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Age Moderates the Association between Linguistic Distance and Dynamic Executive Control: Evidence from Spanish-English and Mandarin-English Bilinguals

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Abstract. Whether linguistic distance may mediate executive control among bilinguals, and whether its mediation differs across age, remains unclear. This comparative study will recruit 288 Spanish-English and Mandarin-English bilinguals in two age groups (18-30 and 60-75 years), with 72 participants in each language-pair-by-age cell. Participants will complete keyboard-based Flanker and Stroop tasks to assess interference resolution and trial-to-trial adjustment. The primary outcome will be the Flanker sequential congruency effect (SCE), which captures the modulation of current-trial interference by previous-trial congruency. The secondary outcome will be the conventional conflict effects and Stroop performance. Language history, age of acquisition, switching frequency, receptive English proficiency, education, and subjective socioeconomic status will be assessed to characterise bilingual experience and evaluate potential confounding. Trial-level mixed- effects models will test the interaction between current congruency, previous congruency, age group, and language pair, with prespecified sensitivity analyses addressing background differences. The study aims to address whether language-pair discrepancies in dynamic executive control vary across adulthood, while acknowledging that comparisons between two language pairs cannot isolate linguistic distance from other sociolinguistic factors.

Keywords: bilingualism, linguistic distance, cognitive aging, executive control, sequential congruency effect

1. Introduction

Scholarship on bilingualism and executive function has moved beyond the polemics about whether bilinguals possess a general cognitive advantage over monolinguals. Meta-analytic studies do not corroborate a consistent advantage after accounting for publication bias and methodological heterogeneity [1]. One reason is that bilingualism is heterogeneous rather than dichotomous. Bilinguals differ in age of acquisition (AoA), proficiency, daily use, language dominance, switching frequency and interactional context. The Adaptive Control Hypothesis therefore postulates that cognitive control is dynamically calibrated to recurrent demands of language management, rather than to bilingual status per se [2].

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Linguistic distance represents another cardinal dimension that informs bilingual language control. Languages that are relatively proximal, such as French and English, structurally and lexically overlap to a large extent, thereby potentially reducing cognitive switching costs. In contrast, more distal language pairs, such as Persian and English, are likely to entail higher costs during task switching. Although a recent systematic review corroborated the pertinence of linguistic distance to bilingual cognitive performance, its effects remain inconsistent across studies [3]. For instance, Radman et al. [4] found faster switching performance among French-English than Persian-English bilinguals, whereas Sörman et al. [5] reported no evident advantage in switching efficiency between proximal and distal language pairs.

Ageing is another overarching factor that modulates bilingual cognitive control. Bialystok et al. [6] documented age-related differences in executive performance that interacted with task-specific bilingual effects. Moreover, cross-age comparisons intrinsically entail disparities in accumulated language experience, which indicates that the same language may differentially engage cognitive control mechanisms between younger and older bilinguals. Gallo et al. [7] underscored that distance associations in older bilinguals varied with bilingual experience, but this does not establish equivalence or divergence across age groups.

This study thus elaborates on whether age moderates the effect of linguistic distance on executive control. Participants will be subdivided into four groups as younger Spanish-English, older Spanish-English, younger Mandarin-English, and older Mandarin-English bilinguals, given that Spanish and English are comparatively closer at the lexical and syntactic levels than Mandarin and English, rendering these language pairs viable for examining potential associations between linguistic distance and executive control [8]. The study prioritises sequential congruency effects (SCEs), which index whether current-trial interference changes depending on whether the preceding trial was congruent or incongruent. Conventional conflict effects, the extra reaction-time cost on incongruent vis-à-vis congruent trials, serve as a secondary outcome. Treating bilingualism as a continuum retains within- group variability that categorical labels obfuscate. Executive control is one component of executive function. The tasks are thus geared towards interference and sequential modulation rather than global executive capabilities.

2. Literature review

2.1. Bilingual experience and executive control

The hypothesis that domain-general executive control may be conditioned by managing two active languages has become embroiled in polemics. Bialystok et al. [9] highlighted the benefits of bilingualism on the Simon task. Besides, Bialystok et al. [6] observed reduced Stroop interference among older bilinguals. Notwithstanding, Paap and Greenberg [10] reported no consistent advantage across executive tasks. Lehtonen et al. [1] also manifest no systematic advantage after correction for publication bias. These strands of scholarship discourage considering bilinguals as sufficient accounts for executive performance, which progressively nudges categorical comparisons into individual- differences approaches.

Multidimensional bilingualism may trigger different control demands. AoA reflects developmental history [11]; proficiency and use influence activation strength [12]; balance informs the relative accessibility of the two languages [13, 14]; switching frequency reflects recurrent reconfiguration of language goals [15]. Accordingly, Green and Abutalebi [2] underscored that adaptive control should hinge on interactional experience. Yurtsever et al. [16] provided recent evidence for this approach. Among 98 bilingual young adults, L2 AoA and switching frequency

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predicted selected Flanker and Stroop outcomes. Its associations were apparent for dynamic measures, as in SCEs. The present study thus regards bilingual experience as continuous dimensions rather than a binary property.

2.2. Conflict effects and sequential congruency effects

Conflict effects and SCEs capture two related but functionally dissociable components of executive control. The conflict effect is the extra time required when task-relevant and task-irrelevant information point to different responses. It can be calculated as mean reaction time on incongruent trials minus that on congruent trials. A larger value indexes greater interference cost. The SCEs capture trial-to-trial adjustment. Specifically, the current conflict effect often changes depending on the previous trial's congruency. It can be calculated as (cI – cC) – (iI – iC), where lower-case letters indicate the previous trial and upper-case letters the current trial. By and large, conflict effects reflect immediate interference, while SCEs reflect how recent conflict affects subsequent processing.

Grundy et al. [17] observed smaller SCEs among bilingual young adults, construing this as faster attentional disengagement. Goldsmith and Morton [18], however, observed SCEs without a bilingual group difference. Taken together, neither smaller nor larger SCEs will be translated as superior control. Feature repetitions and learned stimulus-response contingencies can likewise generate sequential patterns [19]. Grounded in this, the SCE mainly reflects dynamic, context-sensitive performance adjustments rather than a pure measure of domain-general executive function. Its centrality in this study stems from the concentration on adaptive control processes, rather than from the presupposition that it is more sensitive than conflict effects.

2.3. Linguistic distance and ageing

The distance effect does not demonstrate a consistent directional pattern across studies. Radman et al. [4] found both behavioural and electrophysiological differences between bilingual groups, substantiating the relevance of linguistic characteristics to cognitive control. The rationale for measuring switching experience stems from Prior and Gollan [15], whose groups differed on both switching habits and task performance. These evidential roles should remain distinct.

Among bilinguals aged 50-75 years of age, Sörman et al. [5] observed no statistically reliable differences in executive function between Swedish-English and Swedish-Finnish bilinguals. Gallo et al. [7], by contrast, identified distance associations that varied across stages of bilingual experience in older bilinguals. Similarly, Leivada et al. [3] likewise underscored heterogeneity not only in empirical findings but also in the operationalisations. Although well-trodden, present-day evidence explains only tentative associations between linguistic distance and executive control in later life, rather than robust and generalisable benefits attributable to distance per se. The central unresolved issue is whether language pair differences in sequential interference vary between younger and older bilinguals. Coupling age comparison and SCEs can address the issue, while measuring bilingual experience helps assess alternative explanations. Given that age groups are sampled cross-sectionally, any moderation will concern age group differences, not demonstrated within-person ageing.

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3. Research questions and hypotheses

The study embarks on three questions. RQ1 asks whether language pair groups differ in Flanker SCEs. H1 predicts a group difference, tested two-sided, as existing evidence does not justify a directional prediction. RQ2 asks whether age moderates those discrepancies. H2 predicts an Age Group × Language Pair interaction on SCEs. Attenuation with age and stronger differentiation after accumulated experience remain competing interpretations; neither is assumed in advance. RQ3 asks whether the interaction persists after adjustment for chosen background differences and appears in Stroop SCEs. This is a secondary robustness question without a directional hypothesis.

4. Methods

4.1. Participants

The study will subdivide participants into four groups as younger Spanish-English, older Spanish-English, younger Mandarin-English and older Mandarin-English bilinguals. Younger bilinguals will be aged 18-30 and older adults 60-75. Spanish or Mandarin will be the L1 and English the L2.

An a priori Monte Carlo power analysis was executed for the primary age-by-distance difference in SCEs, equivalent to the Current Congruency × Previous Congruency × Age Group × Distance Group interaction. Considering no study provides an estimate for this four-way effect, a conservative small- to-moderate planning effect of partial $\eta^2 = .03$ was used, informed by age-by-bilingualism interaction effects in executive-control research [6]. With $\alpha = .05$, 10,000 simulations indicated that 64 analysable participants per cell (N = 256) provided approximately 80% power. The recruitment target is 72 per cell, allowing for about 10% attrition or unusable data.

Participants must have normal or corrected-to-normal vision and adequate hearing. Neurological developmental history will be used for screening. Besides, participants must report whether they are right-handed or left-handed before embarking on tasks.

4.2. Materials

An adapted Language and Social Background Questionnaire [20] will assess AoA, daily use, and switching frequencies, such as questions 'At what age did you begin learning English?' and 'What percentage of a normal day do you spend using English?'. A five-point frequency scale from never to very often will be employed in the study. It is only indicative and will not be described as a validated composite.

The Cambridge English Placement Test (CEPT) will serve as a commonplace objective index of receptive English capabilities, evaluating reading comprehension, listening comprehension, and grammatical and lexical knowledge [21]. It is not tailored for productive skills, namely speaking and writing, so it should not be construed as an indicator of overall English proficiency. The same test version will be administered across all participants, and score distributions will be examined for ceiling effects.

Socioeconomic background will be embodied regarding two respects, namely completed education years and subjective social status. Participants will be asked to place themselves vis-à-vis people in the UK, considering income, education, and occupational standing [22]. The selected rung, on a scale of 1- 10, indexes subjective status rather than an objective SES composite. Education plays a key role in recruiting participants, while score enters the prespecified sensitivity analysis.

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As to older participants, a validated Spanish or Mandarin version of the Montreal Cognitive Assessment [23] needs to be completed by them. Implementation will follow the corresponding requirements. The score will be used only for eligibility rather than as a clinical diagnosis or a continuous measure of neurotypicality.

The Flanker task will show a central arrow among four flankers, using for response direction to permit sequences without immediate feature repetition. Congruent arrays share a direction, whereas incongruent ones point elsewhere. The Stroop task will display RED, BLUE, GREEN or YELLOW in matching or mismatching ink colours. Participants will choose the central direction or ink colour using four labelled keys. English colour word comprehension will be checked beforehand. Each task will comprise 320 trials across four blocks, with equal congruency proportions and approximately balanced cC, cI, iC, and iI transitions. Sequences will dodge immediate target, distractor and cross-role feature repetitions. Pilot check will verify these constraints and usable transition counts.

4.3. Procedure

Participants will complete screening, measures for linguistic competence and socioeconomic status, and the language profile. Older participants will also need to complete cognitive screening. Participants will practice the response mappings before completing the two executive tasks in counterbalanced sequence, with breaks between blocks. Each trial will show a fixation cross for 500 ms, followed by the stimulus until response or a 3000 ms deadline, then a 500 ms blank interval. Feedback will appear during practice only. Sessions will use given computers and keyboards. Practice will include at least 16 trials. Persistent difficulty after one repeat will trigger exclusion before experimental trials. The pilot will establish session duration and break requirements.

4.4. Data analysis

Reaction time refers to the interval from stimulus onset to the keypress identifying central arrow direction in Flanker or ink colour in Stroop. Accuracy is whether that task-specific response is correct. Omissions count as incorrect. Reaction times will be analysed on correct trials, with transformation if required by model diagnostics. Accuracy will be analysed using logistic mixed-effects models. Random intercepts for participants and theoretically justified random slopes for within-participant congruency factors will be included where supported by convergence.

Primary analyses will have recourse to trial-level mixed-effects models rather than relying only on aggregated difference scores. For conflict effects, the critical model will test Current Congruency × Age Group × Distance Group. For SCEs, the primary model will test Current Congruency × Previous Congruency × Age Group × Distance Group.

Flanker and Stroop will initially be analysed separately, as they impose different attentional demands. Selected higher-order interactions involving switching frequency will be considered secondary or exploratory rather than added indiscriminately to the confirmatory model.

5. Discussion and implications

If the result shows a smaller difference in older bilinguals, this would align with an attenuation account in which long-term language management or age-related changes reduce sensitivity to control demands. If the result manifests a larger difference in older bilinguals, this would explain an accumulation/adaptation account in which decades of managing particular language combinations shape later-life control. A null age-by-distance interaction would indicate greater age invariance.

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The distinction between conflict effects and SCEs is essential. An age-by-distance interaction restricted to SCEs would suggest that language-pair differences are expressed primarily in dynamic carry-over and adaptation rather than general interference costs. More broadly, the study would integrate linguistic distance, cognitive ageing, and continuous bilingual experience without returning to a simple bilingual-versus-monolingual advantage claim. Objective proficiency measurement, preregistered trial handling, and trial-level modelling should improve interpretability.

5.1. Limitations and future work

The main limitation lies in linguistic distance. The study only compares two language pairs. Spanish- English and Mandarin-English differ not only in relative distance but also in orthography, culture, migration history, and typical switching contexts. Consequently, any group effect can be described as consistent with a linguistic-distance account but not as caused uniquely by distance. Continuous measurement of switching, proficiency, AoA, use and SES reduces but cannot erase this confounding. The cross-sectional age comparison also cannot separate ageing from cohort effects or years of bilingual experience. Finally, SCEs may partially reflect feature integration rather than pure top-down adaptation. Future work ought to replicate the design across multiple language pairs and, where feasible, use longitudinal or accelerated-longitudinal sampling.

6. Conclusion

This proposal sets out a 2 × 2 cross-sectional study of younger and older Spanish-English and Mandarin- English bilinguals to investigate whether age moderates the effect of linguistic distance on executive control. By combining conventional conflict effects with SCEs, objective L2 proficiency measurement and continuous indices of bilingual experience, the proposal separates current-trial interference resolution from trial-by-trial control adaptation. Trial-level mixed-effects modelling of the age-by- distance interaction will indicate whether the same distance contrast carries equivalent cognitive consequences at different points in adult life. The study is therefore expected to contribute a more differentiated account of bilingual experience, linguistic distance, and cognitive ageing than a general bilingual-advantage framework provides.

Ethics statement

The author will apply for ethical approval from the relevant institutional research ethics committee before data collection begins.

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