better at finding and applying the correct rules in the WCST. Similarly, in the Flanker task non-switchers performed faster and better on conflict trials and had a higher correction rate following an error. Event-related potential recordings furthermore revealed a smaller error-related negativity in the non-switchers, taken as evidence for a more efficient self-monitoring system. We conclude that bilingual language performance, in particular switching behavior, is related to performance on cognitive control tasks. Better cognitive control, including conflict monitoring, results in decreased unintentional switching.

Keywords: Flanker task, ERN, Wisconsin Card Sorting Test, conflict monitoring, inhibition, late bilinguals, cognitive control, executive function

INTRODUCTION

The recent interest in the relation between bilingual language processing and non-linguistic control abilities has been fueled by research showing that bilinguals outperform monolinguals on tasks involving executive functions. These are often distinguished into three subdomains: inhibition, shifting of mental sets (also referred to as task switching or cognitive flexibility), and updating information in working memory (Miyake et al., 2000). Inhibition is necessary to resist distraction in order to stay focused on the currently relevant task or information. Inhibition thus enables us to perform goal-driven, task-relevant, and appropriate behavior (as regards social context, communication constraints, etc.). Set shifting refers to the ability to detach oneself from one task in order to turn to something else. It reflects the ability to adjust to changing demands, priorities, or information. In working memory we hold currently necessary important information and can constantly add more, newer information which might complete, replace, or change previous information.

The explanatory link between cognitive control and bilingualism is that early bilinguals have to constantly control interfering information from the two active and competing language systems which might train and enhance their cognitive control abilities (Martin-Rhee and Bialystok, 2008). Thus, it appears that

bilingualism taxes inhibitory control by requiring speakers to suppress one language when using another, cognitive flexibility by requiring speakers to switch between languages, and working memory by having to keep track of swift changes in multilingual communication, e.g., which language is most appropriate with whom.

Research in executive function abilities in relation to bilingualism is a rather new field with an interdisciplinary and multimethodological approach. Whereas mostly dichotomous groups such as balanced and unbalanced bilinguals (e.g., Vega and Fernandez, 2011) have been used in this research, individual differences have been largely neglected. Reiterer (2009) has listed a number of “factors that matter” in language acquisition and ultimate attainment of L2 proficiency, including biological, psychological, linguistic, and socio-cultural variables. Based on brain imaging studies, she concluded that brain organization is highly dependent on a number of these factors. For example, individual differences in response inhibition are correlated with differences in functional magnetic resonance imaging (fMRI) activation patterns related to inhibitory control (Garavan et al., 2006). Ye and Zhou (2008) grouped monolingual students according to their performance in a color–word Stroop task into readers with higher and lower control abilities, which were found to modulate the resolution of conflict

between sentential representations. Consequently, we suggest that individual differences in executive functions may also play a major role in bilingual language performance.

Children who acquire two languages early in life develop the ability to solve problems that contain conflicting or misleading cues better than their monolingual peers (Martin-Rhee and Bialystok, 2008). Carlson and Meltzoff (2008) examined three groups of kindergarten children. The bilingual group outperformed the monolingual and the English-language-learner group on a variety of conflict tasks. In a recent study in young Spanish undergraduate students (Costa et al., 2009) bilinguals responded generally faster across trial types during high conflict-monitoring conditions in the attention network task (ANT), but did not show an advantage on low conflict-monitoring conditions. In sum, bilinguals are better in “conflict” situations which require the ability to resolve interference among competing representations and thus parallel the situation in which two languages compete and create a conflict for selection in bilingual speech production.

The mechanisms of executive control responsible to resolve conflict in language tasks have been suggested to be similar to those engaged in other cognitive domains (for a review see Abutalebi and Green, 2007; Ye and Zhou, 2009). Bilinguals who frequently use both languages train conflict resolution constantly. Due to the parallel activation of both languages in bilinguals, conflict resolution seems to be inherent to “monolingual language mode” production (for the language mode model, see Grosjean, 1982), i.e., when only one of these languages is required for verbal output. As a consequence, bilinguals are more efficient in dealing with conflicting and distracting information also in other domains, e.g., incongruent flanking information or bivalent displays (see Bunge et al., 2002).

While an advantage on conflict trials can be accounted for by extensive training in resolving the conflict produced by incompatible competing representations or responses (Abutalebi and Green, 2007), the advantage on overall reaction time (RTs) found in many (but not all) bilingual studies can not, as many trials do not require conflict resolution. As an explanation, Costa et al. (2009) suggested that the bilinguals’ monitoring process also kicks in on congruent trials and is responsible for the RT advantage on these trials. According to models of bilingual language production, first, one of the two available language schemas needs to be selected (Green, 1998). Costa et al. (2009) suggested that the bilingual monitoring system controls for the continuous use of the initially selected language in further processing stages. This monitoring activity for production in the target language is only necessary in bilinguals but not in monolinguals and could account for the bilingual RT advantage. Lexical competition according to Costa et al. (2009) can be thought of as the bilinguals’ training stage for conflict resolution on conflict trials.

As a first step toward a more fine-grained look at the bilingual population we previously investigated individual differences in language control abilities (i.e., switching between languages on command) in a group of Russian–German bilinguals with high and balanced proficiency in both languages (Festman, 2011). Bilinguals were grouped according to their errors of cross-language

interference (CLI) on a bilingual picture-naming task. Those who switched – although not required – were called “switchers,” those who did not switch were called “non-switchers.” A number of additional executive function tasks (Tower of Hanoi, Ruff Figural Fluency Task, Divided Attention, Go/Nogo) taxed inhibition of irrelevant information, problem solving, planning efficiency, generative fluency, and self-monitoring (Festman et al., 2010). A strong relationship between language control abilities and executive functions could be established in that “switchers” performed worse on all executive function tests compared to “non-switchers.” This suggests that these groups may differ in their susceptibility to CLI because of individual differences in executive control functions. In Festman et al. (2010), we observed that non-switchers were significantly better able to produce correct responses in the verbal part of the WAIS, but not in the general performance part of the WAIS. Intelligence is thus not a likely candidate to explain between-group differences in all other cognitive tasks. We speculated that non-switchers were more efficient in suppressing irrelevant and conflicting information and thereby reduce response conflict earlier than in the course of switchers’ processing. This advantage might have helped to facilitate response selection and response execution. Some indications of a likely difference in these processes have been found in our earlier tasks already, as non-switchers showed better monitoring abilities in the Tower of Hanoi task (less errors) and in the Ruff Figural Fluency task (fewer perseverations).

To investigate conflict monitoring and conflict resolution more directly, the Wisconsin Card Sorting Test (WCST) and the Eriksen flanker task were employed in the current study. The WCST requires participants to select and apply rules in order to sort trivalent displays (color, shape, number are the three features that constitute each stimulus). More importantly, on every few trials the participant has to shift rules according to cues while on the remaining trials he has to stick to the same rule as used for the previous trial (similar to the required use of one language until language change is signaled). The WCST requires both, staying on a rule and shifting from one rule to another, and thus allows us to determine whether the results of the WCST parallel the groups’ language control abilities. Accordingly, if (a) switchers have difficulties to remain in the target language, because the non-target language continues to cause strong conflict with target language production, this should be paralleled by errors on trials when no rule change is necessary. Non-switchers were thus expected to be better in continuous rule application. If (b) switchers have difficulties to switch to the other language, because they have problems to inhibit the current target language in order to switch to the new target language, this should be paralleled by perseveration errors in the WCST (switch/shift to the new rule while inhibiting the former rule). As non-switchers previously demonstrated superior inhibitory control abilities (Festman et al., 2010), they were expected to show superior set shifting abilities resulting in faster and better performance.

The flanker task provided several measures of executive control and conflict monitoring. First, performance on conflict (“incongruent”) and no-conflict (“congruent”) trials was compared between the groups. Second, the number of errors as well as the number of corrected errors was assessed. If non-switchers

indeed have better conflict resolution abilities, we predicted less interference and hence faster performance on incongruent trials. Moreover, we expected higher correction rates for non-switchers than for switchers. The flanker task, while originally introduced for behavioral studies, has been used extensively in conjunction with event-related brain potentials (ERP) and fMRI over the past 10 years. In the ERP, an “error-related negativity” (ERN; Gehring et al., 1993) emerges in the response-locked averages which is generated when participants make errors. The ERN peaks around 50–80 ms post-error and has a frontocentral maximum. It has been interpreted as an on-line index of performance monitoring and has been related to response conflict (Swick and Turken, 2002).

MATERIALS AND METHODS

PARTICIPANTS

This study had been approved by the ethics committee of the Otto-von-Guericke University, Magdeburg, the affiliation of the authors at the time of the experiment, and was performed in accordance with the 1964 Declaration of Helsinki. Informed consent was obtained from every participant, and participants were paid for their participation. **Table 1** summarizes the characteristics of the switcher and non-switcher group which had been established based on their language control as described in the introduction.

WISCONSIN CARD SORTING TEST

The WCST requires to apply rules continuously, to perform organized search, as well as to shift cognitive sets (rule changes) and to use feedback from the environment (Spreeen and Strauss, 1998). We used a simplified computer version of the WCST developed

by Barceló et al. (2002) which was presented using Presentation software¹.

The trial structure is depicted in **Figure 1**. Participants were instructed to respond as quickly and as accurately as possible. After training for 6 rule changes (1 rule change after 5–7 trials), participants were asked to complete 3 blocks of 12 rule changes each with the possibility to rest between blocks.

Trials were analyzed according to their position in the run. We distinguished trials immediately following a “change-rule-sound.” According to Barceló et al. (2002), these are three-dimensional shift trials (3D) during which participants have to handle three rules in working memory (i.e., inhibit the previous rule and consider the other two rules for responding). On the first trial after a rule change signal, the participant had a 50% chance of choosing an incorrect rule provided that he remembered the previous and thus irrelevant rule. If the participant chose the correct rule, he received positive feedback and had to continue with this rule until the next rule-change signal. The following trials would then be considered trials of the “subblock.” If the first choice after the rule-change signal was wrong, negative feedback was given. After having discarded one of the three rules in the 3D-trial, only two rules had to be dealt with on two-dimensional shift trials (2D), i.e., the incorrect rule had to be inhibited and the only remaining option had to be selected and applied until the next change signal. This is a very efficient trial-and-error process in normal subjects, who can

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Table 1 | Participant information.

| | Switcher | Non-switcher |
|----------------------------------|-----------------------|-----------------------|
| <i>N</i> | 13 | 16 |
| Gender | 11 women, 2 men | 10 women, 6 men |
| Mean age | 26 (6.7) | 23 (3.1) |
| Main languages | L1 Russian, L2 German | L1 Russian, L2 German |
| Age at acquisition of L2 | 13 (8.1) | 11 (4.1) |
| In Germany since | 8 years | 10 years |
| Language proficiency | Same in L1 and L2 | Same in L1 and L2 |
| RT Russian non-sw trials | 1174 ms (201) | 1081 ms (144) |
| RT German non-sw trials | 1164 ms (125) | 1093 ms (139) |
| WAIS-picture completion, correct | 14.4 (1.6) | 15.1 (1.3) |
| WAIS-block design, points | 35.4 (9.6) | 38.1 (7.9) |
| Language control ability | Weak | Strong |
| Bilingual interview, no. of CLI | 11.4 (10.6) | 3.4 (4.7)** |
| Cognitive control ability | Weak | Strong |
| ToH moves | 43.8 (11.7) | 29.3 (12.8)** |
| ToH errors | 515 (684) | 119 (172)* |

WAIS, Wechsler Adult Intelligence Scale; RT, reaction time, CLI, cross-language interference; ToH, Tower of Hanoi; significant differences between groups are indicated by an asterisk with ** $p < 0.01$, and * $p < 0.05$.

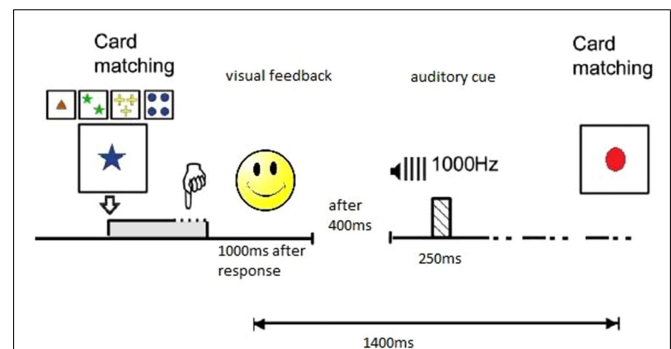


FIGURE 1 | Example trial: After fixation (1000–1700 ms) four cards were presented in one line in the center of a computer screen. Below this display, one larger card (e.g., one blue star) was shown. This critical card had to be sorted according to color, shape, or number and was presented until response was given. Response buttons were assigned in the following way: In the case of the blue-star-card, the number key “1” (depicting one red triangle) should be used to indicate the number rule, “2” (two green stars) to sort it according to the shape rule, “3” (three yellow crosses) would in this case not offer any sorting rule, and “4” (four blue circles) to sort according to the color information. Every critical card differed in color, shape, and number from the previously presented critical cards. One of two different feedback signs (happy or sad “smiley” icons) followed 1000 ms after the response. On all non-rule-change trials an auditory cue of 1000 Hz was presented (“use-the-same-rule-sound”). A new card to be sorted was displayed at 1400 ms after visual feedback. The rule to be applied changed after five to seven trials (e.g., from “sort according to color” to “sort according to shape”). Rule change was indicated by a “change-rule-sound” (500 Hz, 400 ms after the visual feedback, lasting for 250 ms), and participants had to find the correct new rule by trial-and-error.

use past contextual information to optimize set shifting (Barceló et al., 2002).

FLANKER EXPERIMENT

The flanker task (Eriksen and Eriksen, 1974) requires responding to the center letter of a five letter array with either a left-hand (for letter H) or right-hand response (letter S). Additional letters flanking the target letter either favored the target response (congruent trials, HHHHH or SSSSS) or primed the other response (incongruent trials, HHSHH or SSHSS). To increase the number of errors produced 60% of the trials were incongruent. Each stimulus array subtended about 2.5° of visual angle in width, and a fixation cross was presented in the middle of the computer monitor just below the target letter in the array (using Presentation, Neurobehavioral Systems). Each stimulus was presented for 100 ms and a stimulus-onset-asynchrony of 900 ms was used. Letter/hand assignments were counterbalanced between subjects and maintained in both sessions. Prior to the experiment, participants were trained in a short session of 6 blocks of 40 trials each to reach a RT baseline level and were given feedback about their performance. The goal of this procedure was to aim for a reaction time that would yield approximately 10% of errors. The experiment proper consisted of 20 blocks of 200 stimuli each. A 30-s rest period was allowed between blocks. Subjects were required to respond to the stimuli as fast as possible and to correct their errors as fast as possible whenever they detected them.

The electroencephalogram was recorded from 29 tin electrodes mounted in an electro cap against a reference electrode placed on the left mastoid process. Biosignals were re-referenced off-line to the mean of the activity at the two mastoid processes. Blinks and vertical eye movements were monitored with electrodes placed at the sub and supraorbital ridge of the left eye. Lateral eye movements were monitored by a bipolar montage using two electrodes placed on the right and left external canthus. Eye movements were recorded in order to allow for later off-line rejection, which was carried out by a computer program based on an amplitude criterion (75 μ V). All electrode impedances were kept below 4 k Ω . Electrophysiological signals were amplified with a band-pass filter of 0.01–50 Hz and digitized at a rate of 250 Hz (4 ms resolution). Data were analyzed using the Event-Related Potential Software System (ERPSS)².

RESULTS

WISCONSIN CARD SORTING TEST

Response times showed a gradual speed-up from 3D to 2D trials to subblock trials (see **Figure 2**). Group differences were significant on all trial positions with non-switchers being faster (for 3D $U = 48.0$, $p = 0.006$; for 2D $U = 65.0$, $p = 0.0425$; for subbl. $U = 50.0$, $p = 0.008$).

Switchers committed significantly more errors than non-switchers (**Table 2**) with the majority of their errors occurring for subblock stimuli.

FLANKER TASK

The typical general pattern of results was obtained with more errors [$t(28) = -6.631$, $p < 0.0001$], and slower responses

[$t(28) = -7.983$, $p < 0.0001$] on incongruent trials. Importantly, switchers showed a greater interference effect for incongruent stimuli, evidenced by a slower response time for the type of stimulus but not for congruent stimuli (**Table 3**). Moreover, switchers corrected their errors significantly less often than non-switchers, indicating worse self-monitoring abilities. There were no group differences for overall accuracy.

Response-locked averages revealed a typical ERN for the error trials peaking at about 70 ms (**Figure 3**), which was larger in switchers.

The ERN was quantified by a mean amplitude measure (time-window 0–100 ms) which was analyzed by ANOVA. A highly significant main effect was obtained for response type [$F(1, 24) = 31.5$, $p < 0.001$] as well as an interaction between group and response type [$F(1, 24) = 11.6$, $p < 0.001$]. *Post hoc* analyses revealed that this interaction was driven by the smaller ERN to errors in the non-switchers ($p < 0.05$).

DISCUSSION

WISCONSIN CARD SORTING TASK

While both groups had an overall good performance, switchers were slower, and committed more errors with most errors occurring for subblock trials. This suggests that switchers have

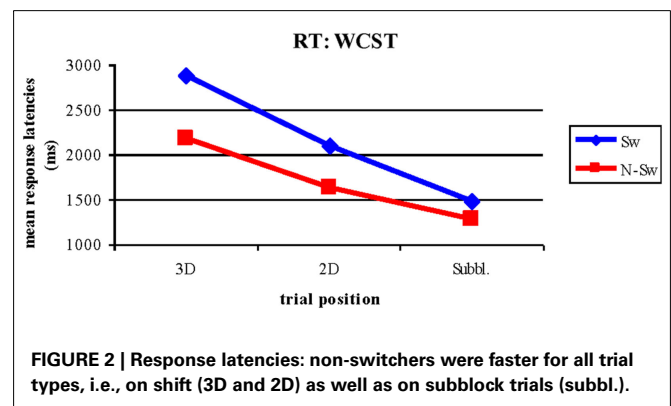


FIGURE 2 | Response latencies: non-switchers were faster for all trial types, i.e., on shift (3D and 2D) as well as on subblock trials (subbl.).

Table 2 | Wisconsin Card Sorting Test: error rate in percent.

| | Switcher | Non-switcher | Statistics |
|-----------------|-------------|--------------|-------------------------|
| All errors | 5.6% (18.4) | 2.0% (3.8) | $U = 66.5$; $p < 0.05$ |
| Subblock errors | 3.8% (14.1) | 1.0% (2.2) | $U = 62.0$; $p < 0.05$ |

Table 3 | Behavioral data of the Flanker experiment (SDs in brackets).

| | Switcher | Non-switcher | Statistics |
|-------------------|--------------|--------------|-----------------------------------|
| Correct responses | 77% (11.7) | 80% (9.5) | $T(27) = -0.775$; $p = 0.225$ |
| Correction rate | 65% (11.6) | 78% (7.8) | $t(27) = 1.805$; $p < 0.05$ |
| RT congr trials | 708 ms (79) | 707 ms (85) | $t(27) = -0.020$; $p = 0.984$ |
| RT incongr trials | 995 ms (107) | 863 ms (118) | $t(27) = -3.104$; $p < 0.01$ |

²<http://sdepl.ucsd.edu/erpss/>

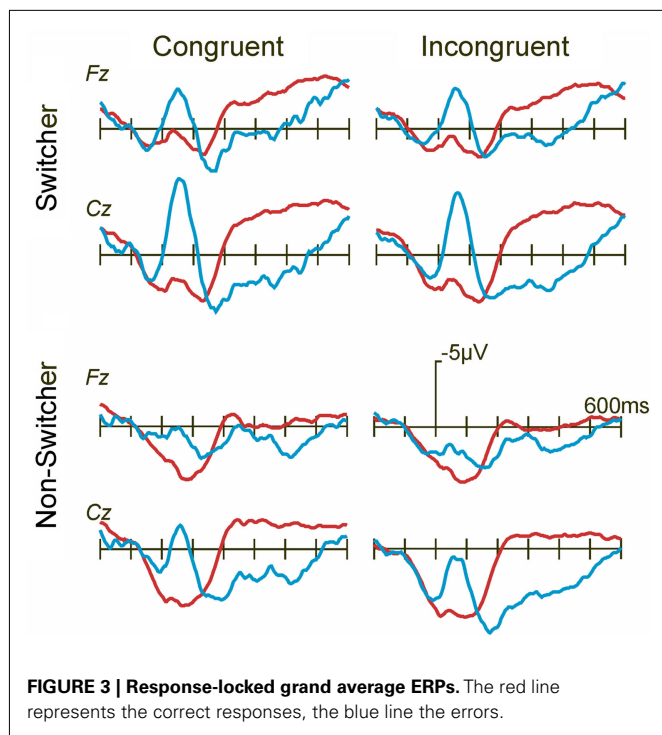


FIGURE 3 | Response-locked grand average ERPs. The red line represents the correct responses, the blue line the errors.

difficulties in maintaining a task set and inadvertently switched to a currently invalid rule.

Bialystok and Martin (2004) and Martin-Rhee and Bialystok (2008) found that bilingual children were better able to shift from one rule (dimension) to the other than monolingual peers on the dimensional change task, which is similar to the WCST. These bilingual children demonstrated an advantage in shifting mental sets, whereas the difference between switchers and non-switchers of the current study emerged mainly during the maintenance of task set which was impaired in the switchers. Vega and Fernandez (2011) recently reported that more balanced bilingual children (with respect to language use) made significantly fewer perseveration errors on the WCST than less balanced children, indicating an advantage in set shifting for the former group. While this suggests a disadvantage of monolingual or less balanced bilingual participants in the inhibition of irrelevant task sets, data from Linck et al. (2008) in L2 Spanish adult learners and proficient Spanish–English and Japanese–English bilinguals revealed that higher language proficiency did not correlate with superior inhibitory abilities as measured by the Simon task.

In contrast to these studies, we measured performance of high proficiency balanced adult bilinguals. The inadvertent rule change in switchers suggests a general problem in this group. While the switcher group has no difficulty in changing from one task set (or one language) to the other, problems emerge in the form of unintentional switches. Thus, we suggest that the switcher group has an increased susceptibility to interference in general.

ERIKSEN FLANKER TASK

Switchers showed a greater susceptibility to interfering information, evidenced in slower response times for incongruent trials, as

well as less efficient performance monitoring, evidenced by lower error correction rates.

The ERN is often viewed as an index of the activity of a response monitoring system either in the sense of an error detection mechanism (Falkenstein et al., 1991) or in the sense of a response conflict-monitoring mechanism (Botvinick et al., 2001; Yeung et al., 2004). The latter account proposes that it reflects the degree of conflict between simultaneously activated response tendencies. Following this reasoning, the reduced ERN in the non-switcher group should correspond to less response conflict. This, however, is at odds with the superior correction performance which must be based on a more efficient detection of errors in the non-switchers. Previous research in other cognitive domains has suggested that more efficient processes might be associated with less neural activity (e.g., Hund-Georgiadis and von Cramon, 1999). Thus, one might speculate that the reduced ERN amplitude in non-switchers might reflect more efficient response monitoring mechanisms. This notion, while in line with the behavioral pattern, needs to be substantiated by further research.

GENERAL DISCUSSION

In this paper we asked whether late bilinguals differing in language control also show differences in tasks taxing executive control functions. Such differences would support the notion that language control in bilinguals, in particular with respect to unintentional switching between languages, is related to generic executive control capabilities. Indeed, robust group differences were revealed in the WCST and the flanker task.

Non-switchers demonstrated superior inhibitory control and better set shifting abilities (faster performance, fewer perseveration errors) in the WCST. Switchers had difficulties with continuous rule application, providing evidence for a deficient shielding of the appropriate task set against interfering task sets. This is very similar to their deficient shielding of the appropriate language against interference from the non-target language.

In the flanker task non-switchers revealed superior interference control with faster performance on incongruent trials as well as a higher correction rate following an error. Together with the reduced ERN component in the ERP this is evidence for more efficient conflict and self-monitoring.

Relevant to our study is Friedman and Miyake's (2004) distinction between *Resistance to Distractor Interference* and *Resistance to Proactive Interference*. The first denotes the ability to resist interference of information from the environment irrelevant for the task (such as flanking letters in the flanker task), whereas the second describes the ability to resist intrusions of information which was relevant for a previous task/trial, but is irrelevant on the current task/trial (such as the former sorting rules in the WCST). Interestingly, our non-switcher group showed advantages in both types of resistance to interference.

The contrast between *transient and sustained control processes* (e.g., Wang et al., 2009) has been used to interpret the findings of a bilingual task switching study by Prior and MacWhinney (2010). Transient control processes are relevant for controlling single trials or stimuli, whereas sustained control processes are engaged for a longer period of time to provide state-related activation

(Braver et al., 2003). Prior and MacWhinney observed that a group of bilingual students showed advantages in transient, but not in sustained control processes when compared to monolingual students performing on a shape-and-color-decision task switching paradigm. Bilinguals showed enhanced efficiency in the executive function of shifting between mental sets such as shape decision and color decision. The WCST data of the current study showed that switchers had difficulties in resisting distractor interference, i.e., to keep on using the same rule, most likely explained by their susceptibility to interference in general (Festman et al., 2010). In the framework of Wang et al. (2009) this points to difficulties in sustained control processes. At the same time, switchers were slower and less accurate in choosing the correct rule, implying difficulties with mental shift as well, which, in more general terms, might be interpreted as a difficulty in transient control processes.

Colzato et al. (2008) made a difference between *active inhibition* (in order to exclude particular information from processing) and *reactive inhibition* (in order to exclude particular information after it has been already activated) and reasoned that bilinguals outperform monolinguals by building up and

maintaining goal representations more efficiently. Also they seem to map these representations more efficiently onto top-down mechanisms of goal-relevant processes. Whereas Christoffels et al. (2007) did not find the expected asymmetric switch costs for low proficient L2 speakers in German–Dutch bilinguals, the differences between switchers and non-switchers in the current study might well be explained in terms of the active–reactive inhibition distinction. In this framework, switchers might engage in a reactive-inhibition-approach, while non-switchers might rely more on active-inhibition processing. More research on group comparisons of multilinguals and on individual differences with respect to language control are needed to further pinpoint the relationship between executive control and language control in bilingualism.

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