Relation between language proficiency and executive function: A comparative analysis of proficiency measures

Volodymyr Revniuk [a, *], Szilvia Bátyi [a]

[a] *University of Pannonia, Hungary*

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Abstract. Research on the effects of bilingualism and multilingualism on executive function has yielded conflicting results over the past decade. Addressing the issue, scholars have made significant advancements in methodological approaches. Yet, the operationalization and analysis of language proficiency, one of the major components of linguistic background, remain unsystematized. This study investigated how various measures of language proficiency and fluency differ in their ability to predict executive function performance in shifting. The Adaptive Control Hypothesis was the framework that motivated the study, with additional analysis of the effects of language proficiency and fluency as independent and interacting variables. The results from 68 Hungarian-English bilinguals showed that only performance in the category fluency task significantly predicted executive function abilities, and only when interacting with levels of engagement in interactional contexts. The study also highlighted that proficiency and fluency are related but not interchangeable constructs; however, further investigations and strict operationalization of the two concepts are necessary to understand the relation between interactional contexts and executive function.

Keywords: *bilingualism, executive function, language proficiency, language fluency, interactional context.*

Ревнюк Володимир, Баті Сільвія. Взаємозв'язок між рівнем володіння мовою та екзекутивною функцією: порівняльний аналіз показників рівня володіння мовою.

Анотація. Дослідження впливу двомовності та багатомовності на виконавчу функцію давали суперечливі результати протягом останнього десятиліття. Вирішуючи це питання, вчені досягли значного прогресу в методологічних підходах. Проте, операціоналізація та аналіз рівня володіння мовою, одного з основних компонентів мовного бекґраунду, залишаються несистематизованими. У цій роботі досліджується, як різні показники рівня та вільності володіння мовою відрізняються своєю здатністю передбачати когнітивну гнучкість. Гіпотеза адаптивного контролю - це теоретична

* Corresponding author. Volodymyr Revniuk, 0009-0000-8652-4048, kuodfz@student.uni-pannon.hu

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основа, яка мотивує дослідження, з додатковим аналізом ефектів рівня та вільності володіння мовою як незалежних та взаємодіючих змінних. Результати 68 угорсько-англійських двомовців показують, що лише результати виконання завдання плавності мови по категорії суттєво передбачали здібності виконавчої функції – і лише під час взаємодії з рівнями залучення у контекстах взаємодії. Дослідження також підкреслює, що рівень та плавність володіння мовою пов'язані, але не взаємозамінні конструкції, однак необхідні подальші дослідження та сувора операціоналізація двох концепцій, щоб зрозуміти зв'язок між контекстами взаємодії та виконавчою функцією.

Ключові слова: двомовність, виконавча функція, рівень володіння мовою, вільність володіння мовою, інтеракційний контекст.

Introduction

The relationship between bilingualism and cognitive control has been a central topic in psycholinguistics research over the past decades. One area of research explores whether bilingualism leads to cognitive adaptations in general-purpose cognitive control mechanism that regulates human cognition – the executive function (EF) (see Bialystok, 2009, for review). The EF system was theorized to consist of three components (Miyake & Friedman, 2012): *inhibition* of dominant or prepotent responses, *updating* and monitoring of working memory representations, and *shifting* between tasks or mental sets. Earlier research on adaptations in EF from bilingualism, labeled as *bilingual advantage* (BA), reported observing significant advantages in different EFs for bilinguals (e.g., Bialystok, 2001; Bialystok et al., 2004; Blair et al., 2005; Costa et al., 2008; see Bialystok, 2009, for review). Later, multiple novel or replication studies reported null results leading to a conflicting picture nowadays (e.g., Antón et al., 2014; Gathercole et al., 2014; see Paap et al, 2016, for review).

To explain such inconsistencies, recent reviews have highlighted significant shortcomings of the operationalization of bilingualism, as well as a lack of a clear theoretical framework of the relation between bilingualism and EF (e.g., De Bruin, 2019; Paap et al, 2016; Surrain & Luk, 2019).

Theoretical Framework

Currently, the most frequently studied theoretical framework examining the relationship between bilingualism and executive function is the Adaptive Control Hypothesis (ACH) (Green & Abutalebi, 2013). The ACH proposes the concept of interactional contexts and differentiates between three of them (Green & Abutalebi, 2013, p. 518):

- Single-language context (SLC) – when bilinguals mostly use one language per communicative situation.

- Dual language context (DLC) – when bilinguals use both languages in each communicative situation in a balanced manner. Language choice is carefully controlled.
- Dense code-switching context (DCS) – when bilinguals mostly engage with linguistically similar bilingual speakers and use both known languages opportunistically, with less control, resulting in more code-switching.

Although the ACH is the most widely studied framework, the overall number of empirical studies testing it remains limited. Findings from these studies have provided varying evidence, both supporting and contradicting the predictions of ACH (see Paap et al., 2021, for review). Inconsistent results for the inhibition EF may be attributed to low convergent validity of tests for measuring it (Paap, 2014), while research with more reliable measures for the shifting EF supports the predictions of the ACH (e.g., Hartanto & Yang, 2020).

Besides interactional contexts, another significantly understudied aspect of the linguistic background with potential implications for EF is the proficiency in the known languages.

Language Proficiency: Self-Reports vs. Objective Measures

In earlier works, *language proficiency* (hereafter referred to as LP) was used to categorize individuals as either monolinguals or bilinguals (see Luk and Bialystok, 2013 for review). In contrast, the ACH focusses on the adaptations of EF from engagement with interactional contexts of *language use* and the role of LP is much more vague, outlined as: "… We simply note here that for speakers in single- and dual-language contexts an increase in proficiency is most likely associated with increased skill in the control of interference" (Green & Abutalebi, 2013, p. 525).

Even when the theoretical foundation for the role of LP is established, researching it requires consistency in the methodology of measuring and analyzing it. In most studies of BA and later of ACH, measurement of LP has usually been conducted via self-reports (Surrain & Luk, 2019), but researchers keep emphasizing that test-based measurement of LP is necessary as it is much more reliable than self-reports (see De Cat et al., 2023, and Surrain & Luk, 2019, for reviews). Yet, with test-based measures, due to the great variety of them, there is very little consistency in their selection across studies.

Language Fluency

In addition to LP, there is one more construct that represents the ability to use languages and could potentially be associated with EF – language fluency

(hereafter - LF). Relatively few works have investigated the relationship between LF and EF (e.g., Lai & O'Brien, 2020; Woumans et al., 2016).

Within the framework of ACH, for individuals who engage with SLC and DLC, it was highlighted that: "... An increase in second-language proficiency yields a concomitant increase in interference that reduces fluency. Interactional cost imposes a demand to adapt the control processes of goal maintenance, conflict monitoring, and interference suppression. In the dual-language context the demands on control processes are more complex and, so too, is the adaptive response." (Green & Abutalebi, 2013, p. 521). From this, it can be suggested that an increase in LP without an increase in LF reflects a lack of adaptation in EF. As such, it could be argued that LF can potentially have a more direct relation to EF compared to LP.

Current Study

The main goal of this study is to analyze multiple measures of LP and LF for their convergent validity and compare their predictive power of the performance in an EF task, thereby providing research-based motivation for choosing specific tests of LP/LF for further research. The current study adopts the ACH as its theoretical framework and investigates whether LP and/or LF moderate the effects of engagement with interactional contexts on executive function.

The research questions for the study are the following:

1. Which measure of language proficiency and/or fluency is the best predictor of EF?

2. Which measure of language proficiency and/or fluency is the best moderator variable of the relation between engagement with interactional contexts and EF?

It is hypothesized that measures of LP and LF (including self-reports on LP) have a significant relation with EF. The best predictor is expected to be the test-based measure of LP. The relation between LF and EF is harder to predict because of the lack of earlier research in this area.

Methodology

Participants

68 (Females = 38) participants were recruited for this study. All participants were born in Hungary and were native speakers of Hungarian. Participants were included only if they reported using English on a daily basis. Fifteen

participants (Females = 7) reported active daily use of more than two languages but were included in the study and analyzed with bilinguals as one group. None of the participants were immigrants or had lived abroad for extended periods.

Materials

Multilingual Language Experience Survey (MILES)

Existing questionnaires about linguistic background did not fully correspond to the needs of the current study, and a new questionnaire was developed and validated, based on the consensus of researchers, teachers, and speech and language therapists (De Cat et al., 2023). The questionnaire included the following sections:

- General demographic data and health
- Social and economic status
- Age and manner of language acquisition
- Language proficiency
- Duration of engagement with communicative contexts and percentages of language use
- Language switching frequency in communicative contexts
- Language attitudes

Detailed information was required about bilinguals' language use, so the questionnaire included sections on language use with different interlocutors, for various activities, and places. For each context, participants reported the approximate duration of engagement with them over an average week, as well as the percentage of language use in each communicative context.

C-Test

The C-test requires vocabulary and grammar knowledge for completion and was argued to estimate general LP. Texts for the current study were derived from the version developed for a Hungarian population and already validated for reliability (Dörnyei and Katona, 1992). The test included three small texts, with the first and last sentences completely unedited. In the middle part of the texts, every second word is missing its second half. Participants were instructed to fill in the missing halves of words in the texts. An example of the first text is provided in Figure 1. Participants completed the task in pen-and-paper format within 10 minutes.

Figure 1
Example of Text for C-Test

Text 1

One cool autumn evening, Bob L., a young professional, returned home from a trip to the supermarket to find his computer gone. Gone! all so___ of cr___ thoughts ra___ through h__ mind: H__ it be__ stolen? H__ it be__ kidnapped? H_ searched h__ house f__ a cl__ until h_ noticed a sm___ piece o_ printout pa___ stuck un__ a mag___ on h__ refrigerator do__. His he__ sank a_ he re__ this sim__ message: CAN'T CONTINUE, FILE CLOSED, BYE.

Verbal Fluency

Similarly to earlier investigations of bilingual advantage that implemented verbal fluency measures, category fluency and letter fluency tasks were used in this study.

In the category fluency task, participants were instructed to list the words that belonged to a given category. The task was to list as many words as they could within one minute. The category for the task was "animals".

In the letter fluency task, participants were instructed to list as many words as they could that began with a given letter (not sound) within one minute. Participants were instructed not to list proper names, but otherwise, there were no limitations on the category of the words. The letter for the task was "A".

Shifting Executive Function – Number-Letter Switching Task

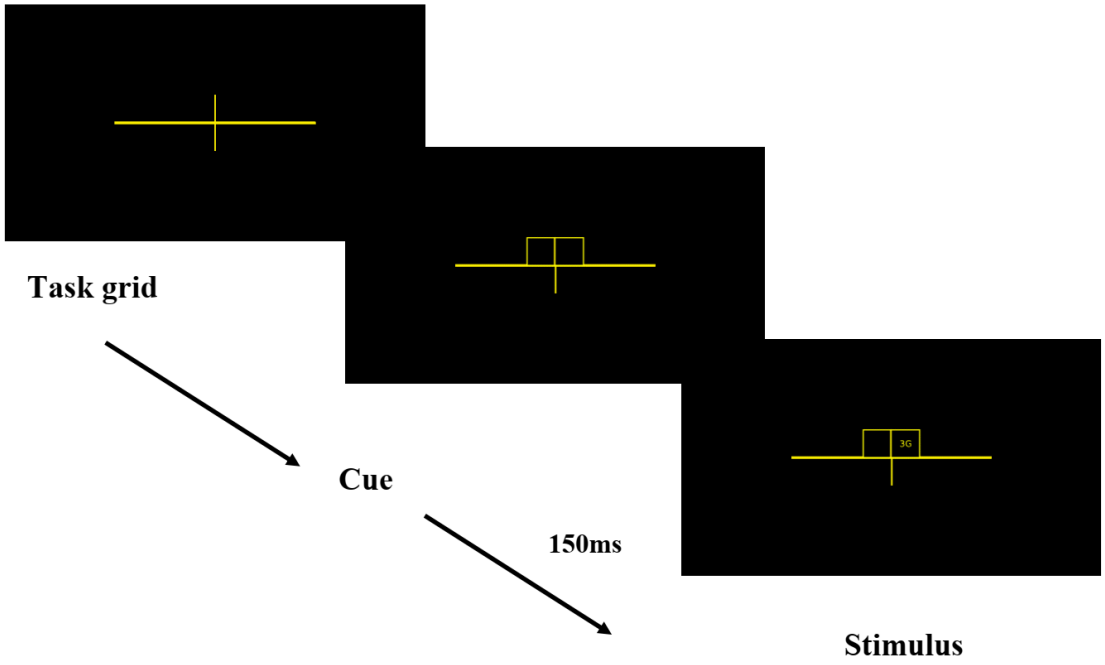
For this study, *shifting* EF was chosen because its measures have higher convergent validity, and it was operationalized using switching costs in the number-letter shifting task (adapted from Rogers & Monsell, 1995). On each trial, a letter & number pair (e.g., E3) was presented in one of two squares above or below a line dividing the computer screen in half (see Fig. 2). Depending on the location where the pair appeared, it was required to classify the number (at the top – as odd or even) or the letter (at the bottom – consonant or vowel).

Participants completed three practice blocks, with stimuli appearing only at the top, at the bottom, and a block with stimuli appearing in both parts, in clockwise order. Next, participants completed 2 blocks with a clockwise

pattern of stimulus appearance (48 trials each). Finally, participants completed one practice block (24 trials) and two target blocks with stimuli appearing on top and bottom in a randomized order (48 trials each).

The dependent measures were the switch costs in random-switch blocks: the difference between RTs in switch and repetition trials.

Figure 2
Number-Letter Task Trial Sequence



Procedure

The study was conducted with each participant individually, in a single session. After signing the informed consent for participation in the study, participants completed the two fluency tasks, the C-test and the number-letter shifting task. After the session, participants received and completed the online linguistic background questionnaire online.

For each task, a researcher was present with the participants at the beginning of testing to provide task instructions and monitor their understanding of the instructions. For fluency tasks, the researcher stayed with the participants for time management. For the C-test, after being presented with instructions, participants were left to perform the task individually. For the number-letter switching task, after being monitored during the first three practice blocks, participants were left to perform the task individually.

Data Preparation and Analysis

Self-reported LP for each language was calculated as the mean of four skills – reading, listening, writing, and speaking.

Recordings of the performances in the fluency tasks were transcribed and calculated for the number of unique entries/units. Results of the C-tests were calculated based on the number (not percentage) of correct answers.

Questionnaire data about the percentage of language use was transformed using the language entropy formula (Gullifer & Titone, 2020). This value indicated the balance of language use in the given communicative context, which was then weighted on the relative time spent in those contexts. To account for DCS, data about language switching were collected for the same communicative contexts and weighted in the same manner.

The two-way interaction term between language entropy and language switching was used to represent the degree of engagement with all three interactional contexts from the ACH. Lower values of language entropy corresponded to greater engagement with SLC. Higher language entropy with rarer code-switching corresponded to DLC, and an increase in code-switching corresponded closer to DCS.

The relationship between LP/LF, engagement with interactional contexts, and EF was estimated with a series of linear regression models (see Table 1). Four sets of analyses were run for each measure of LP/LF included in this study: subjective self-reported proficiency, number of correct answers in the C-test, number of unique entries in the category fluency task, and letter fluency task.

Table 1
Predictor Variables Included in the Regression Models

Predictors	Model 1	Model 2	Model 3	Model 4
Language proficiency/fluency measure	X	X	X	X
Language entropy*language switching (interaction)		X	X	X
Age			X	X
SES			X	X
Education			X	X
Entropy*switching*proficiency/fluency (three way interaction)				X

In the first model, switching costs in the number-letter switching task were regressed on a given measure of LP/LF. The second model added the interaction term between language entropy and language switching to the analysis, representing the degree of engagement with three interactional contexts of ACH. The third model added demographic covariates of participants' age, education, and SES to indicate whether there was a unique and independent relationship between linguistic background and EF.

The fourth model analyzed LP/LF measures as the moderators of the relation between interactional contexts and EF. It is represented as the three-way interaction term between language entropy, language switching, and LP/LF.

Results

Descriptive statistics

Descriptive statistics of the linguistic background of the participants are presented in Table 2. Language entropy scores are reported separately for bilingual and trilingual individuals, as the maximum scores for them differ (1.0 for bilinguals and approximately 1.585 for trilinguals; see Gullifer & Titone, 2020, for details). On average, trilingual participants demonstrated a significantly higher degree of language entropy compared to bilinguals ($t(66) = 5.07$, $p < .001$). Trilinguals and bilinguals demonstrated similar tendencies for language switching ($t(66) = 1.75$, $p > .05$). All participants, on average, reported similarly excellent proficiency in L1 ($t(66) = 1.78$, $p > .05$). However, trilinguals reported higher proficiency in L2 compared to bilinguals ($t(66) = 2.31$, $p < .05$).

Table 2
Descriptive Statistics of Research Participants

Participant group	**Entropy**	**Language switching**	**Self-reported proficiency**		
			L1	**L2**	**L3**
bilinguals	M = .48 (.16)	M = 2.39 (1.08)	M = 6.23 (.81)	M = 4.97 (1.30)	-
trilinguals	M = .72 (.16)	M = 2.94(0.92)	M = 6.63 (.58)	M = 5.88 (1.42)	M = 3.47 (1.26)
all participants	M = 0.53 (.19)	M = 2.51(1.07)	M = 6.32 (.79)	M = 5.17 (1.38)	-

Correlation Analyses of Proficiency Measures

Correlation analyses were conducted between self-reported and objective measures of language proficiency to investigate the relationship between the measured concepts. The summary of the correlation analyses is provided in Table 3.

All measures have significant positive weak to medium correlations with each other, confirming that they measure highly related constructs. Significant and relatively higher correlations were observed between self-reports of language proficiency and test-based measures, validating the accuracy of participants' self-estimation.

Nevertheless, none of the correlations was high, indicating that each test measured related, but clearly separable constructs. The implications of this finding will be further analyzed in the Discussion section.

Table 3
Correlations Among Measures of Language Proficiency and Fluency

	Self-reported proficiency	**C-test**	**Category fluency**	**Letter fluency**
Self-reported proficiency				
C-test	.68***			
Category fluency	.51***	.54***		
Letter fluency	.42***	.49***	.50***	

Note: p< .001***, p< .01**, p< .05*, p< .05

Regression Analyses

Linear regression analyses were conducted for all 4 measures of language proficiency and fluency. The summary of regression analyses is provided in Table 4.

Regression models with measures of test-based general language proficiency (C-test) scores and letter fluency task scores were not significant. Participants' performances in these tasks could not reliably predict their performances in the shifting EF task.

Table 4
Summary of Regression Models for Switching Costs in the Number-Letter Shifting Task

	Model 1	**Model 2**	**Model 3**	**Model 4**
C-test	Adj R^2 = .0002	Adj R^2 = .0445	Adj R^2 = .0216	Adj R^2 = .0004
Category fluency	Adj R^2 = .0288’	Adj R^2 = .0736’	Adj R^2 = .0633	**Adj R^2 = .1796***
Letter fluency	Adj R^2 = .0061	Adj R^2 = .0551	Adj R^2 = .0295	Adj R^2 = .0580
Self-reported proficiency	Adj R^2 = .0003	Adj R^2 = .049	Adj R^2 = .0268	Adj R^2 = .1101’

Note: Significant model highlighted in bold; ’ = $p < .1$; * = $p < .05$

For self-reported language proficiency, only Model 4 was marginally significant ($p = .076$). This model included the three-way interaction between language proficiency, language entropy, and language switching. The 3-way interaction was *the only* significant predictor of the shifting task performance in Model 4 ($\beta = 373.188$, $p < .05$). The model explained approximately 11% of the variance in EF.

Category fluency was the best predictor of shifting EF among all proficiency and fluency measures included in this study. The category fluency score alone was a marginally significant predictor of shifting EF in Model 1 ($\beta = 9.355$, $p = .089$, Adjusted $R^2 = .0288$).

Adding two-way interaction between language entropy and switching improved the predictive power in Model 2 (Adjusted $R^2 = .0736$, $p = .066$), but category fluency score was not a significant predictor anymore ($\beta = 7.889$, $p = .163$), only the interaction was ($\beta = 467.584$, $p < .05$).

Adding the non-linguistic background variables in Model 3 decreased the model’s predictive power (Adjusted $R^2 = .0633$, $p = .14$), but the interaction between language entropy and switching remained a significant predictor ($\beta = 427.935$, $p < .05$).

Finally, adding the 3-way interaction between language entropy, switching and category fluency score for Model 4, yielded the only significant regression model in the data analysis (Adjusted R^2 = . 1796*, p = .016). Within the model, interaction between language entropy and switching remained a significant predictor (β = -1450.41, p < .05), and the only other significant predictor was the three-way interaction between language entropy, switching, and category fluency (β = 94.30, p < .01).

Figure 3 illustrates the two-way interaction between switching costs and language entropy (representing of interactional contexts) in predicting switching costs during shifting EF tasks. A more balanced use of two languages with reduced language switching corresponds to DLC (RED line on the right side of the box in Fig. 3), while the same balanced use with increased language switching corresponds to DCS (GREEN line on the right side of the box in Fig. 3). In line with predictions of the adaptive control hypothesis, lower switching costs were associated with more engagement with DLC, but higher switching costs were associated with more engagement with DCS.

Figure 3
Visualization of Estimates of the Two-Way Interaction Between Language Entropy and Switching

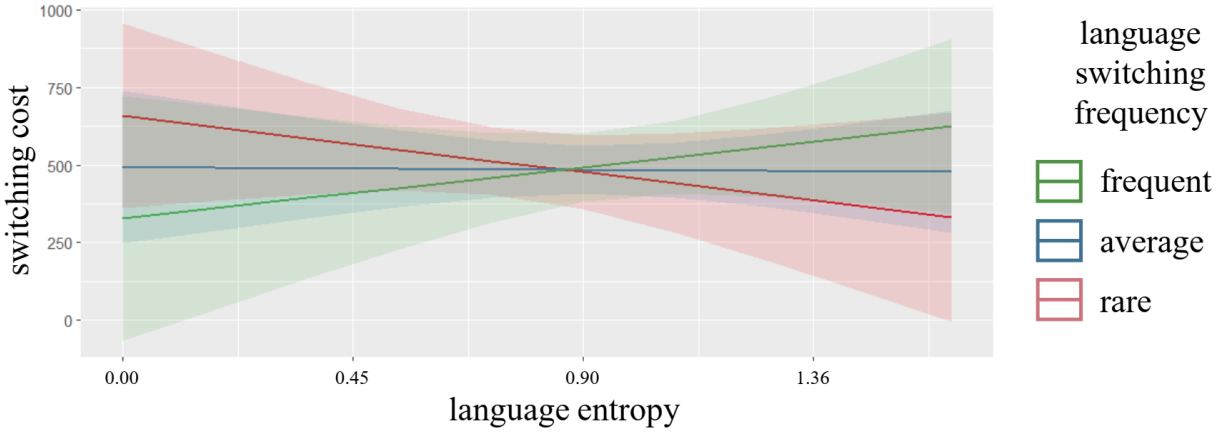
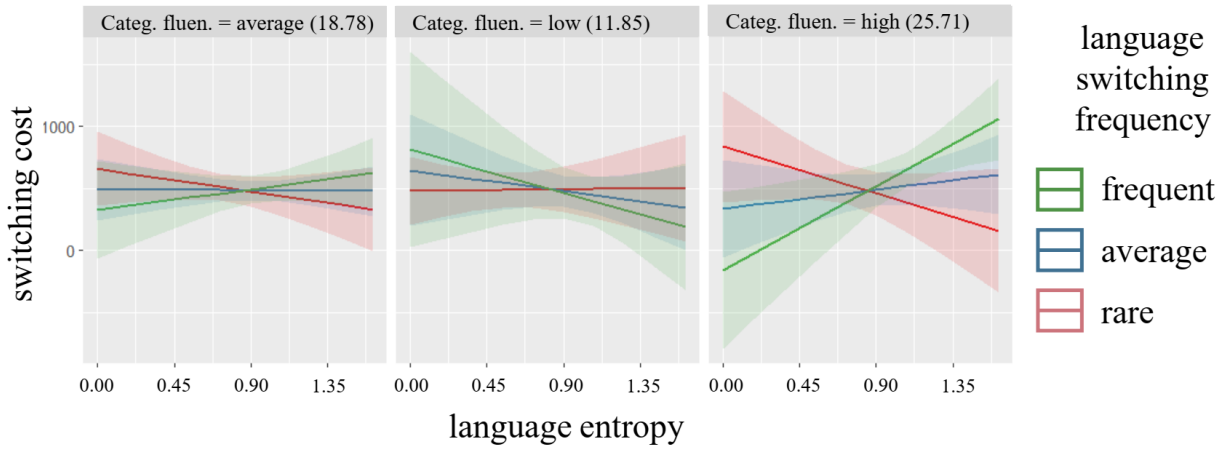


Figure 4 provides a visualization of the three-way interaction between language entropy, switching, and proficiency. The pattern from the two-way interaction reviewed above can be observed in the average performances in the category fluency task (left box in Fig. 4), with lower switching costs associated with greater engagement with DLC and higher switching costs associated with greater engagement with DCS. With the increase in category fluency (as shown in the right box in Fig. 4), the previous pattern becomes even more pronounced.

Figure 4
Visualization of Estimates of the Three-Way Interaction Between Language Entropy, Switching, and Category Fluency



Discussion

The aim of the current study was to conduct a comparative investigation of multiple language proficiency and fluency measures on their relation to the shifting component of executive function. Tests of general language proficiency and verbal fluency, as well as self-reports on language proficiency, were used for this study. The current study was conducted within the framework of the Adaptive Control Hypothesis. Two approaches to analyzing the effects of language proficiency were used: when it was analyzed as an independent predictor of EF and as a moderator of the relation between interactional contexts of ACH and executive function.

Relation Among Measures of Proficiency and Fluency

As expected, performances in language proficiency and fluency tests have significant correlations with each other, as they measure closely related concepts (see De Jong, 2018). At the same time, all test-based measures have significant correlations with self-reports on general language proficiency, supporting earlier observations about the high accuracy of self-reports (e.g., Gollan et al., 2012).

Interestingly, the correlation between the two verbal fluency tasks was among the loweest correlations in the analysis. This pattern of relationship is rather unexpected, given the very similar task design and both tasks tapping into verbal fluency ability. It was suggested that letter fluency requires that participants inhibit naturally generated but irrelevant semantic associates in

order to focus on the letter criterion. Certain restrictions in the letter fluency task (like excluding proper names) further increase the monitoring demands, and therefore the involvement of executive control (e.g., Kemper & McDowd, 2008). Greater monitoring demand might explain greater variation in the letter fluency that is less consistent with category fluency task performance, but that element of EF was not investigated in the current study, which is why the letter fluency task could not predict shifting EF.

Ultimately, the analyzed tests measure related concepts, but further investigation into their relationship with executive function reveals that they cannot be used interchangeably and require theoretical and research-based elaboration to select a specific measure for a study.

Language Proficiency, Fluency, and Executive Function

Among the multiple regression analyses used in this study, only one model proved to be significantly predictive of performance in the shifting EF task. As the predictive power of correlating measures varies, to the degree of being significant or not, it can be concluded that each test taps into unique aspects of language proficiency and fluency, which have very different relationships with executive function.

First, it is necessary to highlight that, irrespective of the measure of language fluency or proficiency, it does not seem to have any *independent* relation to EF. Bilingualism was suggested to constantly engage the executive control system during language production (Bialystok, 2009), so it is the use of language that is supposed to engage and exercise EF, not the attained proficiency in the known languages. Certainly, better language proficiency requires more experience, both past and present, in using a language, but the relationship with cognitive control is less direct (e.g., Kheder & Kaan, 2021).

In this study, shifting EF was significantly predicted only by self-reported general language proficiency, and category fluency task score, and only within the three-way interaction between language entropy, switching, and these proficiency and fluency measures. The only significant regression model was the one with the category of the fluency score.

The idea behind investigating language proficiency as a moderator variable is that with an increase in language proficiency, cognitive activation of the corresponding language increases, in active and even in resting state (e.g., Dijkstra et al., 2019). Consequently, with increased cognitive activation of the known languages, controlling them requires more cognitive effort. Therefore, the amount of cognitive control required during language use in interactional contexts would also vary based on proficiency and/or fluency in the known languages.

The findings of the current study support the predictions of the ACH, with lower switching costs being observed for individuals who engage with dual language contexts that are expected to require more cognitive control. Additionally, the significant predictive power of the 3-way interaction indicates that the relation between interactional contexts and EF becomes even more prominent at higher levels of language proficiency and/or fluency. Yet, this pattern was observed only for self-reports in general language proficiency and category fluency scores.

A potential explanation for these findings is that self-reports and category fluency scores provide better representations of language activation during language use. The category fluency task might more closely resemble the actual process of communication when language is produced quickly. Additionally, while everyday communication typically does not involve time limitations like those imposed by a verbal fluency task, the gap between natural language use and pen-and-paper proficiency tasks is often even greater. Therefore, performance on a verbal fluency task that requires rapid production under time pressure better reflects an individual's ability to use language in real-time communication as well as the level of cognitive activation that language receives during use. Contrastingly, the C-test and the letter fluency task differ significantly from regular everyday communication and cannot accurately represent language activation during habitual, naturalistic language use.

Conclusion

Research into the relationship between bilingualism and executive function for the past two decades consistently included some form of inquiry about language proficiency. Despite its central role in bilingualism research, there have been few systematic efforts to standardize the methodological approaches used to measure it. This study contributes to the discussion on the methodology for measuring and analyzing language proficiency and its relationship to executive function. The findings of this study showcase the positive prospects of doing so and provide insights into cognitive adaptations from bi-/ and multilingualism.

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