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# Task strategy may contribute to performance differences between monolinguals and bilinguals in cognitive control tasks: ERP evidence

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ABSTRACT

A bilingual advantage in the efficiency of executive control in young adults has been demonstrated in many but not all studies. We aimed to test the efficiency of executive control in a lateralized version of the Attentional Network Task and to investigate accompanying ERP components. The performance of young adult bilinguals who acquired their L2 relatively late but were balanced in proficiency and daily usage of L1 and L2 was compared with that of young adults who reported low proficiency and marginal daily usage of L2. Balanced bilinguals were more accurate in the incongruent condition and at the same time as fast as the control group across conditions. Interestingly, in comparison to the control group, the bilingual group demonstrated more enhanced response-locked negativities to both incorrect (ERN) and correct responses (CRN). The obtained pattern of results suggests that the groups may have differed in terms of task strategies. Bilinguals may have controlled their performance more effectively, which resulted in their better conflict resolution, as compared to the control group. In conclusion, we point to the importance of considering qualitative differences in task processing and strategy while studying group differences - an approach rarely considered in current research on executive functions in bilinguals.

## 1. Introduction

In recent years, the hypothesis that bilingualism may enhance executive control has been highly disputed. The superior performance of bilinguals in tasks measuring executive control has been reported across many, but not all studies (e.g. see Paap, Johnson, & Sawi, 2015; Valian, 2015; for a recent discussion on this topic). This lack of consistency in the literature generates a need for more refined questions about the exact nature of the potential benefit of bilingualism and leads to the formulation of new hypotheses about the interaction between specific language experience and executive control (e.g. Dong & Zhong, 2017; Green & Abutalebi, 2013).

A bilingual advantage in the efficiency of executive control has been found in children (Bialystok & Martin, 2004), adults (Bialystok and Craik et al., 2005; Costa, Hernández, & Sebastián-Gallés, 2008) and the elderly (Bialystok, Craik, Klein, &

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Viswanathan, 2004; Wodniecka, Craik, Luo, & Bialystok, 2010). However, the magnitude of the effect substantially varies across different age groups (Bialystok, Martin, & Viswanathan, 2005). In the present paper, we focused on young adults for whom results have been especially inconsistent. While some studies have reported a bilingual advantage in this age group (e.g. Costa et al., 2008; Marzecová, Asanowicz, Krivá, & Wodniecka, 2013), others have failed to observe this effect (e.g. Kousaie & Phillips, 2012). A meta-analysis conducted by Donnelly, Brooks, and Homer (2015) revealed that a bilingual advantage in young adults is the hardest to observe and replicate. Following the developmental trajectory of executive control, it has been proposed that cognitive benefits in young adult bilinguals may not be observable because young adults are at the peak of their cognitive abilities and, thus, may not show any additional benefits of being bilingual (e.g. Bialystok & Barac, 2012).

Investigations of young adults are further complicated by the fact that various experimental paradigms have been used to examine the cognitive consequences of bilingualism. Since different experimental paradigms may tap into functionally different components of executive control (see Marzecová, 2015; Paap et al., 2015; for a discussion), it is often hard to disentangle the sources of discrepancy in results across studies. In this paper, we focus on the task that has been used in several previous studies on the cognitive consequences of bilingualism in young adults: The Attentional Network Task (ANT; Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Costa et al., 2008).

The ANT allows for a reliable assessment of the efficiency of the three attentional networks (alerting, orienting, and executive) that subserve three different functions (maintenance of alertness, orienting, and executive control; Fan, McCandliss, Sommer, Raz, & Posner, 2002, and see MacLeod et al., 2010, for a detailed analysis of psychometric properties of the ANT). In the ANT, participants are asked to resolve a classical flanker conflict: identify the target stimulus while ignoring the flanking stimuli. The flanking stimuli may be the same as the target (congruent condition; e.g. → → → → →) or different (incongruent condition; e.g. → → ← → →). Incongruent trials lead to slower reaction times and less accurate responses, presumably because the flanking stimuli and the target are associated with different responses. In order to respond correctly, participants must resolve this conflict. Within the ANT, difference in performance between the incongruent and the congruent condition is assumed to reflect efficiency of executive control (Fan et al., 2002); for this reason, this task has been often employed in studies on bilingualism. Although the task has also been used to study younger populations (e.g. Antón et al., 2014), below we summarize only the results concerning young adults to allow direct comparison with the current study.

In two ANT studies conducted by Costa et al. (2009, 2008), young adult Catalan–Spanish bilinguals who acquired their second language (L2) early were compared with young Spanish functional monolinguals. In the first study (Costa et al., 2008), faster reaction times (RT) of bilinguals in the incongruent condition were interpreted as reflecting more efficient executive control in young bilinguals. In the second study (Costa et al., 2009), this effect was observed only in a more difficult version of the task (i.e. a high monitoring version of the ANT in which only 25% of trials were incongruent; Experiment 2).

The bilingual advantage in the efficiency of executive control in young adults has also been investigated in studies that employed a lateralized version of the ANT (LANT; Marzecová, Asanowicz et al., 2013; Marzecová, Bukowski et al., 2013; Tao, Marzecová, Taft, Asanowicz, & Wodniecka, 2011). The LANT appears to impose a greater conflict than the classic ANT due to its peripheral presentation of stimuli (see Asanowicz, Marzecová, Jaśkowski, & Wolski, 2012; Tao et al., 2011; for justification). In the study conducted by Tao et al. (2011), three groups of young adults were compared: English monolinguals and both early and late Chinese–English bilinguals. Both late and early bilinguals revealed more efficient executive control in RT compared to monolinguals, but the late bilinguals (who were also more balanced in the proficiency and use of L1 and the L2) were significantly more efficient in RT than the early bilinguals. Additionally, late bilinguals showed more efficient executive control in their accuracy, whereas no difference in the accuracy measure was reported between the early bilinguals and monolinguals. In the other study conducted by Marzecová, Asanowicz et al. (2013), Marzecová, Bukowski et al. (2013), Polish monolinguals were compared to early bilinguals who were speakers of different Slavic languages; the bilinguals were found to have more efficient executive control in RT and, marginally, in accuracy, as compared to monolinguals.

The peripheral presentation of stimuli in the LANT not only increases the difficulty of the task, but also allows the interhemispheric organization of executive control to be examined. Several previous studies have indicated that bilinguals reveal reduced hemispheric asymmetry for both verbal (Dehaene et al., 1997; Moreno, Bialystok, Wodniecka, & Alain, 2010) and non-verbal cognitive functions (Hausmann, Durmusoglu, Yazgan, & Gunturkun, 2004). In particular, studies that employed the LANT (i.e. Marzecová, Asanowicz et al., 2013; Marzecová, Bukowski et al., 2013; Tao et al., 2011; described above) have indicated that bilingualism may reduce right hemisphere (left visual field; LVF) dominance for stimuli processing. In the study conducted by Marzecová, Asanowicz et al. (2013), Marzecová, Bukowski et al. (2013), monolinguals revealed right hemisphere dominance for incongruent targets in accuracy, while early bilinguals showed no asymmetry in either of the task conditions. In the study conducted by Tao et al. (2011), both monolinguals and late bilinguals revealed right hemisphere dominance in RT, while early bilinguals showed a strong trend towards reduced hemispheric asymmetry in RT. Based on a comparison of late and early bilinguals, Tao et al. (2011) suggested that early experience in L2 might be especially important for the reduction of right hemisphere dominance. The participants in the study of Marzecová, Asanowicz et al. (2013), Marzecová, Bukowski et al. (2013) were early, relatively balanced young adult bilinguals who used languages that are typologically similar to each other (mostly Czech–Slovak). In contrast, Tao et al. (2011) tested early and late, less balanced young adult bilinguals who used two typologically distinct languages. It remains an open question whether similar effects could be observed in young adult bilinguals with relatively late exposure to two typologically similar languages.

The aim of the current study was to investigate the efficiency of executive control in young bilingual adults using a modified LANT. We tested a group of young adults who acquired their L2 (Polish) relatively late and were balanced in terms of their proficiency and daily usage of L1 and L2 (bilingual group). Performance of bilinguals was compared with that of native speakers of Polish who reported low L2 (English) proficiency and, critically, a marginal daily use of their L2 (control group). Since the bilingual group and the control group were demographically matched but substantially differed in their L2 experience and usage, we expected to find an executive control advantage in the bilingual group. In particular, based on previous findings we expected that the bilingual group, relative to the control group, would reveal better accuracy and faster RT overall and in the incongruent condition in particular. The behavioural measures were accompanied by measurement of event-related potentials (ERPs) to monitor the dynamics of the neural processes that underlie executive control mechanisms. To the best of our knowledge, none of the previous studies investigated executive control of bilinguals by combining the ANT with ERP measurement. However, previous ERP studies on the cognitive consequences of bilingualism that employed other executive control tasks (e.g. flanker task, Stroop task, go/no-go task) have offered some insights into how ERPs in the LANT may be modulated by bilingual experience. Previous research suggests four ERP components regarded as neural indices of executive control efficiency. Two of them are sensitive to manipulation of congruency (N2 and P3b), while the latter two components are sensitive to response accuracy (Error-Related Negativity and Pe).

The N2 is a fronto-central negativity occurring 200–350 m s after stimulus onset and is thought to be generated in the anterior cingulate cortex (ACC; see Folstein & Van Petten, 2008; for a review). Within the flanker paradigm, a larger (i.e. more negative) N2 amplitude for incongruent trials relative to N2 amplitude for congruent trials is assumed to reflect inhibition of incorrect response induced by the incongruent flanking stimuli (Folstein & Van Petten, 2008). Previous ERP studies have brought discrepant evidence for modulation of the N2 component by a bilingual experience. While several studies have demonstrated a larger N2 component in bilinguals (e.g. Barac, Moreno, & Bialystok, 2016; Fernandez, Tartar, Padron, & Acosta, 2013), others have shown a smaller N2 in bilinguals (e.g. Kousaie & Phillips, 2012; Zhang, Kang, Wu, Ma, & Guo, 2015). Due to these contradictory results, we decided to formulate predictions concerning the N2 component on the basis of the conflict monitoring theory *per se*, rather than on previous research related to bilingualism. According to the theory, the N2 component reflects the effort put into inhibiting an incorrect response. On these grounds, a smaller N2 component is assumed to reflect more efficient inhibition (Folstein & Van Petten, 2008; Grundy, Anderson, & Bialystok, 2017; Lamm, Zelazo, & Lewis, 2006; Paap et al., 2015). We expected that enhanced performance of bilinguals in the present study would be accompanied by a smaller N2 component.

The P3b is a broad positivity with a centro-parietal distribution that occurs around 200–500 ms after the target (Polich, 2007). Previous studies that combined the ANT with ERP measurement consistently reported the P3b with a larger (i.e. more positive) amplitude for congruent relative to incongruent trials (i.e. Galvao-Carmona et al., 2014; Neuhaus et al., 2010; Williams et al., 2016).[2] In these studies, the P3b is assumed to reflect the cognitive resources engaged in stimulus evaluation. In the field of research on bilingualism, Dong and Zhong (2017) recently combined a flanker task with ERP measurement and reported a larger P3b component (with more positive amplitude for congruent relative to incongruent trials) for participants with more intense experience in L2. The larger P3b in the group with more intense experience in L2 was then interpreted as reflecting better efficiency of executive control involved in conflict monitoring and/or interference suppression (see Dong & Zhong, 2017; for a detailed discussion of an argument). In line with the study of Dong & Zhong, we expected a larger P3b component in bilinguals relative to the control group.

The Error-Related Negativity (ERN) is a fronto-central negativity that starts at, or shortly before, an incorrect response and peaks 100 ms later (e.g., Falkenstein, Hohnsbein, Hoormann, & Blanke, 1990, 1991; Gehring, Goss, Coles, Meyer, & Donchin, 1993). The ERN is assumed to reflect error detection which is a result of a comparison between actual and required response (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000) or the magnitude of conflict between multiple simultaneously active response tendencies (Botvinick, Braver, Barch, Carter, & Cohen, 2001). The ERN, as with N2, is thought to be generated in the ACC (Gehring, Liu, Orr, & Carp, 2012, pp. 231–291). The ACC has been also assumed to reflect differential functional activation in bilinguals compared to monolinguals (Grundy et al., 2017), which additionally motivates investigation of the ERN and the N2 components in the context of the cognitive consequences of bilingualism. To the best of our knowledge, only two studies have examined the ERN in the context of the cognitive consequences of bilingualism (i.e. Kousaie & Phillips, 2012; Morales, Yudes, Gómez-Ariza, & Bajo, 2015). Firstly, Kousaie and Phillips reported a smaller ERN in bilinguals than monolinguals during the Stroop task. Secondly, Morales et al. have shown a smaller ERN in bilinguals than monolinguals using the AX-CPT. The authors of both of these studies proposed that bilinguals have more training in error detection, which improves their executive control and is reflected in the smaller ERN component. In line with previous studies, we expected a smaller ERN component in the bilingual group relative to the control group.

Correct-Related Negativity (CRN) is response-related negativity following correct responses that occurs within the same time window and scalp distribution as the ERN (Ford, 1999; Vidal, Burle, Bonnet, Grapperon, & Hasbroucq, 2003; Vidal, Hasbroucq, Grapperon, & Bonnet, 2000). It is usually assumed to reflect reduced certainty about the correctness of the actual response (Pailing & Segalowitz, 2004; Scheffers & Coles, 2000). It has been proposed that the modulation of both the ERN and the CRN might reflect the response evaluation process, leading to error detection (Vidal et al., 2000) or the need to adjust task performance strategy (Bartholow et al., 2005). To the best of our knowledge, no prior studies in the field of research on bilingualism have investigated the CRN. However, observation of this component seems to give additional information about the response evaluation process and for this reason we investigated the CRN along with the ERN in our study.

The ERN is often followed by a positive deflection with a centro-parietal distribution that occurs around 200–500 ms after an incorrect response; this is known as error positivity (Pe; Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Falkenstein, Koshlykova, Kiroj, Hoormann, & Hohnsbein, 1995). The Pe is assumed to reflect participants' error awareness (Endrass, Reuter, & Kathmann, 2007; Nieuwenhuis, Ridderinkhof, Blow, Band, & Kok, 2001). Therefore, a larger Pe component is associated with a better ability to self-evaluate cognitive performance. We can find no studies that investigated the Pe component in the field of research on

[2] However, Williams et al. (2016) observed this effect for older participants only.

bilingualism. However, since the Pe component usually accompanies the ERN in executive control tasks, we also explore this component in our study. It could be hypothesized that a bilingual advantage in implementing executive control entails improved ability to self-evaluate performance, reflected in the larger Pe component in bilinguals, relative to control participants. However, given that a recent study by Folke, Ouzia, Bright, De Martino, and Filippi (2016) suggests that bilinguals may have less of this metacognitive ability, we made no directional hypotheses concerning the Pe component and the bilingual advantage.

To summarize, in this report we focus on the efficiency of executive control in a group of young adult bilinguals who acquired their L2 relatively late and were balanced in terms of their proficiency and daily usage of L1 and L2. For the RT and accuracy measures, we predicted that more efficient executive control of bilinguals would be reflected in their higher accuracy and faster RT, especially in the incongruent condition, as compared to the control group. For the ERP measures, we predicted that enhanced performance of bilinguals would be accompanied by smaller N2 and ERN, and a larger P3b components.

## 2. Methods

### 2.1. Participants

In total, 42 female participants took part in the study. One participant was excluded from further analyses due to both poor accuracy in the main task (near chance accuracy in the LANT) and low score in the intelligence test (2 out of 18 in a shortened version of Raven's Advanced Progressive Matrices test, sRAPM[3]). Additionally, 7 participants had to be excluded from the analyses due to excessive artefacts in the EEG recordings; 3 were excluded due to an insufficient number of incorrect trials for the ERN analysis. In total, 31 participants (16 bilinguals, 15 participants in the control group) were included in the reported analyses. All participants were right-handed[4] and matched with respect to age, IQ (measured by sRAPM), completed years of education, and daily computer use.

A Language History and Background Questionnaire (based on Li, Sepanski, & Zhao, 2006) was employed to collect information on participants' language experience. The questionnaire consisted of a set of questions about the age of exposure, daily use and proficiency in the first (L1), second (L2) and third (L3) language. Participants self-assessed their proficiency in each language in four domains (reading, speaking, and writing) using the following scale: 1 = very poor, 2 = poor, 3 = fair, 4 = functional, 5 = good, 6 = very good, 7 = native-like. Overall proficiency in each language was then calculated as a mean of scores for all domains. Table 1 presents demographic and language characteristics of participants.

The bilingual participants were recruited via the mailing list of an organization for Eastern European students living in Kraków. All the participants were students or graduates of Polish universities. The participants were born and grew up in one of the following countries: Belarus, Ukraine, Russia, Kazakhstan, Lithuania, or Latvia. All the bilingual participants reported language experience in L1, L2 and L3. For most of them, L1 was Russian (Ukrainian was L1 for 3 participants, while for 3 participants it was Polish), while L2 was Polish (for two participants L2 was Lithuanian, for one L2 was Latvian). Although bilingual participants acquired L2 relatively late (mean age = 13.47), they did not differ in proficiency and daily use of L1 and L2 ($ps > 0.05$). For most of the participants, L3 was English, for others it was German (N = 1) or another Slavic language (Ukrainian, N = 2; Belarusian, N = 2; Russian, N = 1; Lithuanian, N = 1). Although bilingual participants were exposed to L3 earlier (mean age = 7.00) than to L2 and they assessed their proficiency in L3 as good (mean score = 5.17), they barely used L3 on a daily basis (9% of language daily use). For this reason, we use the term "bilinguals" when referring to this group of participants.

Participants for the control group were recruited mainly through a database at the Institute of Psychology in Kraków. All participants were native Polish speakers, born and raised in Poland. All of them reported some experience in L2 (English, N = 14; German, N = 1). Five participants reported also knowledge of L3 (German, N = 1; English, N = 1; Italian, N = 1; French, N = 1; Russian, N = 1). They were exposed to L2 and L3 relatively late in their lives (mean age = 9.17 and 14.80, respectively) and reported a rather low proficiency in L2 and poor proficiency in L3 (mean scores: 3.42 and 2.20, respectively). Based on the proficiency measure, they could be regarded as low-proficient bilinguals; however, their experience in L2 was constrained to foreign language courses taken at school and they reported marginal daily use of L2 (3%). Given that an interaction between language proficiency and usage is considered as a critical factor determining identification of an individual as a monolingual or bilingual (Bialystok & Hakuta, 1994; Fishman & Cooper, 1969; Hakuta, Bialystok, & Wiley, 2003; Luk & Bialystok, 2013), it could be also argued that this group of participants was actually close to being functionally monolingual. Given the controversies about how to match monolingual and bilingual participants (Luk & Bialystok, 2013), we take a neutral stance between these two options and use the term "control group" for the purpose of this study. Critically, given that both groups of participants significantly differ in their L2 proficiency and daily L2 usage in particular (see Table 1), the expectation of the executive control advantage in the bilingual vs. control group seemed justified.

[3] A shortened version of Raven's Advanced Progressive Matrices test (sRAPM) was used to measure participants' fluid intelligence; see Marzecová, Asanowicz et al., 2013, Marzecová, Bukowski et al., 2013, for a detailed description and rationale.

[4] As measured by the Edinburgh Handedness Inventory; see Oldfield, 1971, for a detailed description.

**Table 1**
Background information about participants and their language knowledge, self-report measures of language proficiency, and language use. Statistically significant effects of between-group comparison are marked by asterisks.

| | Bilingual | Control | p |
|---|---|---|---|
| *Background information* | $N = 16$ | $N = 15$ | |
| Age (in years) | 23.03 (3.14) | 21.46 (1.37) | ns |
| Education (in years) | 14 (3.01) | 14.17 (1.80) | ns |
| Handedness (LQ) | 66.96 (42.66) | 51.55 (56.49) | ns |
| IQ score (RAPM, 0–18) | 11.56 (3.31) | 12.69 (3.82) | ns |
| Computer (hours/day) | 6.84 (3.71) | 5.23 (2.69) | ns |
| *Language experience: L1* | $N = 16$ | $N = 15$ | |
| Age of exposure (in years) | 0.00 | 0.00 | ns |
| Percentage of daily use (%) | 40% (25%) | 97% (5%) | *** |
| Proficiency - overall* (1–7) | 6.91 (0.31) | 6.62 (0.75) | ns |
| Listening ability (1–7) | 7.00 (0.00) | 6.54 (0.88) | * |
| Reading proficiency (1–7) | 6.88 (0.50) | 6.69 (0.63) | ns |
| Speaking fluency (1–7) | 6.88 (0.34) | 6.69 (0.75) | ns |
| Writing proficiency (1–7) | 6.88 (0.50) | 6.54 (0.88) | ns |
| *Language experience: L2* | $N = 16$ | $N = 15$ | |
| Age of exposure (in years) | 10.07 (7.05) | 9.17 (4.01) | ns |
| Percentage of daily use (%) | 45% (23%) | 3% (4%) | *** |
| Proficiency - overall* (1–7) | 6.03 (0.74) | 3.42 (0.96) | *** |
| Listening ability (1–7) | 6.50 (0.52) | 3.46 (1.20) | *** |
| Reading proficiency (1–7) | 6.31 (0.79) | 3.92 (104) | *** |
| Speaking fluency (1–7) | 5.81 (1.05) | 2.77 (1.24) | *** |
| Writing proficiency (1–7) | 5.69 (1.08) | 3.54 (1.05) | *** |
| *Language experience: L3* | $N = 16$ | $N = 5$ | |
| Age of exposure (in years) | 7.00 (3.72) | 14.80 (3.42) | *** |
| Percentage of daily use (%) | 9% (7%) | 1% (1%) | *** |
| Proficiency - overall* (1–7) | 5.17 (1.47) | 2.20 (0.84) | *** |
| Listening ability (1–7) | 5.81 (1.56) | 2.60 (1.14) | *** |
| Reading proficiency (1–7) | 5.94 (1.29) | 2.60 (1.52) | *** |
| Speaking fluency (1–7) | 4,50 (1.79) | 2.00 (0.71) | *** |
| Writing proficiency (1–7) | 4.63 (1.78) | 1.60 (0.89) | *** |

*p < .05.
***p < .001.

## 2.2. Materials

### 2.2.1. The lateralized attention network test

The lateralized Attention Network Task (LANT; Greene et al., 2008) was implemented to measure the efficiency and lateralization of the two attentional networks (alerting, executive).

In each trial, five arrows vertically arrayed in one line were displayed. The target was always the middle arrow pointing either up or down, flanked by four other arrows: two above and two below. The flanking arrows were either pointing in the same direction as the middle arrow (congruent condition), or were pointing in the opposite direction (incongruent condition). The height of the array was 3.2°. The array was presented either in the left visual field (LVF) or the right visual field (RVF) at distance of 2.2° from the central fixation cross (see Fig. 1).

There were three cue conditions in the task.[5] In the centre cue condition, an asterisk was briefly presented in the same location as the fixation cross before the arrows were displayed. In the double cue condition, two asterisk marks were displayed on the both left and right side of the visual field, at the position of the target arrow. In the no cue condition, the arrows were not preceded by presentation of any cue. In the centre cue and double cue conditions, the cues were presented either 500 ms (SOA = 500 condition) or 100 ms (SOA = 100 condition) before the arrows.

The task was divided into six blocks of 144 trials. In each block, the stimuli were balanced with respect to congruency, cue, and visual field. In addition, within the centre and double cue conditions, there was an equal number of trials within each level of SOA. Each trial began with the presentation of the fixation point in the centre of the screen for a variable duration. In the no cue condition, the fixation

[5] Since previous studies have not shown any effects of bilingualism on the orienting component of attention (Costa et al., 2008; Marzecová, Asanowicz et al., 2013; Marzecová, Bukowski et al., 2013; Tao et al., 2011), spatial cue has not been included in the task design.

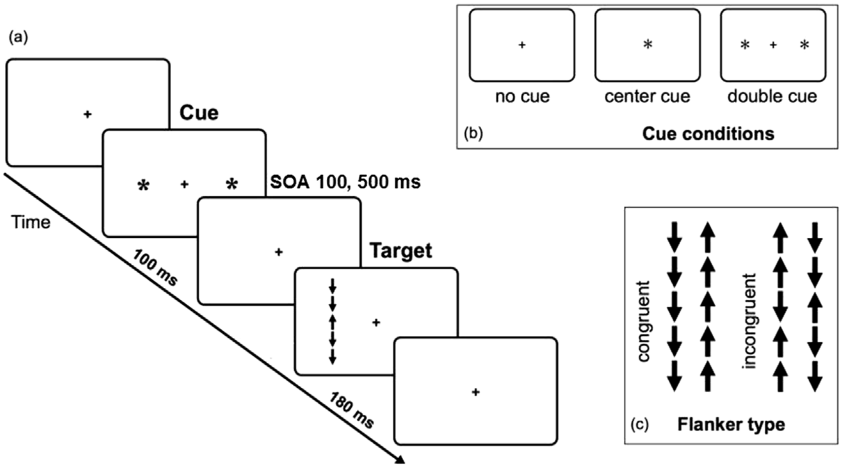


**Fig. 1.** Schematic representation of events in the lateralized attention network task (LANT) (a), types of cues (b), and congruency conditions (c).

period varied between 3300 and 4700 ms. In the centre and double cue conditions, the fixation period varied between 2800 and 4200 ms and was followed by the presentation of the cue for 100 ms. In the SOA = 100, the cue was immediately followed by the presentation of the target stimulus. In the SOA = 500, the presentation of the target stimulus was preceded by the presentation of the fixation point for another 400 ms. The target stimulus appeared either on the left or the right side of the screen and remained for 180 ms. During and after the presentation of the target stimulus, the fixation point remained on the screen until a response was given or until the timeout (1800 ms).

### *2.3. Procedure*

Participants were seated in a sound-attenuated, softly-lit room. After providing written informed consent to participate in the study, participants filled in the Language History and Background and Handedness Questionnaires. After the electrode placement, they performed the LANT task. At the end of the experimental session, participants were asked to complete the sRAPM.

In the LANT, participants were instructed to respond to the direction of the target arrow and to ignore the four flanking arrows as quickly and as accurately as possible. They responded with the computer mouse held sideways, so that the two buttons were oriented vertically. When the central arrow pointed up, they were asked to press the upper button; if the central arrow pointed down, they were asked to press the lower button. The response hand alternated between the blocks. A training session of two blocks of 16 trials (one block to practice each response hand) was performed before the task. During the training, participants received feedback on accuracy for each response. The entire task lasted about 1 h. Participants were allowed to take a break between the experimental blocks of the LANT.

### *2.4. Electrophysiological recording and preprocessing*

We used the Biosemi Active Two recording system. The electroencephalogram (EEG) was recorded at 256 Hz from 32 A g/AgCl scalp electrodes, positioned at the standard 10–20 locations and mounted in an elastic cap. Electrodes were initially referenced online to the C1 electrode and re-referenced off-line to average mastoids. The vertical EOG was monitored with two electrodes placed below and above a participant's right eye; horizontal EOG was recorded from electrodes at the outer canthi of the eyes. The EEG signal was filtered off-line with a band-pass filter (0.1 Hz–20 Hz frequency range; slope 12 dB/oct).

ERP data were analysed using a Brain Vision Analyzer. Epochs of 700 ms before and 2000 ms post-stimulus onset were extracted from the continuous EEG. Systematic artefacts resulting from eye-movements, blinks, and motor artefacts were filtered out using a procedure based on ICA (Delorme, Sejnowski, & Makeig, 2007). Segments containing non-stationary artefacts (such as skin potentials, or artefacts resulting from head-movements) were manually rejected. Baseline correction was performed using the average EEG activity in the 150 ms epoch preceding the point when the procedure for all the conditions diverged (500 ms before the target stimulus in the no-cue condition and in the SOA = 500; 100 ms before the target stimulus in the SOA = 100).

### *2.5. Behavioral data analysis*

All statistical analyses were conducted using SPSS (version 12.0.1). We performed an omnibus ANOVA with Congruency (congruent, incongruent), Visual Field (left, right) and Cue (no cue, centre-100, centre −500, double-100, double-500) as within-subject variables, and Group (control, bilingual) as a between-subject variable for both median reaction times for correct trials (RT) and mean accuracy (percentage of correct responses).[6] In this report, our focus is on the impact of bilingualism on the executive control

[6] The analyses for RT and accuracy data with Experimental Block (1–6) as an additional within-subject variable did not reveal any clear interactions with the other variables; thus for the sake of simplicity, we did not include this variable in the analyses.

**Table 2**
Median reaction times for correct responses in ms and mean accuracy in % for all task conditions by Group (BIL = bilinguals, CTR = control participants). Standard deviations are in parentheses.

| Congruency | Cue type | SOA (ms) | Visual Field | RT | | Accuracy | |
|---|---|---|---|---|---|---|---|
| | | | | BIL | CTR | BIL | CTR |
| congruent | centre | 100 | Left | 569 (23) | 545 (24) | 97 (1) | 96 (1) |
| | | | Right | 551 (23) | 554 (24) | 99 (1) | 98 (1) |
| | | 500 | Left | 529 (22) | 527 (23) | 97 (1) | 99 (1) |
| | | | Right | 534 (21) | 520 (22) | 99 (1) | 97 (1) |
| | double | 100 | Left | 558 (20) | 545 (21) | 96 (2) | 96 (2) |
| | | | Right | 551 (21) | 546 (22) | 98 (1) | 96 (1) |
| | | 500 | Left | 528 (20) | 524 (20) | 99 (1) | 98 (1) |
| | | | Right | 529 (21) | 518 (22) | 98 (1) | 97 (1) |
| | no cue | – | Left | 571 (23) | 559 (24) | 97 (1) | 96 (1) |
| | | | Right | 562 (20) | 551 (20) | 98 (1) | 97 (1) |
| incongruent | centre | 100 | Left | 673 (21) | 672 (21) | 82 (4) | 80 (4) |
| | | | Right | 689 (24) | 689 (25) | 76 (4) | 57 (5) |
| | | 500 | Left | 668 (26) | 657 (27) | 85 (4) | 84 (4) |
| | | | Right | 675 (23) | 654 (24) | 81 (4) | 64 (4) |
| | double | 100 | Left | 682 (22) | 677 (23) | 80 (4) | 70 (4) |
| | | | Right | 695 (27) | 691 (28) | 69 (5) | 50 (5) |
| | | 500 | Left | 663 (25) | 655 (26) | 86 (4) | 82 (4) |
| | | | Right | 675 (20) | 655 (21) | 83 (4) | 69 (4) |
| | no cue | – | Left | 675 (25) | 667 (26) | 85 (3) | 82 (3) |
| | | | Right | 691 (25) | 675 (26) | 79 (4) | 61 (4) |

and consequently, all analyses pertaining to within-subject effects and the comparison between the groups in executive control are reported in the main body of the text, whereas the remaining behavioural analyses are reported in Appendix A.

### *2.6. ERP data analysis*

The same baseline was applied to stimulus-locked and response-locked epochs. Stimulus-locked ERP averages included only correct trials and were computed for each participant separately for the congruent and incongruent conditions (collapsed over Cue and Visual Field). Response-locked ERP averages were computed separately for correct and error trials (collapsed over Congruency, Cue, and Visual Field). Each participant had a minimum of 25 trials per ERP average.

To identify ERP components reflecting the effects of congruency and response accuracy, we inspected the grand-averaged ERP waveforms (incongruent vs. congruent trials and incorrect vs. correct responses) to find differences between the conditions (i.e. ERP components). Based on visual inspection and in line with previous literature, we identified one stimulus-locked component and two response-locked components. In the stimulus-locked ERP averages, we found a P3b component in the 375–500 ms time-window which was most prominent (i.e. the difference between ERP grand-averages for incongruent and congruent trials was the largest) at four centro-parietal electrodes (i.e. Cz, CP1, CP2, Pz). In the response-locked ERP averages, we found an ERN and a CRN in the 0–80 ms time-window at five central electrodes (i.e. Cz, FC1, FC2, CP1, CP2) which was followed by a Pe component in the 160–400 ms time-window at four centro-parietal electrodes (i.e. Cz, CP1, CP2, Pz). The components did not differ in distribution and latency between groups.

Analyses of ERP results were conducted on mean voltage amplitudes in the P3b, ERN and Pe component-specific time-windows and electrodes using SPSS (version 12.0.1). For the P3b, we conducted a 2 × 2 repeated-measure ANOVA with a within-subject Congruency factor (congruent, incongruent) and a between-subject Group factor (control, bilingual). In auxiliary analyses, we investigated potential effects of SOA and VF on the P3b (see Appendix B). For the ERN/CRN, we conducted a 2 × 2 repeated-measure ANOVAs with a within-subject Response Accuracy factor (correct, incorrect) and a between-subject Group. The same type of analysis was conducted for Pe.

## 3. Results

### *3.1. Behavioural results*

Median RT and mean accuracy for each task condition are shown in Table 2. The statistics for the omnibus ANOVA results observed in the RT and the accuracy analyses are shown in Table 3.

#### *3.1.1. Within-subject effects*

A main effect of Congruency was significant in both RT and accuracy. Participants were faster and more accurate in the congruent condition (RT: $M = 543$ ms, $SD = 49$ ms; accuracy: $M = 97\%$, $SD = 6\%$) relative to the incongruent condition (RT: $M = 674$ ms, $SD = 50$ ms; accuracy: $M = 75\%$, $SD = 7\%$). A main effect of Cue in both RT and accuracy was also observed, reflecting a significant

**Table 3**
Summary of the RT and the accuracy analyses. Omnibus ANOVAs were performed including listed variables. Con = Congruency, VF = Visual Field. Statistically significant effects are marked by asterisks.

| Variable | RT | | | Accuracy | | |
|---|---|---|---|---|---|---|
| | *F* | *p* | $\eta^2$ | *F* | *p* | $\eta^2$ |
| Con | 258.3 | *** | 0.9 | 106.3 | *** | 0.79 |
| Con x Group | 0 | ns | – | 5.4 | * | 0.16 |
| Cue | 19 | *** | 0.4 | 22.5 | *** | 0.44 |
| Cue x Con | 4.1 | ** | 0.12 | 16.3 | *** | 0.36 |
| Cue x Con x Group | 0.8 | ns | – | 0.9 | ns | – |
| Cue x Group | 0.3 | ns | – | 1 | ns | – |
| Cue x VF | 0.2 | ns | – | 1.2 | ns | – |
| Cue x VF x Con | 0.8 | ns | – | 4.7 | ** | 0.14 |
| Cue x VF x Con x Group | 0.3 | ns | – | 0.8 | ns | – |
| Cue x VF x Group | 1.3 | ns | – | 1.2 | ns | – |
| Group | 0.1 | ns | – | 5.7 | * | 0.16 |
| VF | 0.3 | ns | – | 15.5 | *** | 0.35 |
| VF x Con | 3.1 | ns | – | 23.4 | *** | 0.45 |
| VF x Con x Group | 0.3 | ns | – | 4.8 | * | 0.45 |
| VF x Group | 0 | ns | – | 5 | * | 0.15 |

* p < .05.
** p < .01.
*** p < .001.

alerting effect (see Appendix A, for a description of the alerting effect). While the RT analysis did not reveal any other significant within-subject main effects, the accuracy analysis indicated a significant main effect of Visual Field. The accuracy was higher for the LVF targets than for the RVF targets. Furthermore, a significant interaction between Congruency and Visual Field was observed. Post-hoc analyses revealed that the advantage in accuracy for the targets appearing in the LVF was present in the incongruent condition, $t(31) = 4.10$, $p < .001$, but not in the congruent condition, $p > .05$.

### 3.1.2. Effects of bilingualism

For the RT measure, no main Group effect was observed, but a significant main Group effect was found in accuracy (see Table 3). Overall, bilinguals were more accurate ($M = 89\%$, $SD = 2\%$) than controls ($M = 83\%$, $SD = 2\%$). We found significant interactions in accuracy between Group and Visual Field; Group and Congruency; Group, Congruency and Visual Field (see Table 3). Post-hoc analyses, which involved significant interactions with Group, are reported below.

In the incongruent condition, bilinguals, relative to controls, were more accurate, thus indicating more efficient executive control, $t(29) = 2.42$, $p < .02$. Further, in the incongruent condition, the control group showed a significantly higher accuracy for the LVF targets relative to the RVF targets, $t(14) = 4.65$, $p < .001$, whereas the balanced bilinguals showed no such asymmetry, $p > .05$. These results indicate a right hemisphere dominance in the control group, and no such asymmetry in the bilingual group. The bilingual and the control group did not differ in their accuracy in the congruent condition, $ps > 0.05$.

No interactions involving Group and Cue were found either in the RT or the accuracy analyses (all $ps > 0.05$; see Table 3).

## 3.2. EEG results

### 3.2.1. N2

Panel A of Fig. 2 shows stimulus-locked ERPs. We did not find any component that showed critical characteristics of the N2 component (i.e. a fronto-central distribution and more negative amplitude in the incongruent than in the congruent condition in the 200–350 m s post-stimulus).[7]

### 3.2.2. P3b

P3b amplitude was significantly more positive in the congruent ($M = 9.15\,\mu V$, $SD = 0.73\,\mu V$), relative to the incongruent condition ($M = 6.57\,\mu V$, $SD = 0.79\,\mu V$); this was confirmed by a significant main effect of Congruency, $F(1,29) = 32.16$, $p = .000$, $\eta^2 = 0.53$. A main effect of Group, as well as the interaction between the Group and Congruency factors were not significant, $Fs < 1$ (see Panel B of Fig. 2). For a description of the visual field effect and the alerting effect for the P3b component, see Appendix B.

### 3.2.3. ERN/CRN

Panel A of Fig. 3 shows response-locked ERPs. The analysis revealed a significant main effect of Response Accuracy, *F*

[7] In another large-sample ERP study recently published (Kałamała et al., 2017), we also found no modulation of the N2 in a basic flanker task with equiprobable congruent and incongruent conditions. In the article, we argue that what some of the previous studies interpreted as the N2 component might in fact be a frontal aspect of difference between congruent and incongruent trials in the amplitude of the P300 component.

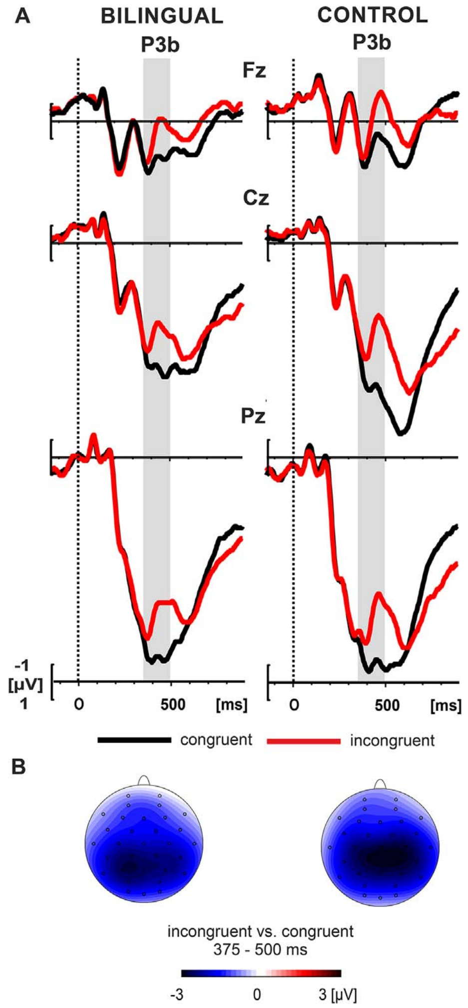


**Fig. 2.** Stimulus-locked ERPs. Panel A shows grand-averaged ERP waveforms for the congruent condition (black line) and the incongruent condition (red line), as measured at midline frontal (Fz), central (Cz) and posterior (Pz) electrode sites for the bilingual group (left column) and the control group (right column). Time window for the P3b component is marked. Each plot shows amplitude in microvolts on the y-axis and time in milliseconds on the x-axis. Panel B shows scalp topography of the P3b component in the bilingual group (left) and the control group (right). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

(1,29) = 21.63, $p < .001$, $\eta^2 = 0.43$, with the amplitude significantly more negative for the incorrect (ERN; $M = -1.25$ μV, $SD = 0.36$ μV), relative to the correct responses (CRN; $M = 0.63$ μV, $SD = 0.35$ μV). Moreover, both the CRN and the ERN amplitudes were significantly more negative in the bilingual group ($M = -1.20$ μV, $SD = 0.41$ μV) than in the control group ($M = 0.58$ μV, $SD = 0.42$ μV), which was confirmed by a significant main effect of Group, $F(1,29) = 9.24$, $p = .001$, $\eta^2 = 0.24$. However, the interaction between Response Accuracy and Group was not significant, $F < 1$.

### 3.2.4. *Pe*

The Pe amplitude was significantly more positive for incorrect ($M = 0.11$ μV, $SD = 0.64$) relative to correct responses ($M = -3.41$ μV, $SD = 0.67$ μV), which was confirmed by a main effect of Response Accuracy, $F(1,29) = 59.60$, $p = .000$, $\eta^2 = 0.67$. However, a main effect of Group and the interaction between Response Accuracy and Group factors were not significant, $F < 1$ and $F(1, 29) = 3.78$, $p = .06$, respectively (see Panel B of Fig. 3).

## 4. Discussion

In this report, we focus on the efficiency of executive control in a group of young adult bilinguals who acquired their L2 relatively late and were balanced in their proficiency and daily use of L1 and L2. Performance of bilinguals was compared with that of native speakers of Polish who reported some experience in L2, but their L2 proficiency and usage were significantly lower than that of the bilingual group. We replicated previously obtained results from the LANT: faster and more accurate responses in the congruent condition relative to the incongruent condition, and a right hemisphere dominance (i.e. LVF advantage) for conflict resolution

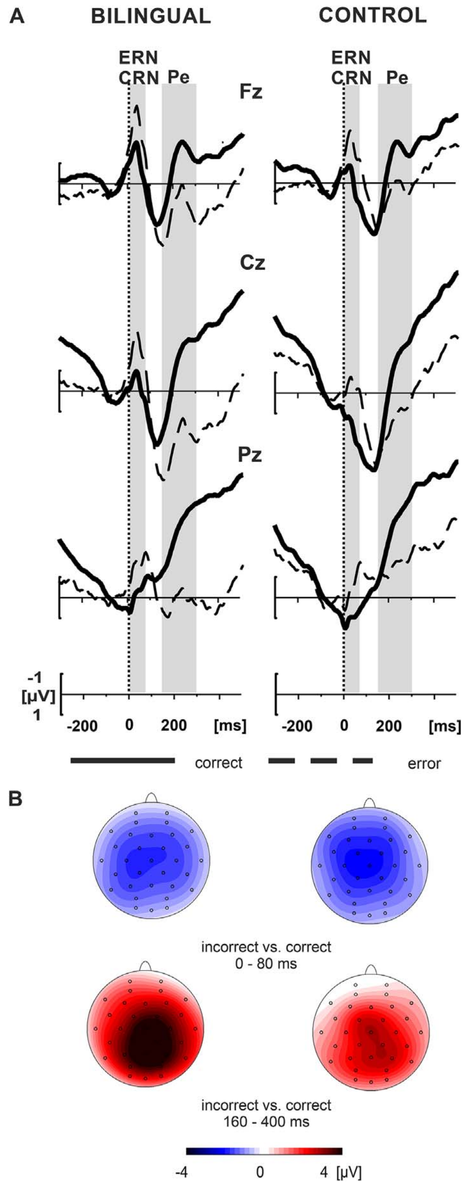


**Fig. 3.** Response-locked ERPs. Panel A shows grand-averaged ERP waveforms for the correct responses (solid line) and the incorrect responses (dashed line), as measured at midline frontal (Fz), central (Cz) and posterior (Pz) electrode sites for the bilingual group (left column) and the control group (right column). Time windows for analyzed components are marked. Each plot shows amplitude in microvolts on the y-axis and time in milliseconds on the x-axis. Panel B shows scalp topography of the ERN and the Pe components in the bilingual group (left) and the control group (right).

(Asanowicz & Marzecová, 2017; Marzecová, Bukowski, et al., 2013; Tao et al., 2011).[8] Similarly to previous studies by Tao et al. and Marzecova et al., the right hemisphere dominance was present in the control, but not in the bilingual group (see below). Since the task we employed allowed us to replicate the pattern of main effects reported in previous literature, it provides a reliable assessment of the efficiency of executive control.

As for the influence of bilingualism on the efficiency of executive control, we observed a bilingual advantage in the efficiency of executive control. Participants in the bilingual group were more accurate in the incongruent condition, but the two groups did not differ in accuracy in the congruent condition. At the same time, we did not find group differences in RT either in the efficiency of executive control (reported previously by Costa et al., 2009, 2008; Marzecová, Asanowicz et al., 2013, Marzecová, Bukowski et al., 2013; Tao et al., 2011) or in the overall performance (reported previously by Costa et al., 2009, 2008; Tao et al., 2011). Bilinguals in our study were as fast as participants in the control group across the congruent and incongruent conditions. Moreover, participants in

[8] A pattern of results for the alerting network was also replicated, but it is beyond the scope of the present paper and therefore is reported in Appendix A.

the control group revealed a typical right hemisphere dominance (indicated by left visual field advantage, cf. Asanowicz et al., 2012), while bilinguals were equally accurate across the visual fields, and showed no right-hemisphere dominance (see Marzecová, Asanowicz et al., 2013; Marzecová, Bukowski et al., 2013; Tao et al., 2011; for earlier results).

In addition to behavioural measurement, we employed ERP methodology in order to gain further insight into the efficiency of executive control in bilinguals. Based on previous research, we expected that bilinguals, relative to the control group, would display smaller N2, larger P3b and smaller ERN component. Additionally, we explored CRN and Pe, but given that these components are not usually explored in the context of bilingualism, we did not formulate any hypotheses concerning them.

Overall, flanker congruency modulated the P3b component, while response accuracy effects were reflected in ERN/CRN and Pe. Surprisingly, we found no evidence for the modulation of the N2 by congruency; however, as we argue in our recent paper (Kałamała, Szewczyk, Senderecka, & Wodniecka, 2017), the congruency modulation of the N2 does not necessarily occur in tasks that employ flanker-like manipulation with equiprobable congruent and incongruent trials and no other manipulations. As for the between-group differences, the bilingual and the control group differed in the ERN/CRN; the balanced bilingual participants showed enhanced response-locked negativities to both incorrect (ERN) and correct responses (CRN). Although the larger ERN in the bilingual group is in contrast with our predictions based on the previous studies on the bilingual advantage (Kousaie & Phillips, 2012; Morales et al., 2015), the finding (together with the report of increased CRN in the same group) seems to be consistent with outcomes of studies investigating both ERN and CRN in clinical samples (e.g. Hajcak & Simons, 2002). In the following sections, we discuss the present pattern of results and offer a speculative explanation for the absence of group differences in the RT.

### 4.1. *Efficiency of executive control in bilinguals*

The observed bilingual advantage in the accuracy measure suggests that the bilinguals in our sample may have adopted a specific task performance strategy. Bilinguals may have controlled their performance more effectively, which resulted in their better conflict resolution, as compared to the control group. A recent study by Incera and McLennan (2016) suggests that bilinguals and monolinguals may indeed systematically differ with respect to their task performance strategies. The authors used mouse tracking and demonstrated that bilinguals responded in a different way than monolinguals: they waited longer to initiate a response, but then responded faster to the correct response. This finding was interpreted as indicating more efficient task performance strategy of bilinguals.

If bilingual participants in the current study indeed employed a different task strategy than participants in the control group, then this could perhaps explain why the bilinguals in the present study did not reveal any advantage in the RT measure and were as fast as the control group. The fact that bilinguals focused on accuracy could have resulted in their response slowing and ultimately may have nullified the advantage in RT that was previously reported in bilinguals using (L)ANT (Costa et al., 2008, 2009; Marzecová, Asanowicz et al., 2013; Marzecová, Bukowski et al., 2013; Tao et al., 2011). In other words, on this account, the absence of an RT difference between the groups could be due to the fact that bilinguals in the current study employed a different strategy of task performance that was more sensitive to the conflict. This strategy may have resulted in increased accuracy in the incongruent condition on one hand, and in the relative slowdown of bilinguals' responses on the other. However, this speculative interpretation should be taken with caution. An alternative, more parsimonious interpretation is that bilinguals in our study were equally fast as participants in the control group, independently of their focus on accuracy in the incongruent condition. Our results do not allow us to adjudicate between these two interpretations. The ERN/CRN findings, however, shed some further light on the nature of the task strategy adopted by bilinguals in our study.

As reported earlier, bilinguals revealed more enhanced ERN and CRN, relative to the control group. Interestingly, some studies have also reported a similar pattern of ERP results in clinical samples and hence offer additional support for the strategy-related interpretation of our findings. For example, Hajcak and Simons (2002) reported larger amplitudes of ERN and CRN in participants with an independently measured tendency to over actively control of their performance. They interpreted the larger negativity of ERN and CRN as reflecting the task strategy characterised by an increased control of responses. Based on Hajcak and Simon's interpretation, we therefore speculate that the bilinguals in our study controlled their performance to a higher degree than participants in the control group. It may well be that the accuracy-focused strategy of bilinguals is a consequence of their better control abilities. However, based on the available evidence it is impossible to equivocally settle whether the strategy of bilinguals is a consequence of more efficient executive control.

Taken together, we suggest that the bilingual and the control group in our study might have differed in task performance strategy. However, the precise nature of the differences is unclear; they may be related to the nature of bilingualism *per se* or to some motivational/affective factors that systematically differed between the two groups. Several studies from other research fields have indicated that motivational and affect-related factors can change task performance strategies in executive control tasks (e.g. Bukowski, Asanowicz, Marzecov, á, Lupi, áñ, & ez, 2015; Heitz & Engle, 2007). Since we did not measure these factors in our study, we cannot rule out the possibility that the two groups systematically differed in this respect. Future research will need to address these issues and aim at directly testing the impact of strategy use on differences in language group performance.

### 4.2. *Interhemispheric organization in bilinguals*

Previous research has indicated that bilingualism may alter interhemispheric organization of executive control (e.g. Hausmann et al., 2004). The studies that employed the LANT have brought evidence for the right hemisphere dominance of executive control in monolinguals and late bilinguals and the lack of such asymmetry in bilinguals who acquired their L2 early (Marzecová, Asanowicz et al., 2013; Marzecová, Bukowski et al., 2013; Tao et al., 2011). In our study, we aimed to revisit this effect in a group of relatively late but highly proficient and balanced bilinguals. While participants in the control group revealed right hemisphere dominance for conflict resolution in accuracy, the relatively late bilinguals revealed a lack of such asymmetry across the conditions. This finding contrasts with the study conducted by Tao et al. (2011) in which late bilinguals, similarly to monolinguals, revealed a right hemisphere dominance of executive control. On this basis, Tao et al. (2011) argued that bilinguals who acquired their L2 early are more likely to reveal a reduced right hemisphere dominance. The lack of hemispheric asymmetry in the late bilinguals observed in the present study suggests that not only early, but also relatively late bilingualism may alter the interhemispheric organization of executive control. It is noteworthy, however, that late bilinguals in the Tao et al.'s study were less balanced in their proficiency and use of L1 and L2 than the bilinguals in the present study; however, the bilinguals in the current study, in contrast to the bilinguals in the study by Tao et al., had additional experience in L3. It is therefore impossible to determine which aspects of the language experience are crucial for the reduced hemispheric asymmetry. Nevertheless, in the light of the present results, early experience in L2 should not be considered as a crucial factor in altering interhemispheric organization of executive control. Although it does not do so conclusively, our finding suggests that specific language experience may differentially influence particular aspects of executive control, including interhemispheric organization.

### *4.3. Study limitations*

In the previous literature, evidence for a bilingual advantage in young adults is unequivocal and varies depending on the measures and task design. Differences between bilinguals and monolinguals do not always generalize across studies (Li, Legault, & Litcofsky, 2014; Garcı´a-Penton et al., submitted for publication). Among many tasks commonly used to measure efficiency of executive control in bilinguals, the ANT seems to be noteworthy due to its high reliability in measuring the attentional networks (MacLeod et al., 2010). Here, we used a modified lateralized version of the ANT. Given that even subtle differences in the task design may impact the processing demands of the task (Paap, 2014), the present pattern of results should also be discussed in the context of the specific features of the task design used in the current study.

In contrast to previous studies that employed the LANT (Marzecová, Asanowicz et al., 2013; Marzecová, Bukowski et al., 2013; Tao et al., 2011), we used alerting cues with two different cue-target intervals in order to assess the efficiency of alerting in short (i.e. 100 ms) and long (i.e. 500 ms) cue-target intervals. Previous studies employed one fixed cue–target interval (e.g. 400 ms), which results in high temporal predictability of the stimuli. Since participants were more accurate and faster in long cue–target intervals relative to short cue–target intervals, the particular design of the task used in our study seems to offer another explanation for the absence of the bilingual advantage in RT. Some studies indicated that bilinguals, relative to monolinguals, showed a greater benefit from alerting cues than monolinguals (Costa et al., 2008; Marzecová, Asanowicz et al., 2013;; Marzecová, Bukowski et al., 2013; see also; Tao et al., 2011). Temporal preparation has, in turn, been shown to influence conflict processing (Correa, Cappucci, Nobre, & Lupiáñez, 2010) and bilingual benefits in executive control may be linked to the efficient use of predictive information (Bonifacci, Giombini, Bellocchi, & Contento, 2011). Due to the two different cue-target intervals, the temporal predictability of the stimulus was lower in the current task than in the previous studies that used the (L)ANT. In effect, participants may have been prepared less efficiently for the upcoming target. Although currently only speculation, reducing the temporal predictability of the stimuli may have affected the temporal preparation and thus alleviated differences between groups in the efficiency of executive control reflected in measures based on time, such as RT.

It may also be argued that our study was too underpowered for bilingual advantage in RT to emerge in such a small sample size. To be able to recruit and compare groups that are well matched in demographic factors has always posed a pragmatic challenge in research on bilingualism. However, the use of large samples of participants will certainly be critical in future studies to overcome the power issues and improve our understanding of the cognitive consequences of bilingualism.

### *4.4. Concluding remarks*

The present study shows an advantage of balanced bilinguals in executive control in the accuracy measure and the absence of this effect in RT. A possible explanation of these effects may be that the bilingual participants used a specific task strategy when performing executive control tasks. Our argument is complemented by the ERN/CRN data that showed systematic differences between the two groups in control of performance in the task (as reflected by amplitudes of both ERN and CRN). The motivational and strategic aspects of performance have been largely neglected in research exploring the cognitive consequences of bilingualism (Bak, 2016). At the same time, research in the domain of emotion has demonstrated that factors such as participants' motivation, attitude to tasks, as well as sensitivity to monotony may systematically affect task strategies and performance in executive control tasks (e.g. Bukowski et al., 2015). Initial evidence from a recent study by Incera and McLennan (2016) has shown that bilinguals and monolinguals may systematically differ with respect to task performance strategies. Therefore, we propose that factors affecting task performance strategy should be taken into account when comparing participants sampled from different populations. These factors may conspire in multiple factorial interactions with bilingualism and contribute to marked discrepancies in the outcomes of research on bilingual advantage in executive control. Although we cannot rule out the contribution of factors such as subtle differences in the present task design, we believe that the evidence related to task strategy provides an important insight into comparisons of performance across different groups.

Additionally, the results of the current study indicate that relatively late but proficient and balanced bilinguals do not necessarily differ from early bilinguals in the interhemispheric organization of executive control. In this way, our study has extended the scope of empirical evidence for the reduced hemispheric asymmetry observed in the bilingual population.

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## Appendix A. Analyses of alerting effect for RT and accuracy.

Post-hoc analyses showed that participants did not differ in RT and accuracy between the SOA = 100 ms and the no cue condition: $ps > 0.05$. However, participants were faster in the SOA = 500 ms than in the SOA = 100 ms, $t(30) = -5.72$, $p < .001$; and in the no cue condition, $t(30) = -6.87$, $p < .001$. Type of cue (centre cue vs. double cue) did not influence RT in any of the SOAs (100 ms and 500 ms), $ps > 0.05$. Post-hoc analyses of accuracy revealed that participants were more accurate in the SOA = 500 ms relative to the SOA = 100 ms, $t(30) = 5.53$, $p < .001$; and the no cue condition, $t(30) = 2.92$, $p < .001$. In the SOA = 500 ms, participants were more accurate in the double cue condition relative to the centre cue condition, $t(30) = -2.09$, $p = .045$. In contrast, in the SOA = 100 ms, participants were less accurate in the double cue condition relative to the centre cue condition, $t(30) = 5.22$, $p < .001$. When no cue preceded the presentation of the target, participants were similarly accurate as when the centre cue was presented with the SOA = 100 ms, $p > .05$. The analyses also revealed significant interactions between Cue and Congruency in both accuracy and RT, and between Cue, Visual Field, and Congruency in accuracy. These effects replicated previous evidence on the interactions between alerting and executive network (cf. Asanowicz & Marzecová, 2017).

## Appendix B. Analyses of visual field and alerting effects for the P3b component.

To investigate potential effects of visual field and cue-SOA on the P3b component, two exploratory analyses were conducted. To test the effect of the visual field, an ANOVA was performed with Congruency and Visual Field (left, right) as within-subject variables, and Group as a between-subject variable. The analysis revealed a significant main effect of Congruency [$F(1,29) = 30.89$, $p < .001$]. The other effects were not significant [$ps > 0.05$]. As such, manipulation of visual field did not influence the P3b component. To test the effect of cue and SOA, an ANOVA was performed with Congruency and Cue-SOA (no cue, centre-100, centre-500, double-100, double-500) as within-subject variables, and Group as a between-subject variable. The analysis revealed significant main effects of Congruency [$F(1,29) = 25.41$, $p < .001$], Cue-SOA [$F(4,116) = 31.35$, $p < .001$] and the interaction of Congruency and Cue-SOA [$F(4,116) = 3.25$, $p < .01$]. Post-hoc analyses showed that the P3b amplitude for congruent and incongruent trials did not differ between the SOA = 100 ms ($M = 9.07$ μV, $SD = 4.43$ μV) and the no cue condition ($M = 8.65$ μV, $SD = 4.16$ μV), $p > .05$. However, the P3b amplitude for congruent and incongruent trials was significantly smaller (i.e. less positive) in the SOA = 500 ms ($M = 5.96$ μV, $SD = 4.03$ μV) than in the SOA = 100 ms, $t(30) = -7.90$, $p < .00$, and in the no cue condition, $t(30) = -6.57$, $p < .00$. Type of cue (centre cue vs. double cue) did not influence the P3b amplitude in any of the SOAs (100 ms and 500 ms), $ps > 0.05$.

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