Khodos, Iryna; Moskovsky, Christo. “Dimensions of bilingualism promoting cognitive control: impacts of language context and onset age of active bilingualism on mixing and switching costs”. Published in *Linguistic Approaches to Bilingualism* Vol. 11, Issue 5, p. 739-752 (2021).

Available: http://dx.doi.org/10.1075/lab.19064.kho

Dimensions of bilingualism promoting cognitive control: Impacts of language context and onset age of active bilingualism on mixing and switching costs

This is the authors' accepted manuscript of the paper:

Khodos, I., & Moskovsky, C. (2020). Dimensions of bilingualism promoting cognitive control: Impacts of language context and onset age of active bilingualism on mixing and switching costs. *Linguistic Approaches to Bilingualism*. Advanced online publication.
http://doi.org/10.1075/lab.19064.kho

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Abstract

The study investigated the capacity of language experiences to predict cognitive performance of bilingual adults, with a special focus on participants' proactive (mixing costs) and reactive (switching costs) control processes. Using a Language and Social Background Questionnaire, demographic and language data were collected from a linguistically diverse group of 60 bilingual adults residing in Australia. The participants were then tested on a non-verbal switching task. The results of multiple regressions revealed that two of the language variables being examined accounted for the variance in the mixing and switching costs. In particular, reduced mixing costs were related to the use of two languages in a dual-language context and earlier onset age of active bilingualism; reduced switching costs were linked to a dual-language context only. These findings reveal that bilingual experiences contribute to shaping proactive and reactive control processes across cognitive domains.

Keywords: bilingualism, language experiences, mixing costs, switching costs

1. Introduction

The idea of bilingualism leading to long-term benefits that extend beyond the sphere of language has attracted considerable attention over the past four decades. This growing number of studies notwithstanding, the body of findings regarding the effects of bilingualism on the speaker's cognitive operations remains mixed and inconclusive. One of the possible reasons for that may be the multidimensional nature of bilingualism (Luk & Bialystok, 2013) and the possibility that at least some of the cognitive consequences of bilingualism are a function of bilingual experiences (Green & Abutalebi, 2013; Kaushanskaya & Prior, 2015). In the present paper, we focus on the capacity of language factors/experiences to predict the performance of bilingual adults on a non-verbal switching task.

Cognitive benefits associated with bilingualism are ascribed to the fact that both of a bilingual speaker's representational systems are constantly active even when one of them is not required for the current context (Marian & Spivey, 2003). This implies that bilingual speakers have to switch between their two languages so that a contextually appropriate language is selected and interference from the other language is inhibited (Bialystok, 2009).

However, the way bilinguals switch and the degree of switching are a function of multiple factors, in particular language background (e.g., onset age of active bilingualism and levels of proficiency in each of the languages) and general sociolinguistic context (i.e., the environment in which a bilingual acquires their languages and the context(s) in which they use the languages throughout their lifetime). Taken together, these factors are argued to play a significant role in determining the ways in which bilingualism interacts with the general cognitive system (Kaushanskaya & Prior, 2015; Zirnstein, Bice, & Kroll, 2019).

This is in line with the Adaptive Control Hypothesis (Green & Abutalebi, 2013). It suggests that bilinguals use different sets of control processes depending on the interactional context they are in (dense code-switching, single-language and dual-language contexts). Exploring those control processes in terms of non-language tasks requires a procedure which recreates the conditions of the context(s) and thus allows to tap the relevant control components. With this in view, a task-switching paradigm seems to be best-equipped to achieve this (Meiran, Chorev, & Sapir, 2000; Prior & MacWhinney, 2010; Rosselli, Ardila, Lalwani, & Vélez-Uribe, 2016).

In standard cued task-switching paradigms, participants are typically asked to perform two interspersed subtasks: single- and mixed-task blocks. In the single-task blocks, one type of stimuli (e.g., either color or shape) is provided for the whole block of trials. In the mixed-task blocks, participants are presented with two types of stimuli simultaneously (e.g., both color and shape) and they are asked to make a decision on the basis of the cue preceding the stimulus. This procedure enables for two measures of cognitive control to be computed: mixing and switching costs.

*Mixing cost*s are considered to reflect sustained, proactive control mechanisms that enable to keep two competing tasks in mind (Braver, Reynolds, & Donaldson, 2003; Rubin & Meiran, 2005). These costs are associated with the resolution of task-set interference, caused by the stimuli on each and every trial (Rubin & Meiran, 2005); therefore, they include not only working memory load (updating), but also an incongruence effect (interference). *Switching costs* are regarded as transient, reactive control processes (Braver et al., 2003) involved in the preparation and execution of the actual switch. In addition to updating and inhibiting, these costs include monitoring, reconfiguration of the task set and switching.

Given that mixing and switching costs are associated with different control processes, it seems reasonable to assume that different language experiences might affect them in different ways. However, earlier task-switching studies relied on categorical classification of participants (bilinguals vs. monolinguals): they did not look at different dimensions of bilingualism. Moreover, most of them did not take into account the differences between the participants’ language factors/experiences while interpreting their performance on non-verbal switching tasks, which may have contributed to the inconclusive nature of the earlier findings. Some studies established bilingual advantages in mixing costs (Barac & Bialystok, 2012; Wiseheart, Viswanathan, & Bialystok, 2016); another revealed switching-cost benefits (Prior & MacWhinney, 2010); and the others did not find any (Hernández, Martin, Barceló, & Costa, 2013, Experiment 3; Paap & Greenberg, 2013).

In order to shed light on inconsistencies in previous research (i.e., whether or not they are rooted in the participants' language background and use experiences), the current study tested a linguistically diverse group of bilinguals on a non-verbal switching task. More specifically, it examined whether typological proximity/distance, onset age of active bilingualism and/or language context can predict mixing and switching costs in bilingual adults.

The effects of most of these presumed predictors have already been considered in previous research, but with mixed and inconsistent findings – hence the need to examine them further. The role of the typological proximity/distance between L1 and L2 does not seem to have received much attention. This state of affairs is probably at least in part due to the fact that most previous research has worked with participant samples that were linguistically relatively homogeneous – same L1 and same L2. Notably, our sample involved participants with the same L2, but from very diverse L1 backgrounds, which provided an opportunity to explore the possible effects of the typological proximity/distance variable. Furthermore, we targeted young to middle age adults, an age group with less well established bilingual advantage than children and older people (Barac & Bialystok, 2012; Prior & MacWhinney, 2010).

2. Present study

2.1 Procedure

Twenty-to-forty-year-old bilingual adults speaking English as their second language were recruited from the research sites located in the Newcastle/Hunter area, NSW, Australia. The participants were screened on key demographic and language variables using the Language and Social Background Questionnaire by Anderson, Mak, Chahi, and Bialystok (2018).[1] To administer the questionnaire, face-to-face sessions were run so that questions could be clarified and responses discussed. The participants were then asked to perform a non-verbal switching task to measure proactive (mixing costs) and reactive (switching costs) control processes (Miyake et al., 2004; Prior & MacWhinney, 2010). This took place in a computer-equipped room on the premises of the University of Newcastle.

2.2 Participants

The sample consisted of 60 bilingual adults (20-40 years old) from non-English speaking backgrounds[2], including 22 males and 38 females. Descriptive statistics are provided in Table 1.

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[1] Some of its items were slightly adjusted to suit the context of the current study: 1) questions specific to neuroimaging were excluded, 2) references to Canada were replaced with Australia, 3) the life stages were adapted for adults and clearly defined with years cut-offs, and 4) a question on the onset age of active bilingualism was added.

[2] The bilinguals' first language belonged to one of the following language branches: Germanic (11); Romance (13); Slavic (7); Iranian (9); Indo-Aryan (5); Sinic and Tibeto-Burman (6) and other (9).

Table 1. Descriptive Statistics for Demographic and Language Variables. Parental education as a proxy for socio-economic status.

Variable	***N***	**Mean**	***SD***
Demographic			
Gender	Male 22 Female 38	-	-
Age	60	31.92	4.45
Parental education (1-4, 1 = upper secondary, 2 = post-secondary non-tertiary, 3 = short-cycle tertiary, 4 = tertiary education).	60	3.27	.92
Language			
Age of L2 acquisition start-point	60	9.35	4.64
Onset age of active bilingualism	60	21.33	7.83
Language context	Separated 36 Dual 24	-	-

The participants had normal or corrected-to-normal visual acuity (no cases of color-blindness were reported) and no language or hearing impairment. All of them held a higher university degree (*M* = 4.00, *SD* = .00). Thus, education was excluded from further analysis.

The bilinguals were born outside Australia and arrived in the country in adolescence or early to mid-adulthood (ages ranged from 13 to 37). Most of them had started acquiring English in childhood (*M* = 9.35, *SD* = 4.64) in a single first language-oriented environment and had begun using both languages on a regular basis (in the same or different contexts) shortly before or after arriving in Australia (i.e., onset age of active bilingualism; *M* = 21.33, *SD* = 7.83).

In Australia, the bilinguals were immersed in a mostly single second language-oriented environment: on average, they indicated the use of mostly English in terms of broader social contexts (e.g., commercial, healthcare, government services, *ps* > .05). Nevertheless, the participants varied in the way and extent to which each of the two languages was used in close social contexts (e.g., at home, for social activities, *ps* < .05). This enabled us to explore two language contexts: dual and separated. Those, who reported equal use of the two languages in close social contexts depending on the interlocutor (3-3.4 on a 5-point scale), were classified as dual-context bilinguals; those, who rated their language usage as 3.5 and above, were treated as separated-context bilinguals. Descriptive statistics are provided in Table 2.

It is worth noting that the dual- and separated-context bilinguals also varied on language proficiency. The dual-context bilinguals were equally proficient in their two languages and were more proficient in both their first [non-English] language (M = 9.94, SD = .22) and English (M = 9.32, SD = .31) than separated-context bilinguals (M = 9.69, SD = .45 and M = 8.53, SD = .88, respectively), $ps < .05$. This points to the systematic co-variation between language proficiency and language use in second-language contexts, which was supported by the results of the correlation analysis, r = .304, $p < .05$.

Table 2. Means (Standard Deviations) for Language Proficiency and Language Use by Language Context. L1 – non-English. L2 – English. Language proficiency recorded on a 10-point scale, 0 = no proficiency, 10 = high proficiency. Language use recorded on a 5-point scale, 1 = all English, 5 = only the other language.

Language context	***N***	**Language proficiency**		**Language use**	
		L1	**L2**	**Close social context**	**Broad social context**
Separated	36	9.69 (.45)	8.53 (.88)	3.89 (.32)	2.00 (.17)
Dual	24	9.94 (.22)	9.32 (.31)	3.00 (.00)	2.00 (.00)

2.3 Experimental task

The Color-Shape Switching Task was programmed and controlled by Millisecond Software. The design, materials and procedure were closely modelled on those described by Miyake et al. (2004).

The task consisted of two parts: the blocked condition (two blocks of pure-task trials) and the mixed condition (two blocks of mixed-task trials). In both cases, the participants were provided with a stimulus (color and/or shape) and they were asked to respond to it as quickly and as accurately as possible by using the relevant response key: A-key for circle/red and L-key for triangle/green or vice versa. The response keys were randomly determined for each participant at the beginning of the experiment and were kept constant throughout the session.

The pure-task trials were based on the univalent stimuli – either shape (circle vs. triangle) or color (red vs. green) – presented without any cue in the middle of the computer screen until a response was made. In one block, a black line-drawing of either a circle or triangle shape was given on each trial, whereas in the other block, a square-shaped color patch (red or green) appeared in the middle of the screen.

The mixed condition involved the bivalent stimuli (circle or triangle) superimposed on a square-shaped color patch (red or green). In this case, each of the trials was designated either as a repeat trial if the cued decision was the same as in the previous trial (two consecutive color or shape decisions) or a switch one in case it was different (switching between color and shape decisions). As opposed to the blocked condition, a word cue printed in capital letters (COLOR or SHAPE) was chosen randomly and given 200 ms before each stimulus.

First, the participants completed 32 training trials for the blocked condition and 48 (+ start trial) for the mixed condition to master the response-mapping rules. Then they performed 64 blocked-task trials and 100 (+ start trial) mixed-task test trials with one and two brief breaks, respectively. As opposed to the training trials, participants no longer received an error message (i.e., ‘‘incorrect’’) for incorrect responses but were informed of their accuracy (percentage correct) at the end of each block.

Accuracy and reaction times (RTs) were recorded by Millisecond Software for every trial, except for the first ones following the break. The obtained RT indices were trimmed to account for trial-level outliers: any RTs that were longer than three standard deviations above a participant’s mean RT in that condition were replaced with the value of the mean plus 3 standard deviations. Descriptive statistics for overall accuracy and RT for each condition are given in Table 3.

Table 3. Means (Standard Deviations) for Accuracy and RT on the Color-Shape Switching Task. Accuracy is given out of 100% and RT is provided in ms.

Variable	***N***	**Accuracy**	**RT**
Blocked	60	97.63 (4.37)	569.67 (121.40)
Repeat	60	98.80 (1.66)	796.14 (157.04)
Switch	60	97.47 (2.66)	938.81 (183.85)

3. Results

The background and switching-task data were used to determine which language variables were able to predict the bilinguals’ performance on the non-verbal switching task. With this aim, two multiple regression analyses with backward elimination were performed in IBM SPSS Statistics: one for the participants' *mixing costs* as a dependent variable and the other for the *switching costs*.

The predictors were demographic and language variables. The demographic variables included *gender* (1 = male, 0 = female), *age* in years and *parental education* on a 4-point scale (1 = upper secondary, 2 = post-secondary non-tertiary, 3 = short-cycle tertiary, 4 = tertiary). The presumed language predictors were *typological proximity/distance* between L1 and L2 (1 = Germanic languages, 0 = non-Germanic languages), *onset age of active bilingualism* in years and *language context* (1 = dual, 0 = separated).

Mixing costs were calculated by subtracting mean RTs on single-task trials in single blocks from mean RTs on repeat trials in mixed-task blocks; *switching costs*, on the other hand, were computed by subtracting mean RTs on repeat trials from mean RTs on switch trials in mixed-task blocks. Means and standard deviations are provided in Table 4.

Table 4. Descriptive Statistics for Dependent Variables (in ms).

Variable	***N***	**Mean**	***SD***
Mixing costs	60	226.47	127.25
Switching costs	60	142.66	106.76

In all the analyses, the scatterplots of standardised predicted values versus standardised residuals showed that the data met the assumptions of homogeneity of variance and linearity. In addition, the residuals were approximately normally distributed and the assumption of homoscedasticity was met.

An examination of correlations between the predictors revealed that there was a statistically significant correlation only between *gender* and *onset age of active bilingualism*, $p < .05$ (see Table 5). However, the collinearity statistics were all within accepted limits ($VIF < 2$).

Table 5. Bivariate Correlations Between the Independent Variables (*$p < .05$).

Variable	1	2	3	4	5	6
1. Gender	–					
2. Age	-.02	–				
3. Parental education	-.11	.03	–			
4. Typological proximity /distance	-.00	.18	-.19	–		
5. Onset age of active bilingualism	.36*	.10	-.07	.09	–	
6. Language context	-.16	.00	.06	-.01	-.01	–

The six independent variables were entered all at once and then sequentially removed based on the significance threshold of $p < .05$. The regression models for *mixing costs* and *switching costs* were built in five and six steps, respectively, with each of the steps eliminating the statistically insignificant predictor with the highest p-value (see Tables 6 and 7).

Table 6. Multiple Regression Models with Backward Elimination Showing the Capacity of the Variables to Predict Mixing Costs. Model 1a includes all the predictors entered in step one. Model 1b was built in five steps, with only statistically significant predictors being left (*ps* < .05).

Variable	***B***	**SE *B***	***β***	***t***	**Sig.**
Model 1a: R^2 = 25.4%, p < .05					
ΔR^2= 17.0%, p < .05					
Gender (1 = male, 0 = female)	-52.29	33.94	-.20	-1.54	.129
Age in years	-1.04	3.47	-.04	-.30	.766
Parental education on a 4-point scale	-10.74	16.89	-.08	-.64	.528
Typological proximity/distance (1 = Germanic languages, 0 = non-Germanic languages)	-76.04	40.17	-.23	-1.89	.064
Onset age of active bilingualism in years	5.07	2.09	.31	2.43	.019
Language context (1 = dual, 0 = separated)	-94.09	30.44	-.37	-3.09	.003
Model 1b: R^2 = 16.9%, p < .05					
ΔR^2= 14.0%, p < .05					
Onset age of active bilingualism in years	3.92	1.93	.24	2.03	.047
Language context (1 = dual, 0 = separated)	-87.49	29.93	-.35	-2.92	.005

As shown in Table 6, the six independent variables were able to predict 25.4% of the variance in the *mixing costs*, *p* < .05. Among them, *language context* and *onset age of active bilingualism* were shown to be statistically significantly predictors of the dependent variable, *p* < .05. The use of two languages in a dual-language context led to lower mixing costs (*B* = -94.09) than in a separated-language context. As for onset age of active bilingualism, as it decreased by one year, the participants’ mixing costs decreased by 5.07 ms.

However, when the statistically insignificant independent variables were sequentially eliminated by backward elimination regression analysis, the model explained 16.9% of the variance in the *mixing costs*, $p < .05$. In this case, it was *language context* and *onset age of active bilingualism* that significantly predicted the dependent variable, $p < .05$. The use of two languages in a dual-language context resulted in lower mixing costs ($B = -87.49$) than in a separated-language context. In regard to onset age of active bilingualism, as it decreased by one year, the participants’ mixing costs decreased by 3.92 ms.

As for the *switching costs*, the six predictors accounted for 44.4% of the variance in it, $p < .001$ (see Table 7). Notably, in this case only *language context* came out as statistically significant ($B = -112.09$; $p < .001$). Once the statistically insignificant predictors were removed from the model in six steps, it explained 34.8% of the variance in the *switching costs*, $p < .001$. Once again, *language context* significantly predicted the dependent variable: the use of two languages in a dual-language context led to lower switching costs ($B = -107.71$, $p < .001$) than in a separated-language context.

Table 7. Multiple Regression Models with Backward Elimination Showing the Capacity of the Variables to Predict Switching Costs. Model 2a includes all the predictors entered in step one. Model 2b was built in six steps, with only a statistically significant predictor being left (p < .05).

Variable	***B***	**SE *B***	***β***	***t***	**Sig.**
Model 2a: R^2 ***= 44.4%, p < .001***					
ΔR^2 ***= 38.1%, p < .001***					
Gender (1 = male, 0 = female)	-12.87	21.14	-.07	-.61	.545
Age in years	3.61	2.16	.18	1.67	.101
Parental education on a 4-point scale	19.37	10.52	.19	1.84	.071
Typological proximity/distance (1 = Germanic languages, 0 = non-Germanic languages)	-8.32	25.02	-.04	-.33	.741
Onset age of active bilingualism in years	-1.26	1.30	-.11	-.97	.339
Language context (1 = dual, 0 = separated)	-112.09	18.96	-.61	-5.91	.000
Model 2b: R^2 ***= 34.8%, p < .001***					
ΔR^2 ***= 33.7%, p < .001***					
Language context (1 = dual, 0 = separated)	-107.71	19.34	-.59	-5.57	.000

4. Discussion

The study tested the performance of a diverse group of bilingual adults on a non-verbal switching task to examine whether and which bilingual experiences affect two indicators of cognitive performance – mixing costs (proactive control processes) and switching costs (reactive control processes).

The results of the regression analyses revealed that only two of the language variables being examined showed a capacity to predict participants' scores on the task: these were *language context* and *onset age of active bilingualism*. Their effects, however, manifested themselves in a somewhat different way. Reduced mixing costs were linked to the use of two languages in a dual-language context and earlier onset age of active bilingualism. On the other hand, only one of them, language context, emerged as a statistically significant predictor of switching costs: a dual-language context was associated with reduced switching costs.

A number of conclusions can be drawn from this pattern of results. In the first place, they indicate that variability in language experiences affects domain-general executive control functions. Together with other recent studies (Gulllifer et al., 2018; Seo & Prat, 2019), these findings further suggest that some of the inconsistencies in bilingual cognitive control research may have occurred because the differences between the participants' language factors/experiences were not always taken into account while interpreting their performance on cognitive control tasks.

Secondly, our findings reinforce the view that bilingual experiences do not impact cognitive control as a whole construct, but rather affect specific cognitive control processes and in a different way (Paap, Johnson, & Sawi, 2015; Scaltritti et al., 2017). In line with the dual mechanisms framework described by Braver and colleagues (Braver et al., 2003), proactive and reactive control mechanisms were shown to be variably shaped as a function of different language experiences. In particular, proactive control processes (mixing costs) were modulated by language context and onset age of active bilingualism, whereas reactive control processes (switching costs) were affected only by language context.

The emergence of language context as an important dimension aligns with the Adaptive Control Hypothesis (Green & Abutalebi, 2013) and with recent empirical evidence indicating how different contexts of language use affect cognitive control ability (Gullifer et al., 2018; Hartanto & Yang, 2016; Pot, Keijzer, & de Bot, 2018). In particular, repeated, deliberate use of two languages depending on the interlocutor – even when limited to certain contexts – was shown to lead to lower mixing and switching costs than the use of two languages in a separated-language context.[3] This implies that bilinguals who have mastered adaptive control in a dual-language context or across different interactional contexts are more likely to be better at background monitoring and inhibiting, faster at detecting the cue and making the required response than bilinguals from a separated-language context.

Although these findings are broadly in line with previous studies, the effects of the language context variable should be considered with caution. Given the co-variation between language use (the variable used to extract language context) and language proficiency in our bilingual sample (r = .304, p < .05), the effects of language context variable might have been mediated by language proficiency (see Iluz-Cohen & Armon-Lotem, 2013; Poarch & van Hell, 2012). The dual-context bilinguals reported equal use of the two languages in close social contexts and higher language proficiency than separated-context bilinguals. It might thus be possible that better task-switching

[3] The specific distribution of language usage patterns we had in our sample only allowed us a coarse dichotomization of the language context variable. In view of the fact that context of language use has emerged as an important predictor of bilingual cognitive performance, future research should undertake a more fine-grained examination of this variable – perhaps involving a continuous quantitative operationalization.

performance metrics were associated with a dual-language context not only due to its language usage patterns but also due to higher levels of language proficiency. This may particularly be the case with mixing costs, i.e., proactive control processes, which have been suggested to be affected by language proficiency (Green & Abutalebi, 2013).

Besides language context, onset age of active bilingualism affected mixing costs in the current bilingual sample who, on average, acquired and started to actively use L2 later in life. The results of our study, therefore, extend the previous empirical evidence (Kapa & Colombo, 2013; Luk, De Sa, & Bialystok, 2011) by suggesting that later acquisition and use of a second language after the consolidation of the first one may have a greater impact on proactive control processes, in particular inhibition. However, the more experience bilinguals have later in managing their two languages (earlier onset of active bilingualism), the faster they are at inhibiting.

Furthermore, the typological proximity/distance variable approached significance in the case of mixing costs. In accord with the recent neuroimaging research (Abutalebi, Canini, Della Rosa, Green, & Weekes, 2015), the current results suggest that use of two typologically close languages (as opposed to two typologically distant ones) is likely to result in greater competition and place greater demands on inhibition, thus, potentially enhancing the relevant proactive control process across cognitive domains.

Interesting and noteworthy as this study’s findings may be, they cannot be treated as the final word on cognitive aspects of bilingualism. In view of the extreme complexity of these issues, as well as the extraordinarily diverse and versatile nature of the phenomenon of bilingualism, clearly further research in this area is required: research which will extend into bilinguals with different language experiences (in particular, in terms of interactional context(s) and the extent to which both languages are used). This reinforces the need of a shift in research direction – from looking for positive or negative effects of bilingualism on cognitive control to an inquiry into their nature (for related ideas, see Poarch & Krott, 2019; Zirnstein et al., 2019).

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