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Linguistic distance affects executive performance in trilinguals

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ABSTRACT

Recent research has highlighted potential benefits associated with bilingualism for overall cognitive efficiency and health. One understudied dimension of the bilingual experience is linguistic distance (LD), a measure defining how (dis)similar two given languages are. The previous study has explored the role of LD as a modulator of bilingualism-induced neurocognitive consequences in aging individuals. However, this has scarcely been investigated in young populations. To fill this gap, we examined the impact of LD between second and third language on executive functioning - as indexed by Flanker task performance - in a cohort of young adults (18–29 years old). The results show that L2-L3 LD dynamically modulates multilingualism-induced effects on inhibitory executive control performance in young trilinguals, with a pattern of LD contribution to executive functioning characterized by a two-stage trajectory. In the early stages of multilingual experience, distant non-native languages are associated with maximal cognitive benefits, expressed in faster Flanker reaction times, and explained by a larger cognitive effort in acquiring a distant language. However, as multilingual experience accrues, closer language pairs predict enhanced cognitive processing, likely driven by the more demanding effort of juggling more similar lexicons and grammars.

1. Introduction

As neuroimaging (e.g. Abutalebi et al., 2008; Berken et al., 2016) and behavioral (e.g. Hartsuiker et al., 2004; Kroll et al., 2015) studies show simultaneous co-activation of different languages in the mind and brain of bi/multilingual individuals, there is a need for a mechanism to manage interference between languages and assure the use of the target one at any point in time. It is thought that, by recruiting their domain-general executive control system for the task of avoiding cross-linguistic intrusions (Abutalebi & Green, 2016), bi/multilinguals are able to train their cognitive control mechanisms, resulting in upgraded executive control abilities. Mounting evidence of bilinguals outperforming monolinguals on non-verbal executive tasks like the Flanker task (e.g. Costa et al., 2008), Stroop task (e.g. Bialystok et al., 2014), Simon task (e.g. Salvatierra & Rosselli, 2011) or attention-related tasks (e.g. Treccani et al., 2009) supports the hypothesis that bilingualism provides efficient training for the domain-general executive control system. In addition to strengthening the mechanisms of inhibitory control, the adaptation of this system is associated with the overall changes in a wider set of processes that manage goal maintenance and conflict resolution thus allowing bilingual speakers to enjoy various cognitive benefits (Bialystok & Craik, 2022).

Existing studies with young and older populations show behavioral differences between monolinguals and bilinguals in executive functioning (Adesope et al., 2010; Bialystok, 2017). It has to be noted, however, that when it comes to bilingualism-induced cognitive effects in young adults, in contrast to children or older adults, the literature presents more mixed results. While several studies report enhanced executive performance in bilingual young adults compared to their monolinguals peers (e.g. Woumans et al., 2015), other investigations fail to document the existence of bilingualism-induced effects in this age group (e.g. von Bastian et al., 2016). One of the potential causes of challenges in replicating bilingualism-induced cognitive effects in young adult samples is ceiling effects. Individuals are at the peak of their general cognitive capacities at this time of their lives (Li et al., 2004), meaning there may not be enough variability in their performance for statistical tests to identify any further significant improvements (Bialystok, 2017). The responses obtained in children and older adults

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are usually more diverse (for instance, in terms of their reaction times (RTs)), which offers enough variability for group differences to manifest. Another factor that may explain the reported lack of cognitive effects of bilingualism in young adults is the tendency of traditional research to treat bilingualism as a categorical variable, thus not assessing the graded constituent dimensions of multifaceted individual bilingual experiences. Indeed, the initial research investigating cognitive consequences of bilingualism focused on between-group comparisons and resulting differences. To be valid, this approach requires homogeneity between and within groups, i.e. certain characteristics should be homogeneous not only between monolingual and bilingual groups but also within them. In this sense, bilingualism presents a difficulty as it is not a single uniform fixed entity. Different factors contribute to variations in bilingual experience and thus affect its cognitive impact. Studies show that bilingualism-related outcomes are modulated by, for instance, language proficiency (Blom et al., 2014; Singh & Mishra, 2012; Tse & Altarriba, 2012), age of acquisition (Durand López, 2021) or language switching patterns (Soveri et al., 2011). As bilingualism is composed of multiple dimensions, several research groups have begun to argue for distilling it into continuous variables to account for individual bilingual differences (e.g., Kaushanskaya & Prior, 2015; Luk & Bialystok, 2013).

A turn towards a more nuanced assessment of the spectrum of bilingual experience is being adopted in a growing number of studies (e.g., Del Maschio et al., 2020; Gallo et al., 2021; Gallo et al., 2022; Gallo et al., 2024) which consider different aspects of bilingual experience such as individual language proficiency, proportional usage of each of the languages, age of acquisition, and even personal attitude to specific languages and cultures. To date, however, few investigations have considered the dimension of *linguistic distance (LD)*. As the mechanisms of the domain-general executive control system are used to avoid cross-linguistic intrusions, the relation between the specific languages that a bilingual knows is important because it largely determines the nature, the quantity and the quality of the interference between them.

LD is a quantitative measure that depicts the relative degree of (dis) similarity between a pair of languages in terms of an entire spectrum of factors, including historical development, phonological, lexical and syntactic structures (Richards & Schmidt, 2002). For instance, despite all Indo-European languages reminiscing each other to some extent, the level of affinity between French and Portuguese would be relatively high due to their common Latin ancestor, thus French-Portuguese LD would be relatively small compared to French-German LD, in view of German being a descendant of a putative Proto-Germanic, and not Latin, ancestor. The key variables contributing to LD are to a large degree determined by such phylogenetic factors but are by no means limited to them: for instance, in some cases phylogenetically remote languages may partially share phonology, lexicon and even some aspects of grammar due to geographical and cultural proximity, leading to extensive cross-linguistic borrowings.

Theoretical models of bilingual language control (Green & Abutalebi, 2013) would suggest that closer LD should engage executive control mechanisms (and therefore train/strengthen them) to a greater extent. Languages that are closely related to one another share more characteristics (such as vocabulary and pronunciation), making it more difficult to separate them, as controlling for interference becomes more difficult when the targets are similar (e.g., in lexical selection; Fieder et al., 2019; Rose et al., 2019). This additional challenge is therefore hypothesized to fortify bilinguals' language control and executive control systems to a greater degree. Indeed, previous studies have indicated that a closer LD alters dual language processing, resulting in more efficient metalinguistic performance (Bialystok et al., 2003), receptive vocabulary outcomes (Blom et al., 2020) and reading skills (Bialystok et al., 2005). A beneficial influence of closer LD on bilinguals' cognitive performance has been found using non-linguistic tasks tackling inhibition, switching (Morrison & Taler, 2023) and episodic memory (Ljungberg et al., 2020). Furthermore, a recent study of a diverse cohort of bilinguals speaking different first languages (L1) and a shared second language (L2) (Gallo et al., 2023) showed that the role of LD on the relationship between bilingualism and executive performance may be a dynamic one, and the effect of LD changes with accruing bilingual experience. Early on in the bilingual experience, distant language pairs appeared to exert the bigger influence. We interpreted this result as indicating that, at the learning stage, language pairs with larger LD impose more significant cognitive challenges due to the effort required to acquaint oneself with a variety of very different features of the language. With dissimilar L1-L2 pairs compared to similar ones, little knowledge transfer is available, and one has to go an extra mile to learn new sets of phonemes, phonological and grammatical rules and unfamiliar vocabulary, leading to an observable "learning stage effect" on cognition. Conversely, later on in the bilingual experience, the greatest impact on cognitive abilities appeared to be provided by close language pairs. This effect of closer LD language pairs, once they are already mastered, is likely driven by improved executive control performance arising as a result of the continuous challenge of managing the tight competition between similar L1 and L2 (the "control stage effect"). Results from Gallo et al. (2023) further highlight the importance of assessing the LD dimension when considering cognitive consequences of bilingualism and encourage further consideration of LD's dynamic contribution to bilingual experience. This previous study, however, focused on the LD effect in a sample of older adults (with mean age of ~65 y.o.), and the role of LD in modulating bilingual executive performance at earlier life stages, prior to age-related changes in the neurocognitive system, when cognitive efficiency is still at peak level, remains largely unexplored. Furthermore, the previous study considered the effects of LD between L1 and L2. At the same time, relations between languages change when a new language joins the complex multilingual dynamic. As multilingualism becomes more common, the issue of how an additional language (L3, etc.) is handled by multilingual speakers' cognitive system becomes increasingly relevant.

Indeed, the results of existing L3 acquisition studies suggest that L2 may play a stronger role than L1 in the process of learning an L3 (e.g. Bardel & Falk, 2007; Leung, 2005; Llama et al., 2010; Rothman & Cabrelli Amaro, 2010). Leung (2005) examined the processes of L2 and L3 acquisition in groups of monolingual Vietnamese speakers and Cantonese-English bilinguals, both beginning to learn French. The results for the monolingual group showed systematic L1-to-L2 transfer, as the subjects consistently made use of their L1 Vietnamese grammar to represent L2 French grammar. For the bilingual group, however, no L1-to-L3 transfer was found, with data indicating a transfer originating from L2, rather than from L1, at the initial stages of L3 acquisition. Similarly, Bardel and Falk (2007) reported a syntactic structure transfer attributable to L2, rather than L1, while acquiring two different L3s, in two groups of learners with different L1s and L2s. This suggestion that L2 rather than L1 influences L3 acquisition has been further supported by another study (Rothman & Cabrelli Amaro, 2010), which even suggested that L2 might block L1 transfer.

Still, when considering cross-linguistic interference, the available evidence is rather scarce. Unlike the studies described above, some existing studies indicate an add-up influence from both L1 and L2 during L3 processing. Lemhöfer et al. (2004) investigated the cognate effect via an L3 lexical decision task in a group of trilinguals with L1 Dutch, L2 English and L3 German. According to the results, L1-L3 (double cognates) were recognized faster than control non-cognate words, replicating the 'standard' cognate facilitation effect. What is more, however, L1-L2-L3 cognates (triple cognates) were recognized even faster than double ones, suggesting that non-native language (L2) may also exert influence on recognition performance during L3 processing. Szubko-Sitarek (2011) reported similar results when examining the cognate facilitation effect in a group of L1 Polish-L2 English speakers of L3 German. Double Polish-German cognates were recognized faster than German non-cognate control words. The triple Polish-English-German cognates, however, were recognized faster than double and non-cognates. While the abovementioned studies suggest that one might experience simultaneous interference from L1 and L2 during L3 processing, other studies point out that the source of the interference could be variable. Abbas et al. (2021), for instance, have pointed out that although both L1 and L2 were the sources for morpho-syntactic cross-linguistic influence during L3 processing, the time-courses of the interference were different. According to the results of the study, L2 interference was more prominent for grammatical judgments happening later in the sentence processing. Other studies, nevertheless, indicate that regardless of constraints L2 interference may be more prominent during L3 processing. According to findings by Tomoschuk et al. (2021), during an L3 phoneme monitoring task trilinguals encountered more interference from L2 than from L1. Similarly, de Bruin et al. (2023) have suggested that during multilingual language control one might experience more interference from other non-native languages than from their L1.

Overall, these results hint that the relation between languages changes once an additional language is brought into a bilingual's existing language landscape. As the role of L2 appears to be all in all more prominent for the multilingual dynamic, both during acquisition and processing of L3, it is worth considering whether multilingualism-induced cognitive effects are also modified by the LD between the non-native languages – L2 and L3. We set out to tackle this challenge in the current study. First, we aim to investigate the modulatory effect of LD on multilingualism-induced effects on executive functioning in a group of young adults. This follows up on previous results reported for older adults (Gallo et al., 2023) by examining the modulatory role of LD on the multilingualism-induced cognitive effects in young adults. Secondly, taking into account the dynamic multilingual relationships, we focus on the trilingual experience by specifically considering the LD between L2 and L3. According to the extant evidence, we propose that the modulatory effect of LD on the multilingualism-induced executive control function in trilinguals would depend on the current stage of an individual's trilingual experience. We expect more distant L2-L3 language pairs to pose higher cognitive demands on speakers at initial stages of L3 learning. With accruing L3 experience, however, due to the more demanding language control requirements, we expect to observe increasing executive benefits for closer L2-L3 language pairs.

The aim of the present study is to investigate how linguistic distance affects executive function in trilingual young adults. To this end, we explore, among other dimensions of trilingual experience, the modulatory role of LD between L2 and L3 on the relationship between multilingual experience and inhibitory executive control performance, quantified using individual performance in Flanker task (Fan et al., 2002), an established experimental measure of the executive system's inhibitory control efficiency. For better control over the confounds arising from using diverse experimental languages, we use the same fixed L1 (Russian) and L2 (English) for all participants, while varying the L3 in order to examine its specific LD-related effects.

2. Materials and methods

2.1. Participants

Thirty-nine healthy young adult volunteers (10 males, $M_{age} = 21.8$, SD ± 1.96, range 18–29) participated in the experiment. The selection criteria included: having Russian as L1, English as L2 and at least a partial knowledge of any other language (L3). The L3 languages included German (N = 13), Czech (N = 1), Spanish (N = 5), Italian (N = 2) and French (N = 18). Additional selection criteria included no history of psychiatric or neurological impairments and normal or corrected-to-normal vision. All participants signed an informed consent form prior to taking part in the experiment. The experiment was approved by the HSE University's local ethics committee (Protocol № 80; 7/02/2022).

2.2. Sociodemographics and language background assessment

The socioeconomic status of participants was assessed using the MacArthur Subjective Social Status Scale developed by Adler et al. (1994). In addition to that, the Russian version of the LEAP-Q (Marian et al., 2007) also assessed several dimensions of participants' language background, including which and how many languages they spoke, their overall subjective proficiency for each of the languages (L1, L2, L3) on a scale from 1 to 10, exposure (average exposure across four modalities (i.e., reading, speaking, listening, writing)) to and age of acquisition (AoA) of L2 and L3. Furthermore, an objective measure of L2 proficiency was obtained using the online version of the Cambridge Test for Adult Learners (https://www.cambridgeenglish.org). Additionally, to assess their general intelligence level, participants were asked to fill a subset of the Raven's Standard Progressive Matrices for adults (Court & Raven, 1992). All questionnaires were adapted to the Google Forms platform for convenience purposes. Participants' sociodemographic and linguistic profiles data are presented in Table 1.

2.3. Cognitive performance assessment

The Flanker task (Fan et al., 2002) was used to examine participants' inhibitory executive control performance. This task has been widely deployed to investigate bi/multilingual executive functioning (e.g., Bialystok & Craik, 2022; Chung-Fat-Yim et al., 2020; Del Maschio et al., 2018; Gallo et al., 2021; Gallo et al., 2022). In this task, participants have to indicate, as accurately and quickly as possible, the direction of a central target arrow that is flanked by two additional arrows on each side. The task includes three conditions: a congruent condition (target and flankers point in the same direction; ⟶→⟶→⟶→⟶), an incongruent condition (flankers contradict the direction of the target; ⟵⟵→⟵⟵), a neutral condition (the flankers are dashes without any arrows; ——→——). Incongruent trials require more time to react, as the conflict between target and flanker directions needs to be resolved and the prepotent (incorrect) response needs to be inhibited. The Flanker task was presented in the OpenSesame environment (Mathôt et al., 2012) in a pseudo-randomized order, with two runs of 96 trials total, 32 per condition.

2.4. Linguistic distance assessment

LD between the participants' L2-L3 language pairs was assessed using an available database of linguistic distance for European languages by Gamallo et al. (2017). The distance measure that Gamallo et al. (2017) propose is based on the inverse probability of the text — the perplexity of n-gram models extracted from a corpora of texts from forty-four European languages. Perplexity is an established measure that defines how well a language model fits data. The authors defined their measure of linguistic distance by comparing the n-grams of text in one language with the models trained for the other language. Thus, the language distance calculation proceeded as follows: We first trained a language model on n-grams from English text samples. This model established the statistical patterns characteristic of English. We then applied this trained English model to text samples from other languages (e.g., German) to calculate perplexity scores. The resulting perplexity—representing how well the English-trained model predicts German

Table 1
Sociodemographic and linguistic profiles of the participants.

	Mean (SD)	Range
Education, years	14.69 (1.26)	11–17
Socioeconomic status, score	5.86 (1.43)	2–8
Raven Matrices, score	14.6 (0.7)	12–15
L1 proficiency, score (self-reported)	9.23 (1.02)	6–10
L2 (English) AoA, years	8.57 (3.34)	4–17
L2 (English) proficiency, score (self-reported)	7.40 (1.11)	5–10
L2 (English) proficiency, score (Cambridge test)	19.72 (3.43)	12–25
L3 AoA, years	16.44 (4.07)	7–21
L3 proficiency, score (self-reported)	4.85 (1.95)	1–8

text patterns—serves as our measure of linguistic distance between the two languages. The lower the perplexity, the better the model can fit the data, which indicates that the languages are more similar and the linguistic distance between them is smaller. The authors provide computed distances for language pairs of forty-four European languages.

2.5. Statistical analyses

Mean performance accuracy in the Flanker task for the congruent trials was 98.95 % (SD = 2.04 %), for the incongruent — 95.31 % (SD = 6.65 %), for the neutral — 98.36 % (SD = 3.45 %). Prior to the statistical analyses, we excluded neutral trials, incorrect responses and false starts with RTs <200 ms. We also removed outlier trials displaying RTs greater or smaller than 3 standard deviations from the single participant's mean in a given condition (Baayen & Milin, 2010). The percentage of outliers removed was 2.80 % for congruent condition and 6.21 % for the incongruent condition. Mean RTs for the congruent trials was 385.81 ms (SD = 70.04 ms), for the incongruent – 421.43 ms (SD = 83.35 ms).

The statistical analysis was specifically aimed at investigating the effects of linguistic distance on executive performance, namely, whether the LD between L2 and L3 modulates multilingualism-induced effects on executive performance. We did not perform a separate analysis of L1-L3 LD due to the reason that the L1-L2 LD is a constant as L1 and L2 were always Russian and English, correspondingly. We used *statsmodels* (Seabold & Perktold, 2010) Python (3.8.3 version) implemented in the 6.0.3 version Jupyter Notebook environment (Kluyver et al., 2016), which provides applications for a variety of statistical tests and models, including mixed effect models. To examine the modulation of LD on multilingualism-related cognitive outcomes, we estimated three separate by-trial mixed-effect models via *mixedlm* method. The structure for each of the models was the following: Flanker's RTs as a dependent variable, three-way interaction between L2-L3 LD, Flanker trial type (congruent vs. incongruent trials) and one of the factors of multilingual experience (L3 age of acquisition/L3 proficiency/L3 exposure) as predictors; we also added covariates for age, sex, years of education, socioeconomic status and general intelligence measure. For the model's random effects, we included random intercepts for participants and random slopes for trials. By implementing the by-trial approach, rather than using solely the difference in the RTs between congruent and incongruent trials, we were able to increase the number of data points per individual to 128 (64 per congruent trials and 64 per incongruent ones). To test multilingualism-related effects separately for congruent and incongruent conditions, we included a Flanker trial type interaction term in all our models. Hence, the three fitted models examined multilingualism-induced cognitive effects on Flanker performance and whether these effects were modulated by LD between L2 and L3.

3. Results

Our mixed models analyses revealed a statistically significant effect of L3 proficiency on executive performance in both conditions of the Flanker task (*Est* $= -20.158$, *SD* $= 5.172$, $t = -3.897$, $p < 0.001$) with higher levels of L3 proficiency predicting better performance. We also found a significant interaction between L3 proficiency and L2-L3 LD (*Est* $= 0.535$, *SD* $= 0.137$, $t = 3.914$, $p < 0.001$) on executive performance as indexed by Flanker RTs in both congruent and incongruent conditions. The interaction plot (Fig. 1) showed that L2-L3 LD dynamically modulated the executive control performance in our sample of young trilingual adults. More distant language pairs displayed maximal beneficial effects at low levels of L3 proficiency (i.e., lower RTs); these benefits gradually reduced as L3 proficiency increased. Closer language pairs, conversely, showed an increasing positive contribution on executive performance as L3 proficiency gradually accrued, with predicted RTs progressively decreasing. Including L2 proficiency as an additional covariate in our sensitivity analyses did not influence the outcomes. The models for L3 age of acquisition and L3 exposure yielded no significant results.

4. Discussion

In this study, we investigated the modulatory effect of LD on multilingualism-related cognitive consequences. Specifically, we assessed executive control capability, as indexed by Flanker task performance, in a cohort of young trilingual adults with the same L1 and L2 (Russian/English) and various L3s, providing a range of LDs and thus enabling the statistical assessment of their effects. Our hypothesis was centered on the notion that the impact of LD on executive task performance would vary depending on the stage of multilingual experience. We expected that during the learning phase (i.e. at lower levels of proficiency), multilingualism-induced cognitive benefits, reflected in improved Flanker task performance, would be more pronounced in individuals with large LD between L2 and L3. Due to the effortful

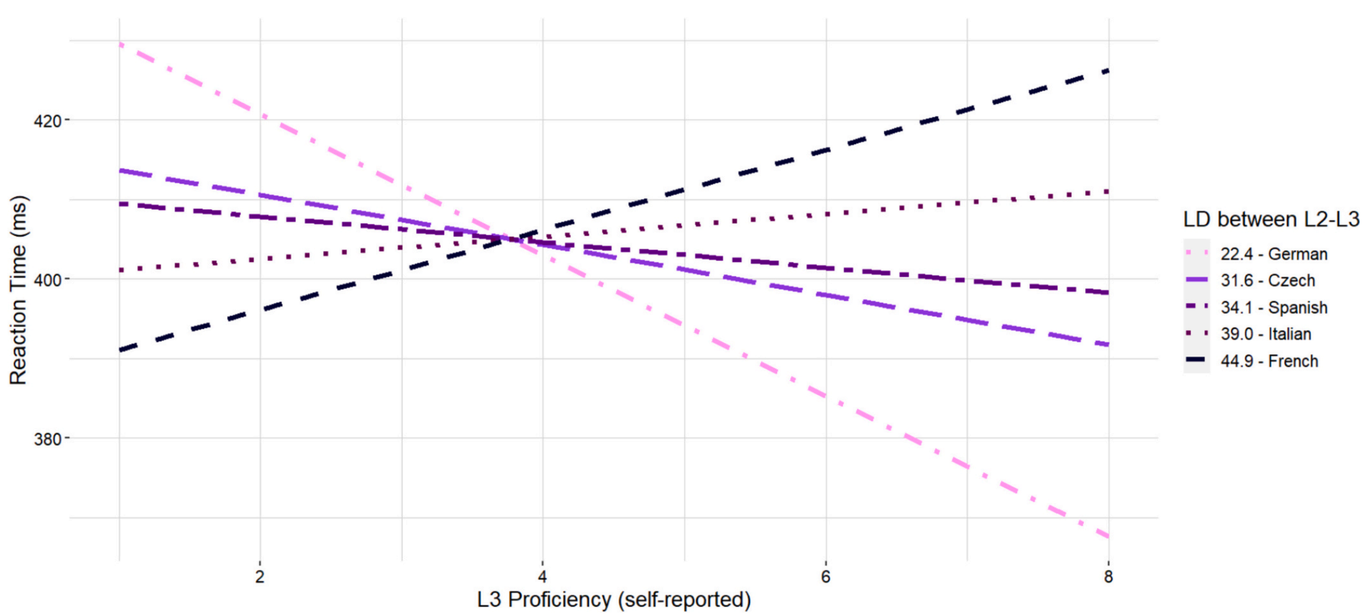

Fig. 1. Interaction plot for L2-L3 LD × L3 proficiency predicting Flanker RTs in both conditions of the Flanker task.

challenge of learning a new dissimilar language, with little-to-no transfer available from L1/L2, at the initial stages of trilingual experience participants with larger LD languages would experience greater cognitive effort – and thus greater cognitive benefits. However, as the language is increasingly acquired and L3 proficiency accrued, these benefits of *the learning stage* would no longer be as profound and relevant as they had been initially. Instead, the largest demands would be placed on the language control as such. Therefore, at *the language control stage*, we anticipated the maximum effect to be observed in individuals with close L2-L3 LD languages. Our prediction stemmed from the hypothesized heightened cognitive demands of managing similar languages, which provide ongoing training to executive control mechanisms, thus allowing participants with close LD languages to exhibit more substantial cognitive consequences.

Both predictions have been confirmed by our results which indeed delineate a pattern where these differential stages of multilingual experience are reflected in the dynamic effect of LD on executive functioning. For individuals speaking languages with large L2-L3 LD, the maximal cognitive benefits observed in the beginning were predicted by our model to gradually subside as they progressed in their multilingual experience and accrued proficiency in their L3. Individuals speaking languages with close L2-L3 LD exhibited an opposite pattern, with bilingualism-induced beneficial effects increasing with increasing L3 proficiency. As the observed effect was present in both congruent and incongruent conditions, our findings align with the claims expressed in Bialystok and Craik (2022), where it is suggested that bilingualism-induced effects may extend beyond inhibitory control and contribute to enhancing the overall attentional control mechanism. The term "attentional control" refers to a set of processes, for example facilitation, selection, inhibition, that are utilized to fulfill various goals. The authors suggest that specific demands that bilingualism entails lead to such adaptation of the domain-general attention system that strengthens both facilitation and inhibition processes, thus bi/multilingualism-related cognitive consequences are not limited to the performance on the incongruent trials and result in better performance of bilinguals in both conditions of the Flanker task.

The results of our study are in line with the conceptual framework of bilingual language control (Abutalebi & Green, 2016). According to the model put forward in this framework, bi/multilinguals mitigate interference from non-target language(s) through the use of language control mechanisms, which are shared with (or at least linked to) domain-general executive control. Disentangling between similar items is known to be a more cognitively demanding task (Furman & Wang, 2008). Due to a larger amount of similarities between close LD languages, the cognitive training that bilinguals experience (Bialystok, 2017) is posited to receive an additional boost by smaller LDs, as the result of an executive system taxed to a higher degree.

Our findings also corroborate and extend the results reported previously for L1-L2 LD influence on cognitive performance in a group of older bilingual adults (Gallo et al., 2023). Similar to the present results, the previous study indicated that more distant LD pairs yield maximal effects in the early stages of bilingual experience. Over time, however, cognitive benefits were increasingly supported by closer LD languages. Our results align with these findings and show that similar benefits can be observed in younger adults (who are in the peak period of their cognitive functionality and general health) and are not obscured by potential ceiling effects in executive performance (Bialystok, 2017). Furthermore, the present findings extend this framework from native/non-native language interaction to non-native/non-native language interaction.

We observed that LD between L2 and L3 affects cognitive consequences induced by bi/multilingualism, expanding the current knowledge of the multilingual dynamic and the resulting cognitive changes. Previous studies have highlighted the distinct nature of language relationships in bilingual and multilingual language systems. In the case of L3, the extant research on L3 acquisition (e.g. Leung, 2005; Rothman & Cabrelli Amaro, 2010) suggests that language transfer seems to stop relying on L1 when L2 is already consolidated. Available studies on cross-linguistic interference in the trilingual language system (e.g. de Bruin et al., 2023) also hint at the potentially heightened role of L2 during L3 processing. The observed impact of L2-L3 LD on cognitive functioning in trilinguals as indexed by Flanker task performance prompts consideration of whether the multilingual language dynamic is approached differently by the domain-general executive control system mechanisms in comparison with the purely bilingual context. Whereas these suggestions are, on the one hand, supported by the present data, they should, on the other hand, be further scrutinized and verified in future research. Our study is cross-sectional and a longitudinal one is needed to assure that the indicated patterns follow the observed dynamic over the prolonged time period. Furthermore, here, we used the same L1-L2 pair for the optimal control over this feature, while the L3 varied. Future research could benefit from varying both L2s and L3s such that the relative input of linguistic distances in L1-L2, L2-L3 and L1-L3 combination could be disentangled.

CRediT authorship contribution statement

M. Nelyubina: Writing – review & editing, Writing – original draft, Project administration, Methodology, Formal analysis, Data curation. **A. Myachykov:** Writing – review & editing, Supervision, Resources, Project administration, Conceptualization. **J. Abutalebi:** Writing – review & editing, Supervision. **Y. Shtyrov:** Writing – review & editing, Supervision, Resources, Project administration. **F. Gallo:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Formal analysis, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.actpsy.2025.105276.

Data availability

The data and analysis scripts that support the findings of this study are available from the corresponding author upon reasonable request.

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