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Tracing the bilingual advantage in cognitive control: The role of flexibility in temporal preparation and category switching

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The present study addressed the question whether bilinguals are characterised by increased cognitive flexibility. Mechanisms of cognitive flexibility were compared between a group of Hungarian-Polish bilinguals and a group of Hungarian monolinguals. The first task explored the effects of temporal orienting (ability to voluntarily orient attention to a certain point in time when a relevant event is expected) and the efficiency of switching between preparatory time intervals of different duration (sequential effects). The second task – the social category switching task – tapped into the mechanisms of switching between 2 types of categories (age and gender) and employed socially relevant stimuli (faces). The results of the first task revealed similar temporal orienting effects for both groups; however, the pattern of sequential effects differed between the groups, showing that bilinguals were less affected by the duration of the preceding preparatory interval. In the social category switching task, bilinguals showed reduced switch costs in the RT measure when categorising gender, and greater accuracy in the specific switch and no-switch conditions. We suggest that bilinguals are characterised by an enhanced mechanism of cognitive flexibility, which is applied to a temporal domain (efficient switching between preparatory intervals of different duration), and extends to the cognitive control processes in social categorisation tasks.

Keywords: Bilingualism; Cognitive flexibility; Temporal preparation; Switching; Sequential effects; Social categorisation.

The benefits of bilingualism for nonlinguistic cognitive processes have become a topic of heated debate. A vast amount of evidence suggests beneficial effects of bilingualism on attentional control (for reviews on the topic, see Bialystok, Craik, & Luk, 2012; Bialystok, Craik, Green, & Gollan, 2009; Hilchey & Klein, 2011). The majority of studies that reported bilingual advantage employed tasks that involved cognitive conflict brought about by task-irrelevant information, such as the Simon task (Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Martin, &

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Viswanathan, 2005; Martin-Rhee & Bialystok, 2008; Poarch & van Hell, 2012), the flanker task (Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Costa, Hernández, & Sebastián-Gallés, 2008; Emmorey, Luk, Pyers, & Bialystok, 2008; Luk, De Sa, & Bialystok, 2011; Marzecová, Asanowicz, Krivá, & Wodniecka, 2012; Tao, Marzecová, Taft, Asanowicz, & Wodniecka, 2011), or the Stroop task (Bialystok, Craik, & Luk, 2008; Hernández, Costa, Fuentes, Vivas, & Sebastián-Gallés, 2010). Managing 2 languages in the mind requires some cognitive control processes that prevent interference from a language that is not currently in use, and select the language that is relevant at the moment (see, e.g., Kroll, Bobb, & Wodniecka, 2006, for evidence that such interference is present and in fact mandatory). The bilingual advantage was thus initially conceptualised as resulting from the enhancement of inhibitory mechanisms that are needed to resolve language interference in bilinguals (Abutalebi & Green, 2007; Bialystok & Martin, 2004; Bialystok et al., 2004; Costa et al., 2008). However, the view of enhanced inhibitory control processes has been questioned due to several reasons. First, a number of studies could not replicate the effects of bilingualism in tasks involving inhibition, raising doubts about the robustness of the effects (Kousaie & Phillips, 2011, 2012; Morton & Harper, 2007; Namazi & Thordardottir, 2010; Paap & Greenberg, 2013). Second, looking more closely at the effects of bilingualism in the interference tasks, a complex pattern of results has been observed. If the bilingual advantage were observed only for conflict resolution (i.e., the comparison of conflict and nonconflict trials), it could be suggestive of the bilingual advantage in the inhibition of interference per se. However, only a few studies reported such a pattern of findings. For instance, Marzecová et al. (2012) showed that bilinguals were faster than monolinguals in detecting a target arrow exclusively on those trials that induced cognitive conflict by flanking arrows that were incongruent with a target arrow. On the other hand, the majority of studies showed a bilingual advantage on both conflict and nonconflict trials (see, for reviews, Costa et al., 2009; Hilchey & Klein, 2011; Tao et al., 2011), and reduced conflict resolution costs were detected in some but not all of the latter studies. The apparent inconsistencies in the findings from previous studies point to the need for a broader theoretical framework, in which they could be integrated. Recently, attention has been drawn to the fact that the emergence and specific tuning of the bilingual advantage in conflict resolution may be modulated by different factors of the language experience, including the age of acquisition of the second language, proficiency, the extent of use of languages, the relative balance between languages, and the context of language use (Green, 2011; Luk et al., 2011; Tao et al., 2011). These factors could account for some of the inconsistencies (see, e.g., Tao et al., 2011), but the empirical evidence is not yet sufficient. Moreover, we lack theoretical models of how specifically these factors mediate the bilingual advantage.

In their recent literature review, Hilchey and Klein (2011) attempted to explain the available findings on the bilingual advantage in cognitive control tasks with the "bilingual executive processing advantage hypothesis" (BEPA), which postulates enhanced efficiency of the central executive system "that regulates processing across a wide variety of task demands" (p. 654), and may lead to bilingual advantages across both conflict and nonconflict conditions in a wide range of tasks that engage executive control. In line with the BEPA postulate, which predicts bilingual advantage in multiple experimental conditions engaging executive control, several studies report differences between bilinguals and monolinguals with a wider range of experimental tasks, suggesting that bilingualism influences an even broader scope of cognitive processes. Among these processes are: the inhibition of irrelevant spatial cues (Colzato et al., 2008; Tao et al., 2011), switching continuously between mental sets (Prior & MacWhinney, 2010), achieving and maintaining alert state (Costa et al., 2008; Marzecová et al., 2012), or anticipating a stimulus (Bonifacci, Giombini, Bellocchi, & Contento, 2011). All these processes are related to cognitive flexibility, as they involve shifting between mental states, either in space, time or task set. Following Meiran (2010), by cognitive flexibility we refer to the ability to shift between mental sets – a feature that plays a key role both in purely cognitive tasks, and in social interactions.

Adopting the BEPA proposal, we hypothesised that other executive control tasks may also tap into bilingual advantage if they involve a component of cognitive flexibility (as defined by Meiran, 2010). We thus explored the differences in the cognitive performance of monolinguals and bilinguals by means of 2 tasks that have not been used previously. These tasks, which allowed us to look at different aspects of cognitive flexibility, were: (1) the temporal orienting task, which measured the effects of temporal preparation, allowing us to evaluate the efficiency of switching the preparation between time intervals of different durations across successive trials; and (2) the social category switching task, which assessed the flexibility of switching between 2 social categories (gender and age), and employed socially relevant stimuli (faces). Moreover, the design of the category switching task allowed us to look into a novel question in the bilingual literature, namely the role of specific stimulus–response bindings in generating switch costs in the context of socially relevant task material.

TEMPORAL PROCESSING IN BILINGUALS

More and more studies on cognitive processes in bilinguals and multilinguals point to the importance of temporal, anticipatory and preparatory processes relevant for an efficient performance on cognitive tasks (see, e.g., Bonifacci et al., 2011). A particularly interesting piece of evidence derives from studies that employed variants of the Attention Network Task (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002) to look at the bilingual advantage in executive functioning (e.g., Costa et al., 2008, 2009; Poarch & van Hell, 2012; Tao et al., 2011; Videsott, Della Rosa, Wiater, Franceschini, & Abutalebi, 2012; Yang, Yang, & Lust, 2011). The task is based on Posner's model of attention system (Petersen & Posner, 2012; Posner & Petersen, 1990) and provides measures of efficiency of 3 attentional networks: alerting, orienting, and executive. An unexpected finding in the studies that initially sought to explore the impact of bilingualism on executive functions pointed to the differences between bilinguals and monolinguals in the functioning of alerting network, which is believed to be responsible for an ability to achieve and maintain high sensitivity to incoming stimuli (Posner, 2008, p. 193). Two studies so far (Costa et al., 2008; Marzecová et al., 2012) have reported a larger alerting effect (reflecting faster reaction times in the alerting cue condition as compared to the no-cue condition) in bilinguals than in monolinguals, and Tao et al., (2011) reported a trend towards a larger alerting effect in late bilinguals and no effect for early bilinguals. In all 3 studies, bilinguals responded faster than monolinguals when an alerting cue was presented. Moreover, Videsott et al. (2012) have recently shown that the alerting effect is related to the linguistic competence in multilingual children, suggesting that the level of proficiency may affect the alerting efficiency.

One of the plausible interpretations of the larger alerting effect in bilinguals points to the importance of the anticipatory processes and a greater efficiency of bilinguals in temporal preparation. What makes such an interpretation feasible is the argument that several processes may in fact be entangled in the alerting effect as measured by the ANT task. First, the alerting effect reflects a joint effect of 2 components: tonic and phasic alertness (Fernandez-Duque & Posner, 2001; Posner, 2008). Consequently, differences in the magnitude of alerting effect may: (1) result from differences in the ability to maintain internal tonic alertness (reflected by performance in the no cue condition), or (2) reflect the efficiency of phasic alertness (evoked by an alerting cue) in achieving the state of readiness to process a target. Second, if an alert cue predicts the appearance of the target with high temporal validity (i.e., the interval between a cue and a target is fixed) and therefore provides information about the exact moment at which a target will occur, an additional process of anticipation, or so called temporal orienting, may be involved in the performance of the task (Correa, 2010; Fan et al., 2007; Foxe, Simpson, Ahlfors, & Saron, 2005; Nobre, 2001). Since in a typical ANT task the cue–target interval is fixed, the observed larger alerting effect in bilinguals (indexed by faster reactions in the alert cue condition) may reflect, in fact, an increased efficiency of temporal preparation or temporal orienting (Marzecová et al., 2012). Temporal orienting is defined as the capacity to voluntarily and strategically direct attention to a certain point in time when an event is expected (Correa, 2010; Correa, Lupiáñez, Milliken, & Tudela, 2004; Coull & Nobre, 1998), and is assumed to be controlled by prefrontal brain regions that subserve executive control (Triviño, Arnedo, Lupiáñez, Chirivella, & Correa, 2011; Triviño, Correa, Arnedo, & Lupiáñez, 2010).

Endogenous temporal orienting is usually indexed by so-called validity effects in the temporal cuing task: Responses are faster for targets appearing at expected (validly cued) intervals compared to unexpected (invalidly cued) intervals (Correa et al., 2004; Coull & Nobre, 1998).

Furthermore, temporal orienting can be modulated by so-called sequential effects, i.e., previous occurrences of temporal preparation (Los & van den Heuvel, 2001). Usually, when the current preparatory interval is short, the preparation is more efficient (responses are faster) if a previous preparatory interval was also short than when there is a requirement to switch from a long preparatory interval to a short one.

The effects of temporal orienting and the sequential effects were shown to be dissociated on behavioural (Capizzi, Sanabria, & Correa; 2012; Correa et al., 2004; Correa, Lupiáñez, & Tudela, 2006; Los & van den Heuvel, 2001) and neural level (Triviño et al., 2010). Triviño et al. (2010) reported that temporal orienting is impaired in patients with lesions in the right prefrontal cortex, but the sequential effects are not affected (see also Vallesi, Shallice, & Walsh, 2007, for a converging evidence from a TMS study). Another recent study by Capizzi et al. (2012) tested the controlled nature of temporal orienting by using a dual task procedure combining temporal orienting and WM tasks. A concurrent WM task interfered with and thereafter reduced the temporal orienting effects. The sequential effects, on the other hand, were not affected by the dual task, which hints at their automatic nature. It seems, therefore, that sequential effects involve more automatic mechanisms, as opposed to the more controlled mechanisms involved in temporal orienting effects (Capizzi et al., 2012; Triviño et al., 2010; Vallesi & Shallice, 2007; Vallesi et al., 2007).

Interestingly, another recent study combining temporal orienting and a go/no-go task showed dissociable patterns of sequential effects as a function of impulsivity (Correa, Triviño, Pérez-Dueñas, Acosta, & Lupiáñez, 2010). Temporal preparation skills were shown to be modulated by individual differences in response inhibition related to the prefrontal functioning. These results therefore suggest that both temporal orienting and sequential effects might be related to control processes regulated by the prefrontal cortex. Because a large body of evidence shows that bilingualism modulates the functioning of the domain-general executive control system subserved by prefrontal regions, it seems plausible to expect that bilingual experience might modulate the temporal preparation abilities. We therefore expected that bilingualism might affect the ability to prepare for upcoming stimuli as reflected in temporal orienting effects. However, extrapolating the evidence on the influence of impulsivity on sequential effects (Correa et al., 2010), we hypothesised that bilingualism may also affect sequential effects. Following our general hypothesis that bilinguals show increased cognitive flexibility across various domains of cognitive functioning, which is reflected in switching between mental sets, we propose a novel hypothesis that bilinguals may also be more efficient in switching between temporal preparatory intervals of different durations, which may be reflected in the different pattern of sequential effects. This hypothesis seems to be in line with a model by Vallesi and Shallice (2007), in which sequential effects are accounted for by changes in arousal level (i.e., readiness to respond). Previous long intervals seem to be cognitively exhausting (Näätänen, 1971) and therefore decrease the level of arousal on the current trial. Taking into account the evidence of increased alerting effect in bilinguals, we hypothesise that bilinguals might be more efficient in adjusting to the current task demands in terms of maintaining higher levels of readiness to respond irrespective of the duration of preparatory interval on previous trials.

FLEXIBILITY OF SWITCHING IN BILINGUALS

One of the key components contributing to cognitive flexibility, which, interestingly, has not been studied very often in the context of bilingual influences on nonlinguistic cognitive functioning, is the ability to switch between mental sets (Meiran, 2010). To the best of our knowledge, the first study that addressed this issue (Prior & MacWhinney, 2010) compared the performance of bilinguals and monolinguals on nonlinguistic task switching, and reported a reduced switching cost in the bilingual group, which suggested that bilingualism enhances the flexibility of shifting between mental sets. The authors interpreted their finding as a result of an effective activation of a relevant task set on a current trial (Prior, 2012; Prior & MacWhinney, 2010).

In the present study, we used a newly developed task that tests the flexibility of switching between social categories. The task explored the effects of switching in a context of bivalent social stimuli (faces) and socially relevant categories: gender (female, male) or age (young, old). This design allowed us to analyse the switching costs with respect to changes in the features of stimuli. Two types of flexibility were assessed: (1) the flexibility of switching between mental sets, which can be explored by comparing switch costs generated by the change of categorisation rule; and (2) the flexibility of managing the stimulus–set bindings, i.e., bindings that are created between stimulus and an associated task set. According to Meiran (2010), these bindings contribute to cognitive rigidity by being automatically retrieved when stimuli are reencountered. The stimulus–task set bindings are analogous to the event files described by Hommel (2004), (2009). The social category switching task (SCST) used in the current study allowed us to measure the flexibility of switching between social categories depending on the type of repetition of stimuli features from trial to trial: complete repetition (both features are repeated), partial repetition (1 of the features is repeated), or complete alternation (both features are different than in the previous trial). These transitions between stimuli and associated tasks demand flexible updating of stimulus–task set bindings. In line with Hommel's event-file theory (2004), we expected that a repetition of 1 feature of the stimulus–response binding would induce *partial repetition costs*, i.e., worsened performance when stimulus features are repeated but the required response is not. Along the lines of the theory, we therefore expected the highest cost under the condition of complete repetition of stimuli features when a switch to another task is required.

The ability to manage event files has been associated with cognitive flexibility. For instance, Colzato, van Wouwe, Lavender, and Hommel (2006) reported that individuals with high fluid intelligence showed reduced partial repetition costs, and hence were more flexible in managing and updating event-files, particularly in stimulus–response "unbinding" on consecutive trials. Analogically, we may expect that bilinguals enjoy the advantages of higher flexibility in updating event files, which helps them to effectively manage the stimulus–task set bindings in the switching task.

THE HYPOTHESES OF THE PRESENT STUDY

In conclusion, we set out the hypothesis that bilinguals are characterised by enhanced mechanisms of cognitive flexibility, which would be manifested in 2 domains: temporal preparation and category switching. In the temporal orienting task, we expected that bilinguals might be more efficient in preparing for an upcoming stimulus, which would influence the temporal orienting effects; and more flexible in switching between temporal preparatory intervals of different duration, which would affect the pattern of sequential effects. We also assumed that the increased flexibility of bilinguals might engender reduced costs of switching between the 2 categories, and a more flexible updating of stimulus–task set bindings (i.e., reduced partial repetition costs) in the social category switching task. Additionally, we tested the hypothesis that bilingualism affects the general mechanisms of cognitive flexibility that are employed in both tasks, by conducting a correlational analysis of the indices of cognitive flexibility obtained from both tasks.

METHODS

Participants

Forty-four adults (22 female, 22 male) participated in the study on voluntary basis. All participants were reimbursed for their participation in the experiment. The mean age of participants was 27 years ($SD = 4$). Bilingual participants ($N = 22$; 11 female, 11 male) were recruited from the community of Hungarian–Polish bilinguals in Budapest, Hungary. Monolingual participants were selected to match the bilingual group in terms of age, gender, and years of education, and all of them were Hungarian speakers from Budapest, Hungary. They were functionally monolingual, as they reported not using any other language than Hungarian on a daily basis and their knowledge of other languages was restricted to compulsory language courses at school and/or university. None of the monolingual participants reported living abroad for work or study purposes. The bilingual participants were proficient speakers of Hungarian (L1) and Polish (L2), who were born in Hungarian–Polish families (Polish mothers and Hungarian fathers) and were exposed to both languages in the first year of life. Although they were proficient speakers of both languages, they reported using mostly L1 during the day, because they were living, studying or working in an L1 environment (see Table 1). The groups did not differ in nonverbal intelligence scores, as measured by the split-half version of

TABLE 1
Background information about participants and their language knowledge, self-report measures of language proficiency and the extent of usage (means, with standard deviations in parentheses)

	Monolingual	*Bilingual*
Background information		
Age (in years)	27.3 (4.0)	27.0 (4.2)
Education (in years)	16.5 (1.7)	17.3 (2.8)
IQ (RAPM, 0–18)	12.8 (1.9)	12.8 (2.9)
Language knowledge and extent of use		
L1		
Age of exposure (in years)	.0 (.2)	.3 (.9)
Proficiency of understanding (1–10)	10.0 (.0)	10.0 (.0)
Proficiency of reading (1–10)	10.0 (.0)	9.9 (.2)
Proficiency of speaking (1–10)	10.0 (.0)	10.0 (.0)
Proficiency of writing (1–10)	10.0 (.0)	9.9 (.5)
Percentage of daily use (0–100%)*	90.4 (8.1)	69.0 (19.2)
L2		
Age of exposure (in years)	11.5 (4.5)	.0 (.2)
Proficiency of understanding (1–10)	4.6 (1.5)	9.4 (.9)
Proficiency of reading (1–10)	5.0 (1.7)	8.9 (1.5)
Proficiency of speaking (1–10)	2.8 (1.5)	9.3 (.8)
Proficiency of writing (1–10)	3.8 (1.8)	8.4 (2.0)
Percentage of daily use (0–100%)*	6.9 (8.9)	20.9 (16.0)

*Participants were asked to assess the percentage of daily use for every language, which would sum up to 100%. Some of the participants reported some knowledge and use of L3.

Raven's Progressive Matrices. The mean scores for monolinguals and bilinguals yielded 12.8 ($SD = 1.9$) and 12.8 ($SD = 2.8$) respectively, $t(42) = -.063$, $p = .95$.

Materials and procedures

Language background questionnaire. Information about the language knowledge and the extent of language use was collected using a questionnaire based on that of Li, Sepanski, and Zhao (2006). It comprised questions on the age of exposure to languages, the extent of language use (expressed in percentage of daily use), as well as self-evaluation scales to assess participants' language skills in comprehension, reading, speaking and writing. Proficiency scores were assessed by means of a 10-point scale (from 1 representing very poor knowledge to 10 representing native – like knowledge). The data are presented in Table 1.

Raven's Advanced Progressive Matrices. A shortened version of Raven's Advanced Progressive Matrices test (sRAPM; Raven, Raven, & Court, 1998) was used to measure participants' fluid intelligence. Participants were asked to complete 18 test items, which were increasing in difficulty. The shortened version included the odd-numbered items from the complete 36-item RAPM test.

Temporal orienting task. Participants were asked to detect the presence of a target (letter "X" or letter "O", $0.38° \times 0.76°$ of the visual angle at viewing distance of 50 cm) presented at the centre of the computer screen by pressing the "B" key on the computer keyboard. The target was preceded by a temporal cue. The cue was either a short bar (early cue, $0.38° \times 0.95°$) indicating that a target will probably appear after a short cue–target onset interval, or a long bar (late cue, $0.38° \times 2.1°$) indicating that a target will probably appear after a long cue–target onset interval. There were no catch trials presented during the task. The task was run on a laptop computer and the presentation was controlled by E-prime software (Schneider, Eschman, & Zuccolotto, 2002).

Each trial started with a fixation cross, which was presented for a random interval ranging between 500 ms and 1500 ms. The temporal cue was presented for 50 ms. Afterwards, a blank screen interval was presented for either 350 ms or 1350 ms, according to the stimulus–onset asynchrony (SOA) between the cue and the target, which was 400 ms in the short SOA condition, and 1400 ms in the long SOA condition. The target was presented for 100 ms, followed by a blank screen presented until a response was made, or for a maximum duration of 2 s.

Participants were seated at a viewing distance of approximately 50 cm from the screen and were asked to respond to the targets as quickly as possible. The task started with a practice block of 24 trials, in which early and late cues were presented with equal probability ($p = .5$) and in random order. During the practice block, only valid cues were presented, i.e., they always signalled the given cue–target interval correctly. Participants received feedback on their accuracy and reaction time. The practice block was followed by 3 experimental blocks, which consisted of 64 trials each. The temporal expectancy was manipulated within the blocks; hence, both early and late cue trials were presented in each block. On 75% of the trials from each block, the cue was valid; on the remaining 25% trials the cue was invalid, i.e., the ''early'' cue was followed by a long time interval, and the ''late'' cue was followed by a short time interval, so that the temporal expectation was not met on these trials. The trials were presented in a new random order to each participant. The participants received feedback if they missed the target, or if they responded before the target was presented.

Social category switching task (SCST).[1] Participants categorised pictures of human faces, according to 1 of 2 social categories: gender (female vs. male) or age (young vs. old). Four black and white photographs – depicting a young female, an old female, a young male, and an old male – were selected from the Center for Vital Longevity Face Database (Minear & Park, 2004), downloaded from http://agingmind.utdallas.edu/stimuli/facedb. All the photographs were placed in the centre of the screen and had the same properties: 7.41 cm width and 6.74 cm height (210×191 pixels). On all trials, a cue in the form of a coloured frame (green or purple) was presented to inform participants about which task (either gender or age categorisation) to perform. The colour–task combination was counterbalanced across participants. The task was run on a laptop computer and the presentation was controlled by E-prime software (Schneider et al., 2002).

Each trial started with the presentation of a fixation cross for 1000 ms. Afterwards, the target picture was presented in the middle of the screen, framed with either the green or the purple coloured frame (the task cue). The cue and the target remained on the screen until the participant responded, or for a maximum duration of 3000 ms. After incorrect responses, a beep was presented and the next trial followed after 1500 ms. Participants responded with both their hands. The ''z'' and ''m'' keys were used to respond to the gender task, and the age task was performed with the ''x'' and ''n'' keys. The matching of the keys to the category exemplars was counterbalanced across participants. (i.e., the responses for ''female'' were made with the ''z'' key and the responses for ''male'' with the ''m'' key or vice versa, and the responses for ''young'' were made with the ''x'' key and the responses for ''old'' with the ''n'' key or vice-versa; see Figure 1). Participants were seated at viewing distance of approximately 50 cm from the screen and were asked to categorise faces. They were given written instructions explaining the matching of keys and the tasks. The task started with 8 practice trials, during which the participants received feedback on their accuracy. The practice trials were followed by 4 experimental blocks consisting of 80 trials each. The stimuli were presented in a new random order to each participant. There was an equal number (80) of presentations for each stimulus photograph.

The 2 tasks (the temporal orienting task and the social category switching task) were presented to participants in a fixed order – the temporal orienting task always being the first 1. Participants also completed another cognitive task (a combined Simon–Stroop task), the results of which will be reported elsewhere. Raven's progressive matrices were administered in a separate session. Participants filled out the Language Background Questionnaire before the experimental session.

Design and data analysis

For the temporal orienting task, we analysed 3 variables: validity, current SOA, and previous SOA. We conducted an ANOVA on the response times (RT) with 3 within-subject factors: previous SOA (short vs. long), current SOA (short vs. long), and validity (invalid vs. valid trials), and with group (monolinguals, bilinguals) as a between-subjects factor. To test for the temporal orienting effects, we analysed the validity effect comparing trials with targets following valid temporal cues (valid trials), and trials following invalid cues (invalid trials), as well as the interaction of validity with current SOA. Moreover, we analysed the interaction between previous SOA and current SOA, which is used to index sequential effects.

In the social category switching task, we analysed 3 variables: type of repetition, task, and task switch. The type of repetition variable coded for specific types of stimuli features repetition with regard to 2 categories: In the complete repetition condition, the same features were repeated (i.e., an identical photograph was presented on consecutive trials, e.g., the ''old woman'' photograph was presented on consecutive

[1] An analogous version of the task that employed emotional and gender stimuli was developed by López-Benítez, Carretero-Dios, Acosta, and Lupiáñez (2012).

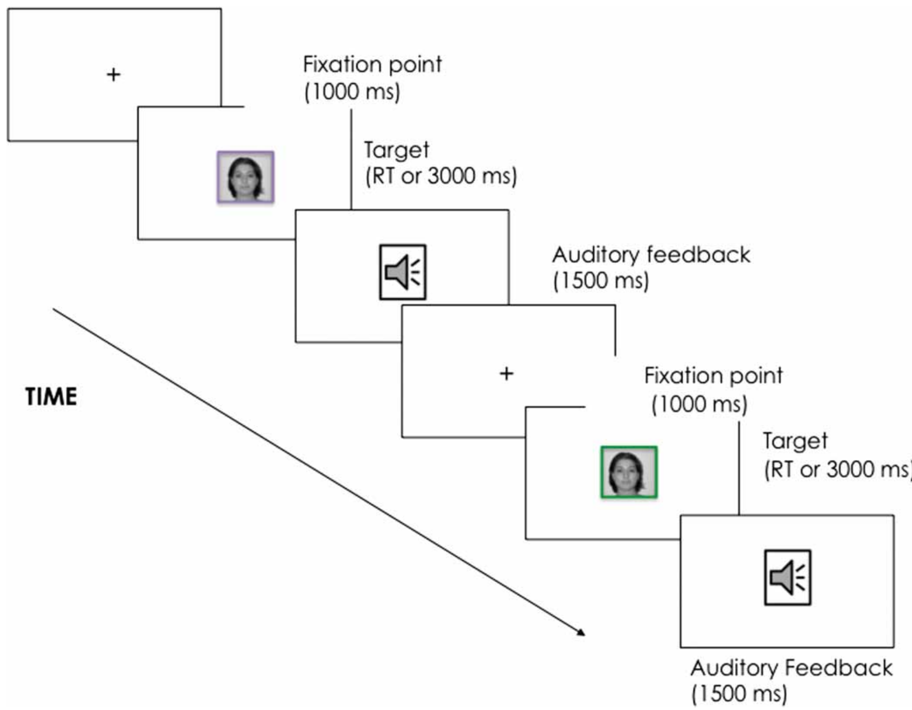

Figure 1. Schematic representation of the social category switching task (SCST). Sequence of events representative for the complete stimulus repetition and category switch condition. The image is reproduced from The Center for Vital Longevity Face Database (Minear & Park, 2004), downloaded from http://agingmind.utdallas.edu/stimuli/facedb [To view this figure in colour, please visit the online version of this Journal.]

trials), in the complete alternation condition, different features (alternative dimensions of both categories with regard to previous trial) were presented (e.g., the ‘‘young man’’ photograph was presented after the ‘‘old woman’’ photograph), in the partial repetition condition, 1 feature was repeated, while the other changed (e.g., the ‘‘old man’’, or the ‘‘young woman’’ photograph was presented after the ‘‘old woman’’ photograph). The type of repetition variable was coded offline, i.e., after the data were collected. The task variable indicated which task participants had to perform, i.e., according to which category they categorised the stimuli (age vs. gender categorisation). The task switch variable indicated whether the participants were required to switch (switch condition) to perform a different task, or perform the same task on 2 consecutive trials (no switch condition). The task switch variable was also coded offline. The RT and percentage of errors (ERR) were analysed by an ANOVA with 3 within-subject factors: type of repetition (alternation, complete repetition, partial repetition), task (age, gender), task switch (switch, no switch), and group (monolinguals, bilinguals) as a between-subjects factor. Additionally, switch costs (switch condition vs. no switch condition) were analysed for each type of repetition condition, and for each task condition.

RESULTS

Temporal orienting task

We analysed the temporal orienting and the sequential effects for mean RT by ANOVA with previous SOA (short, long), current SOA (short, long) and validity (valid, invalid) as within-subject factors, and group (monolinguals, bilinguals) as a between-subjects factor. Only the RTs from experimental blocks were included in analyses. Omissions (.40%) and RTs shorter than 100 ms and longer than 1000 ms, as well as RTs from the first trial of each block, were excluded from the RT analysis (3.17%). Table 2 shows the mean RTs and the proportions of omissions broken down by the experimental conditions and the group of participants.

TABLE 2

Temporal orienting: mean RTs and proportion of omissions (*SD* in parentheses) broken down by group of participants (monolinguals, bilinguals), current SOA (short, long), previous SOA (short, long), and validity (short, long)

	Current trial: Short SOA				Current trial: Long SOA			
	Previous trial: Short SOA		Previous trial: Long SOA		Previous trial: Short SOA		Previous trial: Long SOA	
	Valid	*Invalid*	*Valid*	*Invalid*	*Valid*	*Invalid*	*Valid*	*Invalid*
Monolinguals								
RT	303 (97)	327 (91)	339 (94)	361 (95)	300 (72)	312 (93)	318 (92)	314 (93)
% of omissions	.83 (1.82)	.00 (.00)	.00 (.00)	.41 (1.94)	.46 (1.49)	1.69 (4.63)	.00 (.00)	.70 (1.78)
Bilinguals								
RT	290 (60)	312 (63)	316 (59)	341 (56)	295 (49)	302 (54)	298 (43)	292 (45)
% of omissions	.75 (1.52)	.41 (1.94)	.13 (.63)	.00 (.00)	.25 (.81)	0.78 (2.56)	.00 (.00)	.38 (1.07)

Response times. Mean RT was 310 ms ($SD = 102$ ms). A significant main effect of SOA, $F(1, 42) = 21.66$, $p < .001$, $\eta_p^2 = .34$, showed faster RTs for the long SOA than for the short SOA (304 vs. 324 ms, respectively). We observed the typical validity effect, $F(1, 42) = 24.11$, $p < .001$, $\eta_p^2 = .36$, showing faster RTs for valid (307 ms) than for the invalid condition (321 ms). The interaction between the current SOA and validity, $F(1, 42) = 15.61$, $p < .001$, $\eta_p^2 = .27$, revealed that the validity effect was present only for the short SOA, $F(1, 42) = 33.06$, $p < .001$, $\eta_p^2 = .44$, and not for the long SOA, $F(1, 42) = 1.08$, $p = .305$, $\eta_p^2 = .02$. This is the usually observed pattern of results (see, e.g., Correa et al., 2006, 2010). A significant main effect of previous SOA, $F(1, 42) = 45.52$, $p < .001$, $\eta_p^2 = .50$, indicated slower RT on trials preceded by long SOA trials (320 ms) than on trials that were preceded by short SOA trials (301 ms). The interaction between previous SOA and current SOA was significant, $F(1, 42) = 42.75$, $p < .001$, $\eta_p^2 = .50$, replicating the typical pattern of asymmetric sequential effects. Therefore we looked at the effect of previous SOA at each of the current SOAs. The effect of previous SOA was present for both short and long current SOA; however, it was more pronounced at the current short SOA, $F(1, 42) = 74.25$, $p < .001$, $\eta_p^2 = .64$, and $F(1, 42) = 5.30$, $p = .026$, $\eta_p^2 = .11$, for short and long current SOA conditions, respectively.

Bilinguals vs. monolinguals. In the RT measure, the main effect of group was not significant ($F < 1$); neither was the interaction between validity and group ($F < 1$), nor the 3-way SOA × Validity × Group interaction ($F < 1$). Hence, bilinguals and monolinguals did not differ in the magnitude of the temporal orienting effects.

However, the analysis of sequential effects showed a significant interaction between the previous SOA and group, $F(1, 42) = 4.75$, $p = .035$, $\eta p^2 = .10$ (see Figure 2). As we described earlier, responses were significantly slower on trials preceded by long SOA than on trials preceded by short SOA. The magnitude of this effect (the difference between previous long SOA and previous short SOA) was considerably smaller in bilinguals (13 ms; $F(1,21) = 9.75$, $p = .005$, $\eta p^2 = .32$) than in monolinguals (25 ms; $F(1,21) = 59.10$, $p < .001$, $\eta p^2 = .74$), showing that bilingual participants were less affected by the duration of the previous SOA.

Additionally, we compared bilinguals and monolinguals on another index that we assumed

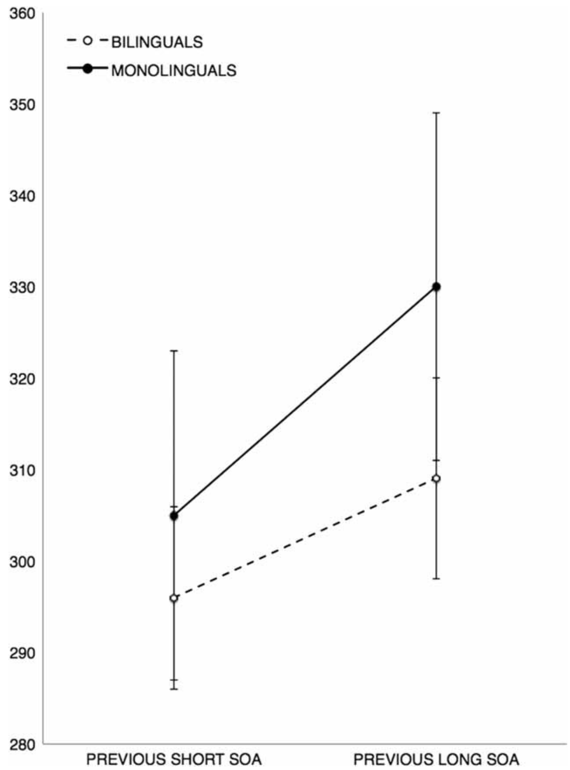

Figure 2. Temporal orienting task: interaction between previous SOA and group of participants in the RT measure (error bars represent standard errors).

might be modulated by the mechanisms of cognitive flexibility – the efficiency of temporal reorienting, i.e., the ability to quickly react to a target which was invalidly cued by an early cue but appearing at a long preparatory interval. The index of reorienting was calculated by comparing the RT following invalid cues in the 2 conditions: the short SOA and the long SOA. The reorienting index yielded 31 ms, $t(42) = 6.12$, $p < .001$. The magnitude of the effect did not differ between monolinguals and bilinguals, $t(41) = -.01$, $p = .989$.[2]

Social category switching task

The data from 1 participant were missing due to technical failure; therefore, data from 43 participants were analysed (22 bilinguals and 21 monolinguals). Only the RTs from the experimental blocks were included in analyses. Erroneous responses, and RTs shorter than 200 and higher than 2000 ms, as well as RTs from the first trial of each block were excluded from the analysis of response times (altogether 12.3%). For both RT and ERR, we conducted an ANOVA with 3 within-subject factors: type of repetition (alternation, complete repetition, partial repetition), task (age, gender), and task switch (switch, no switch), with group (monolinguals, bilinguals) as a between-subjects factor. Table 3 shows mean RT and ERR broken down by condition and group of participants.

Response times. The mean RT was 968 ms ($SD = 342$). In the RT measurement, we observed a significant main effect of type of repetition, $F(2, 82) = 96.68$, $p < .001$, $\eta_p^2 = .70$, indicating that reactions were faster when the same stimulus was repeated (complete repetition) compared to complete alternation (876 vs. 1032 ms), $F(1, 42) = 106.26$, $p < .001$, $\eta_p^2 = .72$, whereas responses in the partial repetition condition were faster than in the complete alternation condition (1002 vs.1032), $F(1, 42) = 10.08$, $p = .003$, $\eta_p^2 = .19$. Reactions were faster when the task remained the same than when the task changed (same task trials vs. task switch trials respectively: 899 vs. 1048 ms), $F(1, 41) = 162.10$, $p < .001$, $\eta_p^2 = .80$. The main effect of task was not significant, $F(1, 41) = 1.20$, $p = .29$, $\eta_p^2 = .03$. We observed a marginally significant interaction between type of repetition and task, $F(2, 82) = 3.06$, $p = .052$, $\eta_p^2 = .07$, showing that reactions were the fastest when the identical stimulus was repeated in the gender task condition. We observed a significant interaction between the type of repetition and task switch, $F(2, 82) = 59.4$, $p < .001$, $\eta_p^2 = .59$, and therefore calculated the switch costs for each repetition condition. Although switch costs were significant in all 3 conditions ($p < .001$), the cost of switching category was larger in the complete repetition condition, than in the partial repetition condition (264 vs. 111 ms), $F(1, 42) = 73.54$, $p < .001$, $\eta_p^2 = .64$, whereas the switch cost in the partial repetition condition was larger than in the complete alternation condition (111 vs. 67 ms), $F(1, 42) = 10.70$, $p = .002$, $\eta_p^2 = .20$. This pattern of results is in line with our expectations that the repetition of some aspects of the stimuli but switch into another categorisation task would produce partial repetition costs (see Hommel, 2004, 2009). We observed a significant interaction between the task and task switch, $F(1, 41) = 51.7$, $p < .001$, $\eta_p^2 = .56$; there-

[2]The pattern of data did not change when data from 1 participant (whose mean RT was above 3 standard deviations from the overall mean) were excluded and data were normalised (by means of log-transformation).

TABLE 3
Social category switching: mean RTs and ERR (*SD* in parentheses) broken down by type of repetition (complete alternation, complete repetition, partial repetition), task (gender, age), task switch (switch, no switch), and group of participants (monolinguals, bilinguals)

			Response time (ms)		*Error rate (%)*	
Repetition	*Task*	*Task switch*	*Monolinguals*	*Bilinguals*	*Monolinguals*	*Bilinguals*
Complete alternation	Gender	No switch	1034 (193)	1024 (156)	13.73 (17.99)	4.13 (5.44)
		Switch	1065 (219)	1022 (155)	9.09 (11.98)	5.90 (7.64)
	Age	No switch	974 (198)	967 (153)	8.64 (14.15)	5.04 (5.03)
		Switch	1091 (212)	1099 (164)	13.96 (12.98)	8.01 (7.20)
Complete repetition	Gender	No switch	742 (138)	765 (131)	3.14 (7.04)	1.13 (2.59)
		Switch	988 (186)	966 (146)	11.76 (13.07)	5.82 (5.83)
	Age	No switch	747 (108)	744 (138)	4.09 (8.08)	1.67 (2.96)
		Switch	1054 (168)	1057 (178)	12.95 (14.38)	8.74 (8.24)
Partial repetition	Gender	No switch	956 (161)	961 (121)	12.22 (15.52)	4.30 (5.18)
		Switch	1061 (187)	1009 (153)	11.39 (15.11)	4.27 (3.56)
	Age	No switch	932 (160)	938 (139)	12.28 (13. 67)	4.40 (3.46)
		Switch	1076 (172)	1086 (190)	10.49 (13.11)	8.21 (7.86)

fore, we calculated the switch costs for each of the tasks separately. The switch costs for both the age and the gender tasks were significant ($p = .001$), and the cost of switching was larger when participants had to switch to perform age judgement than to perform gender judgement (182 ms vs. 100 ms), $F(1, 42) = 44.67$, $p < .001$, $\eta_p^2 = .51$.[3]

Error rates. The mean error rate (ERR) was 7.72%. We observed a significant main effect of type of repetition, $F(2, 82) = 8.42$, $p < .0001$, $\eta_p^2 = .17$, showing that responses were the most accurate in the complete repetition condition (6.16% of errors as compared to 8.56% in the complete alternation, and 8.44% and in the partial repetition condition, respectively). Participants made more errors in the task switch condition than when the task remained the same (9.22% vs. 6.23%), $F(1, 41) = 37.14$, $p < .001$, $\eta_p^2 = .475$. The main effect of task was not significant, $F(1, 41) = 2.61$, $p = .114$, $\eta_p^2 = .060$. We observed a significant interaction between repetition type and task switch, $F(1, 41) = 19.01$, $p < .001$, $\eta_p^2 = .38$; therefore, we calculated the switch costs for each condition. The cost of switching categories was significant only in the complete repetition condition (7.18%, $p < .001$), and was not significant for the complete alternation (1.37% ms, $p = .081$), nor for the partial repetition condition (0.41%, $p = .58$). We observed a significant interaction between task and task switch, $F(1, 41) = 6.78$, $p = .013$, $\eta_p^2 = .14$, and the comparison of switch costs for each task showed that, similar to the RT measurements, the switch costs were significant both for age (3.57%, $p < .001$) and gender (1.02%, $p = .048$), but a significantly larger switch cost was observed when participants had to switch from performing the gender task to perform the age task, than vice versa (3.57% vs. 1.02%), $F(1, 42) = 6.33$, $p = .016$, $\eta_p^2 = .10$. The interaction between repetition type, task, and task switch was only marginally significant, $F(2, 82) = 2.59$, $p = .081$, $\eta_p^2 = .059$.

Bilinguals vs. monolinguals. The comparison between monolinguals and bilinguals in RT measures showed that the main effect of group was not significant. We observed a significant interaction between task, task switch, and group, $F(1, 41) = 4.40$, $p = .041$, $\eta_p^2 = .10$. Therefore, we

[3] RT data in the SCST task were normally distributed, as indicated by Kolmogorov–Smirnov tests for RTs in each condition of the task ($p > .05$). We performed an additional analysis to answer the question whether the gender of participants interacts with the switch costs for female and male gender categorisation. We calculated switch costs separately for female and male pictures, and conducted ANOVA with gender of stimuli (male, female) as a within-subject factor and gender of participant (male, female) as a between-subjects factor. The main effect of gender of stimuli was not significant ($F < 1$), neither was the main effect of group of participants ($F < 1$). However, we observed a significant interaction between gender of stimuli and gender of participants, $F(1, 41) = 4.25$, $p = .046$, $\eta_p^2 = .09$: for female participants, the magnitude of switch costs were larger when they were categorising male pictures as compared to when categorising female pictures (156 ms vs. 134 ms), whereas for male participants the pattern was reversed, the magnitude of switch costs was larger when the categorisation of a female picture was required as compared to the categorisation of a male picture (141 ms vs. 112 ms).

calculated the switch costs for bilinguals and monolinguals for both tasks, which showed significantly lower switch cost in bilinguals than in monolinguals, but only when they had to switch to perform the gender task (73 ms vs. 128 ms for bilinguals and monolinguals, respectively), $F(1, 41) = 4.14$, $p = .048$, $\eta_p^2 = .09$. The switching costs observed for the age task, however, were similar for the 2 groups (179 ms vs. 185 ms, $F < 1$).

After comparing the 2 groups on the magnitude of the asymmetry of switching costs, i.e., larger switching cost when switching to age task than to gender task, bilinguals showed a more asymmetrical pattern of switching than monolinguals (106 vs. 57 ms), $t(41) = -2.05$, $p = .047$. These findings confirmed our predictions based on previous results (Prior & MacWhinney, 2010) that bilinguals would experience reduced costs of switching, but the effects were limited to the performance on the gender task.

Bilinguals tended to commit fewer errors in general than monolinguals (5.1% vs. 10.3%), $F(1, 41) = 3.77$, $p = .059$, $\eta_p^2 = .08$. Importantly, a significant interaction between the type of repetition, task switch, and group was observed, $F(2, 82) = 3.43$, $p = .037$, $\eta_p^2 = .077$. We performed 1-way ANOVAs to compare the performance of bilinguals and monolinguals. Results showed that bilinguals tended to be more accurate than monolinguals when the identical stimulus was repeated but the participants were required to switch into a different task (6.9% for bilinguals vs. 12.3% ERR for monolinguals), $F(1, 42) = 3.27$, $p = .078$, $\eta_p^2 = .07$. They also tended to be more accurate in the condition of complete alternation of stimulus, when the task remained the same (4.6% vs. 11.2%), $F(1, 42) = 3.61$, $p = .064$, $\eta_p^2 = .08$. Bilinguals were significantly more accurate in the condition of partial repetition of stimulus, when the task remained the same (4.28% vs. 11.9%), $F(1, 42) = 6.15$, $p = .017$, $\eta_p^2 = .13$. These results reveal that bilinguals were more accurate especially in conditions that required a certain amount of flexibility in updating stimulus–task set bindings. Additionally, this interaction was modulated by task factor (Type of repetition × Task × Task switch × Group), $F(2, 82) = 5.66$, $p = .005$, $\eta_p^2 = .12$. Therefore, we looked at the performance of bilinguals and monolinguals in individual conditions. Under the partial repetition condition, the accuracy of bilinguals was higher for both the gender, $t(41) = 2.26$, $p = .029$, and the age, $t(41) = 2.62$, $p = .012$, tasks, when the task remained unchanged in 2 consecutive trials. Bilinguals were also more accurate in switching than monolinguals under the complete repetition condition, $t(41) = 1.94$, $p = .059$, and the partial repetition condition, $t(41) = 2.14$, $p = .038$, but only when they were required to switch into the gender task. Interestingly, bilinguals also performed the gender task more accurately when they encountered a complete alternation of stimulus, but the categorisation rule remained the same, $t(41) = 2.39$, $p = .021$. These results point to the plausible conclusion that bilinguals' flexibility, reflected in the accuracy of updating stimulus–task set bindings, was more pronounced for the gender categorisation task.[4]

Relationship between the flexibility indices from the social category switching task and the temporal orienting task

We performed a correlational analysis of the indices of flexibility from the 2 tasks to provisionally test the hypothesis that bilinguals make use of efficient general mechanisms of cognitive flexibility in both tasks. We calculated the correlations of the previous SOA effect (difference between a long previous SOA and a short previous SOA) with switching costs in the SCST. No significant correlations between the previous SOA effect and switching costs were observed overall for all participants, or even for the 2 groups separately (all $ps > .05$).

We also looked at the correlations of the index of reorienting (RT in the short SOA/invalid cue condition – RT in the long SOA/invalid cue condition) with the switching costs in the SCST.

[4] In the SCST task RT and ERR variables were – in general – positively and significantly correlated (except for 2 conditions, namely the complete repetition, no-switch, gender task condition and the complete repetition, no-switch, age task condition). RT and ERR in the SCST task therefore seem to be related measures of cognitive flexibility. Taking into consideration that the effects observed on the error proportion scales are usually nonlinear, we additionally performed mixed effect logistic regression on the ERR data. The mixed effect logistic regression showed a pattern of results very similar to that obtained with ANOVA. The results clearly showed that bilinguals were significantly more accurate than monolinguals when switching into another task under condition of complete repetition of stimuli, and under condition of partial repetition of stimuli (but in this case only when switching into the gender task). Bilinguals also showed a significantly higher accuracy on no-switch trials: under the partial repetition condition (both for the gender and age task) and the complete alternation condition (only for the gender task).

When the analysis was conducted for the entire group of participants, we didn't find any significant correlations between the reorienting index and the switching costs. However, when we looked at correlations in the monolingual and bilingual group separately, the pattern of correlations was different in each group. In the monolingual group ($N = 22$), we found a positive correlation between the reorienting index and the RT switching costs in the complete repetition condition, $r = .50$, $p = .02$. In the bilingual group, the pattern of correlations was different and 3 relatively strong correlations were observed. First, the magnitude of the reorienting index displayed strong negative correlation with the magnitude of switching cost in terms of ERR in the complete alternation condition, $r = -.70$, $p < .001$. Second, the reorienting index was negatively correlated with the RT switching cost in the complete repetition condition, $r = -.56$, $p = .006$, and the RT switching cost in the partial repetition condition, $r = -.57$, $p = .006$. Hence, it seems that, to a certain extent, the indices of flexibility, namely the reorienting index and switching costs, are interrelated within the bilingual group.

DISCUSSION

In the current study, we compared bilinguals and monolinguals on 2 tasks that involve mechanisms of cognitive flexibility and require participants to overcome certain forms of cognitive rigidness: a temporal orienting task that involves switching between preparatory intervals of different duration, and a social category switching task that involves switching between categorisation rules. In the first part of the discussion, we discuss the effects of bilingualism on the processes of temporal preparation. In the second part, we discuss the results observed in the social category switching task, especially focusing on the advantage for bilinguals in switching (as reflected by a reduced switch cost), and on the increased accuracy of bilinguals, which was most prevalent in conditions that require increased flexibility of updating stimulus–task set bindings. Synthesising the evidence from 2 different paradigms, we argue that the flexibility of bilinguals may influence a broader spectrum of cognitive processes than previously thought of, which seems to corroborate Hilchey & Klein, 2011 BEPA hypothesis suggesting that the general bilingual advantage is demonstrated in regulating the processing across a wide variety of task demands. However, we argue that bilinguals are more efficient in adjusting their cognitive system to task demands under specific conditions that require increased cognitive flexibility.

Flexibility of temporal preparation

We set out with the hypothesis that the enhancement of cognitive control should be manifested in bilinguals' increased ability to prepare for upcoming stimuli. To this end, we explored whether bilinguals differ from monolinguals with regard to temporal orienting effects. Standard main effects of temporal preparation were obtained. Specifically, in the short SOA condition, a typically reported validity effect was observed: responses were slower in the invalid cue condition than in the valid cue condition (cf. Correa et al., 2004, 2006, 2010). Moreover, we observed a sequential effect indexed by slower responses after long previous SOA intervals. Although bilinguals and monolinguals did not differ with regard to the temporal orienting effects (as indexed by the validity effect), the pattern of the sequential effects differed between the 2 groups. The responses were generally slowed down after a long previous SOA trial, but the effect was less salient in the bilingual group. It seems, therefore, that bilinguals were less affected by the duration of the previous preparatory interval and were more flexible in reacting to the current demands of the task.

There are several views on the nature of sequential effects in the temporal orienting task; next, we discuss our results in light of 2 prevalent accounts. According to Los and van den Heuvel (2001), the effects reflect automatic processing rather than controlled processing, and are thought to be a result of unintentional trace conditioning between cue and target. The repetition of preparatory intervals of the same duration increases the conditioned strength of the response. Therefore, the conditioned strength is increased on short current trials following short previous intervals, but reduced or diminished on short current preparatory intervals preceded by long intervals. This model, however, does not seem to contribute to the explanation of our findings, as there seems to be no available evidence suggesting that bilinguals would differ from monolinguals with regard to the mechanisms of extinction.

A model of sequential effects proposed by Vallesi and Shallice (2007), on the other hand, assumes a different source of sequential effects, namely the changes in arousal level (i.e., readiness to respond). The arousal level is thought to be increased on trials following a previous short foreperiod, but decreased on those following a previous long foreperiod, irrespective of the current foreperiod duration. According to Vallesi and Shallice, long previous intervals exert refractory effects over preparatory level in the current trial, because they are cognitively exhausting (Näätänen, 1971). In line with this theoretical view of sequential effects, we could assume that a less pronounced previous foreperiod effect in bilinguals might be a result of their ability to maintain higher levels of readiness after long preparatory intervals, which aids in reducing the refractory effect of long previous foreperiods. This explanation is in line with previous findings on alerting efficiency in bilinguals, which suggest that bilinguals are able to achieve and maintain higher levels of readiness to respond to incoming stimuli (cf. Costa et al., 2008; Marzecová et al., 2012). To the best of our knowledge, ours is the first study to report modulatory effects of bilingualism on the mechanisms of temporal preparation, and on sequential effects in particular. These results suggest that the assumed bilingual advantage in the flexibility of cognitive processing may extend to the domain of temporal processing.

Flexibility of switching between categories

In the social category switching task, we observed that the flexibility of switching differed depending on the type of repetition of stimuli, and the type of categorisation rule implied by the task. The largest switching cost (both for the speed and the accuracy of the responses) was observed in the condition when the identical stimulus was repeated, but the categorisation task was different than in the previous trial. This result seems to be in line with our initial hypothesis that partial repetition costs are generated whenever there is a need to update the stimulus–task set binding as a result of a requirement to change the response for a repeated stimulus. Moreover, we noted an asymmetry in switching costs: Switching into the "age categorisation task" was slower than switching into the "gender categorisation task".

A comparison between the bilingual and monolingual performance revealed 3 main findings. The first 1 was detected in the reaction time measure and indicated that bilinguals were considerably faster than monolinguals when switching to the gender task, as reflected in the reduced switch cost in the RT measure. The second outcome was the overall tendency of bilinguals to be more accurate across all conditions. The third result also relates to the accuracy measure: Bilinguals committed fewer errors than monolinguals in particular task conditions, which, as we discuss later, demanded larger amounts of cognitive flexibility. In particular, bilinguals were more accurate than monolinguals when the task remained the same as in the previous trial, but there was a partial repetition of stimuli (1 feature of the stimulus was repeated and the other feature changed), i.e., nonswitch trials with a partial repetition of stimuli features. Bilinguals also committed less errors under the conditions of complete stimulus repetition (both features are repeated) and partial stimulus repetition (only 1 feature is repeated) but only when switching to the gender task. Moreover, bilinguals categorised gender more accurately when they encountered a complete repetition of stimulus, and the task remained the same. We will now discuss the 3 main findings from the SCST task and the possible mechanisms that may have led to the obtained pattern of results.

Reduced switch costs for the gender task. The results showed a reduced switch cost for bilinguals in the reaction time measure. Interestingly, the reduced switch cost was observed only for the gender task, and not for the age task. This result points to a certain limitation to the previously observed general bilingual advantage on flexibility of switching (Prior & MacWhinney, 2010). It has been argued that the flexibility of switching may be tuned by specific characteristics of language use and vary across different populations of bilinguals (Prior & Gollan, 2011). Our results suggest that the enhancement in flexibility of switching may be specific to certain tasks (i.e., categorisation rules) implemented in the switching paradigm.

Why would bilingual performance be specifically enhanced in the gender categorisation task? Previous research on face categorisation showed that although gender and age perception is implicit and takes a comparable amount of time, when explicit categorisation processes are required, age judgements are more difficult to make (as indicated by longer-latency ERP effects;

see Mouchetant-Rostaing & Giard, 2003).[5] Although, in the current study, no overall processing advantage between the 2 tasks has been observed, for bilinguals, switching from age to gender conferred a reduced switch costs compared to switching from gender to age. If, as argued earlier, age is a more complex category to process than gender, then we can interpret the reduced switch cost from age to gender as reflecting greater efficiency in disengaging from the more complex task and reorienting attention to another task at hand. It is therefore tempting to interpret the bilinguals' benefit in switching from age to gender, as yet another manifestation of the same attentional mechanism underlying a (generally) more adaptive behaviour observed for bilinguals: the superior ability to ignore currently/or previously irrelevant information and the flexible adjustment to the ongoing task requirements.

The nature of bilingual advantage in accuracy. An interesting aspect of the current study was that bilinguals tended to be generally more accurate than monolinguals when performing the switching task. The differences between bilinguals and monolinguals in overall accuracy have been rarely reported in young adults. With some exceptions (e.g., Marzecová et al., 2012), the effects of bilingualism in young adulthood are usually manifested in response latencies. The question arises why the index of accuracy proved to be sensitive to the group differences in this study. The task employed in the current study was considerably difficult – the error rate yielded 7.72%. According to Marzecová et al. (2012), less error-prone performance of bilinguals may reflect the ability to efficiently focus the attention on the task at hand. This enhanced ability of sustained attention may be characterised by reduced fluctuations and lapses of attention, which are known to disrupt goal-directed behaviour and lead to response errors (Padilla, Wood, Hale, & Knight, 2006; Sylvester, d'Avossa, & Corbetta, 2006; Weissman, Roberts, Visscher, & Woldorff, 2006). The reduced fluctuations of attention might thereby result in more efficient goal-directed behaviour.

The nature of bilingual advantage in specific task conditions demanding increased flexibility. The accurate performance of bilinguals was most pronounced in particular conditions of the task. Bilinguals committed fewer errors than monolinguals when 1 feature of the stimulus changed with respect to the previous trial, but they were required to perform the same task as in the previous trial. When performing a gender categorisation task, bilinguals were more accurate: (1) under the conditions of complete repetition (both features are repeated) and partial repetition of stimulus (only 1 feature is repeated) when a switch was required; and (2) when they encountered a complete alternation of a stimulus, but the task remained the same. Is there a common denominator between these conditions that leads to the particularly apparent benefit to bilinguals?

It is interesting to note that the bilingual advantage was demonstrated under conditions that required a very specific ability of ignoring an aspect of the stimulus or the task that was previously relevant. However, monolinguals and bilinguals were in general equivalently accurate when the stimuli were altered and required a different response, in other words, whenever the experimental setting changed entirely. The bilingual advantage in SCST task is therefore manifested in a very specific situation, in which an identical or a similar event requires a different response, or the same response is needed in the context of an altered stimulus. Therefore, it seems that a "switch", or a flexible reconfiguration of the experimental settings, is required for the bilingual advantage to emerge. It seems that these results can be explained by referring to processes that contribute to the cognitive rigidity, as discussed by Meiran (2010). Within these processes, Meiran includes a stimulus–set binding, which relates to a formation of binding between task sets and the stimuli on which tasks were executed. Taking into account Hommel's theory of event coding (2004, 2009), we may assume that stimulus–response bindings are responsible for worsened performance under conditions when the same response is repeated, but certain features of stimulus are altered, or when a different response is required, but certain stimuli features remain unaltered. We suggest that these situations induce costs because of the need to "unbind" previously

[5] This might be due to the fact that age classification requires a distinction between less well-delimited classes (young/old), whereas gender judgements are based on more qualitative distinctions between 2 well-defined categories (men/women) (see Mouchetant-Rostaing, & Giard, 2003). It has been shown that the visual clues on which gender judgements are based are more isolated (eye and eyebrow regions) and more prominent than those (skin texture and colour) required for age judgements (Brown & Perrett, 1993; Roberts & Bruce, 1988).

formed stimulus–task set bindings. Increased accuracy of bilinguals under these conditions may be thus accounted as stemming from the enhanced flexibility in stimulus–task set "unbinding".

As stated previously, the advantage of bilinguals in the SCST task was not only manifested on switch trials, but was also observed on some no-switch trials. According to Prior (2012), the reduced switch costs of bilinguals may be a result of a more efficient activation of the relevant task set, which helps to overcome proactive interference that occurs on switch trials, and aids efficient selection between competing task sets. According to several authors (see e.g., Koch & Philipp, 2005; Meiran, 2010), efficient switching involves both inhibitory processes and task-set activation processes. In those switching paradigms that involve task repetitions (which is the case in the SCST), activation of the relevant task would be the dominant strategy (Philipp & Koch, 2006), since the inhibition would be detrimental for the performance on task repetition trials. This view may explain the results from the current study, in which bilingual advantage was observed both on task-switch and task-repetition trials.

Extending bilingual advantage into the domain of social cognition

It is worth emphasising that the results obtained in the social category switching task are the first ones, to our knowledge, that relate to the issue of differences between monolinguals and bilinguals in the domain of social information processing. The question whether bilinguals' advantage in cognitive flexibility transfers into social contexts seems highly relevant and yet still underexplored. Interestingly, our data imply that the type of social category being processed does matter, since the differences between the 2 groups appeared mainly in the gender categorisation task, but not in the age categorisation task. We believe that the reported benefit of bilinguals over monolinguals in switching from a more complex social category as well as the advantage in flexible switching between 2 levels of social categories can be explained by bilinguals' greater efficiency of attentional reorienting when facing social stimuli. One limitation of this study is that no other switching task with nonsocial stimuli was included as a comparison. Further research should help to identify the precise differences in switching between nonsocial and social stimuli for bilingual and monolingual samples. Nevertheless, this study provides preliminary findings on bilingual advantage in a specific domain of switching between 2 social categories represented by facial stimuli. The notion that bilinguals can be more efficient in controlling various types of cognitive biases in more complex environmental conditions (i.e., also controlling the negative impact of background categorical knowledge on perception, judgement, and decision making) carries nontrivial, socially relevant consequences.

Synthesising evidence for increased cognitive flexibility in bilinguals

Comparing the results from both the temporal orienting and the SCST task, we may conclude that bilinguals, in comparison to monolinguals, showed an enhancement in specific processes related to cognitive flexibility. First, they were less affected by the duration of the previous trial in the temporal orienting task, and, second, they exhibited increased flexibility in terms of switching mental sets in the SCST. In particular, they were more accurate on trials that required flexible updating of event files or, in other words, "unbinding" of previously formed stimulus–task set bindings.

An important aspect of these results is that they clearly indicate that the bilingual advantage can be traced in some conditions of the tasks and not in others. Interestingly, we reported an advantage for bilinguals in some switch conditions but also in no-switch conditions, which was not previously reported in studies on nonlinguistic task switching in bilinguals (cf. Garbin et al., 2010; Prior, 2012; Prior & Gollan, 2011; Prior & MacWhinney, 2010). According to Prior (2012), bilinguals may be more efficient at implementing the dominant strategy (activation or inhibition mechanisms) to overcome task set interference in switching tasks, and, in more general terms, they might have better abilities to adjust control mechanisms to particular experimental conditions. The pattern of results obtained in our study seems to be consistent with such a view. To a certain extent, bilinguals were more effective in flexibly adapting to the current task demands both in the temporal orienting task and in the SCST. It seems that the conditions in which the advantage for bilinguals was observed always required an efficient and fluent changing between mental sets in order to pursue the active processing goal. Those conditions demanded increased cognitive effort and flexibility and, as such, may reflect a general cognitive feature.

It is also tempting to interpret the findings on bilinguals' performance in both tasks by pointing to the fact that experimental situations, in which bilinguals have been reported to outperform monolinguals, seem to have 1 common feature: They all require the participant to resist the influence of carryover effects from previous trials. As such, it is possible that bilinguals are trained to be more effective in combating the persistent activation from aspects of a previously performed trial (i.e., timing of an interval in the temporal orienting task, or same stimuli features in a categorisation task). Such an explanation seems to be consistent with the account that persistent activation is an important contributor to switch costs (Koch & Philipp, 2005; Philipp, Kalinich, Koch, & Schubotz, 2008).

We would like to interpret the results in favour of the view that bilingualism enhances general mechanism of cognitive flexibility and leads to more adaptive behaviour. To provide a provisional test of such a hypothesis, we correlated indices from the 2 tasks employed in this study. Interestingly, we observed strong negative correlations between the magnitude of task switching cost and the ability to reorient from invalidly cued temporal interval, but only in the bilingual group. This seems to suggest that, across a variety of tasks, bilinguals indeed make use of a more general aptitude to flexibly adapt to task demands.

CONCLUDING REMARKS

To sum up, the results obtained in the current study provide new evidence that bilingualism positively influences mechanisms of cognitive flexibility which may be applied across various domains of cognitive functioning. Bilinguals who were simultaneously exposed to both languages soon after birth seem to enjoy the benefit of increased cognitive flexibility that helps them to adjust to task demands and efficiently pursue task goals.

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