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Research Article

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Posted Date: October 6th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11186040/v1>

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Additional Declarations: No competing interests reported.

**Multilingualism and ageing: Cognitive and affective trajectories in the Australian
Longitudinal Study of Ageing**

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Abstract

Background: The potential impact of multilingualism on cognitive ageing remains contested, with previous research limited by cross-sectional designs, narrow cognitive assessments, and inconsistent findings regarding cognitive resilience. This study aimed to address these limitations by examining whether multilingual experience is associated with longitudinal ageing trajectories across objective and subjective measures spanning cognitive, affective, linguistic, and non-linguistic domains.

Methods: Multilingual ($n = 193$) and monolingual ($n = 1894$) healthy older adults were drawn from the Australian Longitudinal Study of Ageing. Generalised additive mixed models were used to characterise nonlinear changes in performance on the Boston Naming Test, Digit Symbol Substitution Task, Metamemory in Adulthood Scale, and Philadelphia Geriatric Centre Morale Scale. Models included categorical multilingual status (multilingual vs. monolingual), baseline age, and timepoint as predictors.

Results: Multilingual status was associated with domain-specific differences in longitudinal ageing trajectories. Across subjective cognitive and affective measures, multilinguals showed patterns of change that converged with those of monolinguals over time, with group differences reduced or eliminated in specific subdomains, including aspects of metamemory and affective wellbeing. Overall, multilingual status was not associated with a consistent advantage in objective cognitive performance or slower age-related decline. Instead, monolinguals generally demonstrated higher performance on cognitive measures, including the Boston Naming Test.

Conclusions: Results support a reserve-modulation perspective, whereby multilingual experience may selectively contribute to adaptive regulation and resilience over time, rather than broadly conferring superior cognitive performance in ageing. Although multilingualism was not globally protective against cognitive decline, being multilingual was associated with a range of

costs and benefits for cognition and affect over time. Together, these findings highlight the dynamic and asymmetric nature of the effects of multilingualism for social-cognitive resilience in ageing. Multilingual experience may contribute to adaptive ageing through selective pathways involving cognitive regulation and affective resilience, highlighting the theoretical importance of considering reserve as an interaction between lifelong experiences, specific cognitive demands, and ageing processes.

Clinical Trial Number: not applicable.

Keywords: multilingualism, ageing, longitudinal, cognitive reserve, Generalised Additive Mixed Modelling (GAMMs).

Multilingualism and ageing: Cognitive and affective trajectories in the Australian Longitudinal Study of Ageing

In response to our increasingly globalised society and the resulting interactions between culturally and linguistically diverse groups, multilingualism is steadily becoming the global norm. Defined broadly as the ability to communicate in multiple languages (as opposed to monolingualism), multilingualism encompasses various levels of linguistic proficiency, including bilingualism, trilingualism, and beyond. Over half of the world's population speaks two or more languages in daily life (1). According to current estimates from the Australian Bureau of Statistics (2), approximately 28% of the Australian population speak a language other than English at home. This is reflective of the diverse cultural and ethnic composition of the national populace. In New South Wales alone, linguistically diverse individuals comprise a third of the population, with this figure expected to rise (3,4).

Concurrent with this linguistic diversity is the overall ageing of populations within Australia and worldwide (5–7). In fact, there are currently 4.2 million Australians over 65 years of age, with an expected increase of between 21% and 23% by 2066 (5–7). The intersection of these population demographic trends has resulted in a significant increase in multilingual older Australians: Notably, approximately 28% of Australians with dementia are culturally or linguistically diverse (5–7). Globally, over 50% of people with dementia identify as belonging to culturally or linguistically diverse groups (8,9). These figures underscore the importance of investigating cognition and ageing trajectories in multilingual people to gain deeper insight into the mechanisms that underlie trajectories of resilience and age-related decline.

Multilingual Experience and Cognitive Ageing

A body of evidence suggests that multilinguals experience and express cognitive decline differently than monolinguals (10–12). For multilinguals, current research indicates that the onset of dementia symptoms could occur up to five years later than in monolingual older adults (13–20). This has commonly been attributed to higher cognitive and/or neural reserve, through which neurodegenerative changes and resulting functional decline are masked (10,21–23). Similar delays in the onset of cognitive symptoms for multilingual populations have also been reported for mild cognitive impairment and post-stroke cognitive decline (24,25). These data provide promising support for the potential neuroprotective properties of language experience, but prompt additional questions about how such advantages might arise.

To understand the mechanisms contributing to possible delayed cognitive decline in multilingual older adults, researchers have compared cognitive performance in healthy multilingual people versus monolingual people, across the lifespan. Overall, the prevailing hypothesis is that multilingualism may lead to advantages for brain ageing as a byproduct of constantly selecting and suppressing multiple language systems (26,27). Over time, managing these competing demands is thought to confer benefits for cognitive abilities such as working memory, attention and inhibitory control (28–33), which should be demonstrated as better performance on cognitive tasks. Literature that supports a cognitive advantage for multilingual people has documented better performance for multilinguals compared to monolinguals on experimental tasks such as the N-back working memory task (34–36), the Stroop and Simon tasks for inhibitory control (29,31,37), and Proactive Interference or Dimensional Change Card Sorting tasks for attention (38). Despite these findings, an opposing literature has formed to suggest that these advantages could be spurious or do not exist (39–43). Meta-analyses have both

supported the presence of a multilingual advantage (19,28), and supported the lack of a multilingual advantage, whereby working memory, inhibition and shifting performance effects found in bilinguals do not survive statistical correction for factors such as publication bias (44). Such mixed findings call into question the mechanisms by which multilingual advantages develop in the brain, how they manifest during the ageing process, and even more so, whether they exist at all.

Although the mechanisms responsible are presently unclear and cognitive findings are mixed, neuroimaging research indicates significant structural and functional differences between people with different degrees of language experience (45). Greater grey matter volume and white matter integrity has been observed in the inferior parietal lobules, anterior cingulate cortex and prefrontal cortex for bilinguals (22,46–50). These areas form part of a network of activation necessary for cognitive abilities such as working memory, as well as selection, suppression and conflict resolution (components of attention and inhibition), and along with the basal ganglia are collectively engaged during bilingual language production. Multilinguals also demonstrate less activation in frontostriatal regions during tasks engaging working memory and inhibition, suggesting greater processing efficiency than monolinguals (34,51,52). This efficiency could be explained by systems typically reserved for non-linguistic tasks being recruited during multilingual language conflicts, over time increasing connectivity with language-specific regions such as Broca's area (17,52,53). Consequently, such regions could coordinate to form a larger network that is engaged in both linguistic and non-linguistic contexts (17,53).

Integrative Measurement Approaches to Capture Cognition

While neuroimaging findings suggest a range of neurophysiological correlates of increasing multilingual experience, behavioural research is limited in the range of domains explored (54). It is possible that such a narrow focus on behavioural measures of working memory, inhibition and attention within experimental designs has failed to capture alternate domains of benefit for people who are multilingual. Analyses of additional domains are critical to addressing inconsistencies in the literature and furthering knowledge about trajectories of ageing for multilinguals (54).

Performance can be assessed along multiple dimensions, including objective and subjective, cognitive and affective, as well as linguistic and non-linguistic measures, each capturing distinct aspects of psychological functioning. Some research has suggested that measures of subjective cognitive function may provide comparable or even better sensitivity to cognitive status and decline than objective behavioural measures (55–57). However, the effectiveness of subjective measures is dependent on an individual's metacognitive sensitivity, or level of insight into their own cognition (58,59). Subjective measures could be particularly useful for longitudinal evaluations documenting neurocognitive decline over time, namely the transition from healthy cognition to subjective cognitive decline to Mild Cognitive Impairment and eventually a dementia diagnosis (60). Subjective cognitive decline (SCD) refers to self-estimated impairment in cognitive capacity when compared to an individual's original level of functioning. Compared to individuals' perceptions of their own impairment in daily life, cognitive decline may not be detectable using traditional or objective neuropsychological tools until years later (64,65). Epidemiological evidence has found that among individuals self-reporting SCD, there is a higher risk of future diagnosis of cognitive impairment and higher levels of Alzheimer's

neuropathology such as amyloid- β deposition even in the absence of measurable impairment , supporting the validity of self-reported cognitive change.

While there have been inconsistent reports of multilingual advantages on objective measures of cognition (28–31,40–43), multilingual individuals' self-perceptions of their cognition and ageing trajectories remain largely unexplored. Several studies have examined the metacognition performance of multilingual people, but such studies have focused on linguistic task performance in healthy younger samples (65,66). These studies have also yielded mixed results, much like the objective cognitive data (65,66). For example, one study evaluating self-perceived performance on the Simon task and the Tower of London task in a lifespan sample found neither a significant advantage nor disadvantage of being multilingual in people's actual performance on executive function or the accuracy of their subjective self-evaluations (67). No studies to date have examined longitudinal outcomes of multilingual experience on subjective cognitive functioning for older adults.

Beyond objective versus subjective tasks, multilingualism may influence both cognitive and affective (referring to mood states, feelings, and attitudes) domains in ageing, yet affective outcomes have been comparatively understudied. Research suggests that multilingual experience could support affective resilience, potentially via increased social integration, as well as richer connections to culture, personal identity and overall wellbeing (68–71). It is possible that factors critical to adaptive ageing such as positive affective experiences, memory positivity and motivation for emotional regulation could be impacted by multilingual experience, much like cognitive reserve (70,72). Further research is necessary to clarify these relationships and explore trajectories over time.

Similarly, the distinction between linguistic and non-linguistic cognitive tasks is critical when evaluating multilingual effects. Linguistic measures (e.g., naming, fluency) rely heavily on lexical retrieval and semantic access and are therefore more directly shaped by language experience (73,74). Non-linguistic measures (e.g., visuospatial construction, executive functioning, processing speed tasks) minimise language demands and allow investigation of domain-general cognitive mechanisms (73,74). Existing evidence has suggests that multilinguals may actually show relative disadvantages on tasks requiring rapid lexical retrieval, such as picture naming, likely due to the increased cognitive demands of managing multiple lexicons and the resultant reduced frequency of access for individual lexical items (74,75). These disadvantages are typically not observed on non-linguistic tasks (53,76), making non-linguistic tasks optimal candidate measures for understanding language-independent cognitive effects of multilingual experience. Multilingual lexical disadvantages are thought to be domain-specific rather than reflecting broader cognitive deficits (74,75). Exploring linguistic and non-linguistic performance over time could help clarify how multilingual experience influences cognition at a lexical-semantic level, at a domain-general control level, or both.

Despite these various complex relationships, few studies have simultaneously contrasted multiple dimensions (objective versus subjective, cognitive versus affective, linguistic versus non-linguistic), limiting conclusions about whether multilingualism confers domain-specific or generalisable effects (77). Together, these gaps highlight the need for research that evaluates multilingualism across objective and subjective, affective and cognitive, as well as linguistic and non-linguistic tasks to provide a more comprehensive and ecologically valid account of multilingual ageing. Evaluating long-term trajectories using large-scale longitudinal data may also provide novel perspectives into how these facets of cognitive

functioning may similarly or differentially change over time, depending on multilingual experience.

Current Study

The current study aimed to examine the relationship between multilingualism and cognitive functioning across the adult lifespan using large-scale longitudinal data from the Australian Longitudinal Study of Ageing (78). To address limitations in prior research, this investigation adopted a dimensional approach, incorporating measures that varied along key axes of cognitive assessment, including objective versus subjective, linguistic versus non-linguistic, and cognitive versus affective domains. By analysing performance across these dimensions over repeated observations, the study sought to identify novel domains in which effects of multilingual experience may emerge, to determine whether subjective and objective assessments show convergent or divergent patterns, and to evaluate whether linguistic versus non-linguistic tasks respectively reveal costs and benefits of multilingualism. Additionally, the longitudinal design allowed examination of how these effects may vary both cross-sectionally, using baseline age as an indicator of between-person differences, and longitudinally across study waves, capturing within-person change over time. Through this multidimensional framework, the study aimed to provide a more comprehensive and ecologically valid account of how multilingual experience interacts with cognitive and affective ageing.

We hypothesised that:

- A) Multilingual participants would demonstrate lower levels of subjective memory concern than their monolingual counterparts, with this difference becoming more pronounced for

older people (i.e., a significant Multilingualism $\times$ baseline Age interaction reflecting cross-sectional differences in subjective cognitive outcomes) (34,56,66).

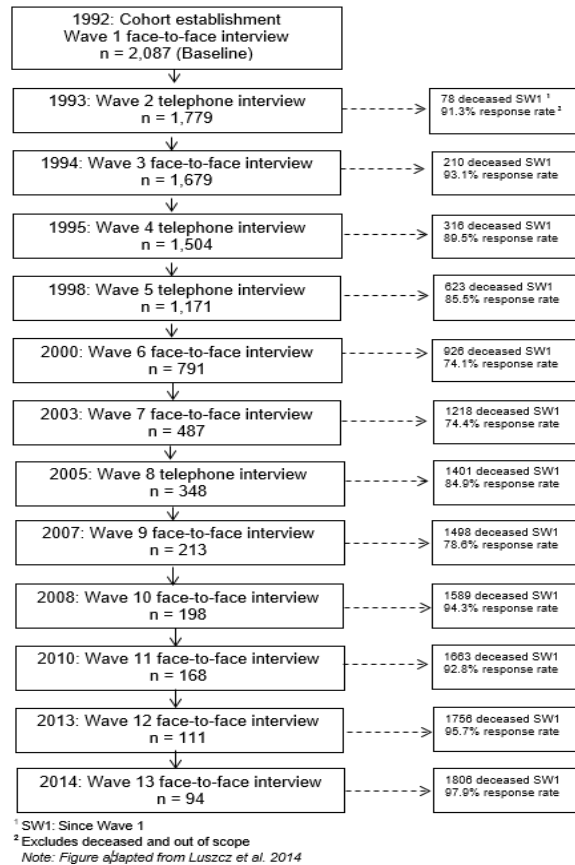
B) Multilingual participants would demonstrate both affective and non-linguistic cognitive performance advantages over time (i.e., a significant Multilingualism $\times$ Time interaction reflecting longitudinal ageing trajectories) (71,79).

C) Multilingual participants would demonstrate poorer performance than their monolingual counterparts on linguistic cognitive tasks (i.e., main effect of Monolingual status) (75,80).

Method

Data Source and Acquisition

Data were obtained from the Australian Longitudinal Study of Ageing (ALSA), a large-scale longitudinal cohort study conducted by the Centre for Ageing Studies at Flinders University (<https://sites.flinders.edu.au/alsa/>). Launched in 1992, the ALSA project aimed to investigate interactions between neural, cognitive, demographic, genetic, and lifestyle factors to understand the determinants of successful ageing (81). The final wave of data collection was carried out in 2014. Figure 1 captures the sample size at each wave of data collection, as well as retention and drop-out rates.

Figure 1*Data Collection and Study Sample*

Household interviews were conducted to gain insight into health, depression, morbid conditions, hospitalisation, hearing and vision difficulties, cognition, gross mobility and physical performance, activities of daily living and instrumental activities of daily living, lifestyle activities, exercise, and income (78,81). Other data collected via self-report questionnaires included dental health, sexual activity and psychological measures of self-esteem, morale and perceived control (78,81). Individual clinical assessments objectively measured both physical and cognitive functioning, while physical examinations collected measures of blood pressure, anthropometry, visual acuity, audiometry and physical performance. The cognitive assessment

included measures of memory, information processing efficiency, verbal ability and executive function. Clinical assessments were conducted by trained nurses with specialty in administering relevant psychological and anthropometric measures. These data were collected over a period of 22 years, equating to a total of 13 waves of data collection.

Access to the ALSA dataset was obtained via a tailored project application and downloaded from the ALSA host platform Dataverse (Australian Data Archive: <https://dataverse.ada.edu.au/dataset.xhtml?persistentId=doi:10.26193/J01NCT>). Institutional ethics approval from the Western Sydney University Human Research Ethics Committee was waived in accordance with their policy for projects with negligible risk using pre-existing data (EX2022-10). Therefore, this study complied with the 1964 Declaration of Helsinki and its later addenda. To maintain data security, data were deidentified and stored on a password-protected OneDrive folder that was only accessible to the research team.

Participants

ALSA recruited a population-based cohort of participants ($n = 2087$) aged 65 years and over. Participants were 1056 males and 1031 females aged 65 to 103 years of age ($M_{age} = 78.2$, $SD = 6.7$). Language experience was captured dichotomously in the ALSA sample. A vast majority of participants were monolingual ($n = 1894$, or 90.8%), with 193 (9.2%) people within the baseline cohort reporting having a language background other than English. Participants who reported monolingual status had a mean age of 78.4 years ($SD = 6.65$, range: 65-103 years), while those reporting multilingual status (Language Background Other than English; LBOTE) had a mean age of 76.2 years ($SD = 6.71$, range: 65-97 years). Modelling of differences between groups using an independent-samples t-test was conducted to compare age between monolingual

and multilingual participants. Results indicated that monolingual participants were significantly older than bilingual participants, $t(14607) = -11.521, p < .001$, Cohen's $d = 0.33$. Analyses indicated a small-to-moderate difference between groups, and thus further analysis proceeded with caution. Approximately 1424 (68.2%) of participants were Australian born, while the remaining 663 (31.8%) were born overseas (Table 1). Among those who were born overseas, participants had resided in Australia for an average of 40.9 years ($SD = 17.3$, range: 8-86). Those reporting monolingual status had lived in Australia for an average of 40.8 years ($SD = 19.3$, range: 9-86), while multilinguals had lived in Australia for an average of 41.3 years ($SD = 10.5$, range: 8-70 years). A diverse range of nationalities were also self-reported, with some participants indicating that they had dual nationality status or considered themselves 'international' (Table 2).

Reported LBOTE was used as a proxy rating for multilingual status within the current study. Of this LBOTE proportion, 68 (35.2%) reported some difficulty with English, although 50 of the 68 were conversationally proficient. English was the preferred language for 82 of the multilingual group, with 109 reporting a language other than English, and 9 participants not reporting a preference. Of the total cohort, 38 (1.8%) participants reported the use of a primary interpreter to assist them with communicating in English (Table 3). Out of those reporting multiple interpreters, 36.8% of secondary interpreters were another relative, 31.6% were a son or daughter, 7.9% were formal, free services, and 2.6% were a friend of the participant. As shown in Figure 1, substantial attrition over the 22-year follow-up period resulted in relatively few observations at the final wave, particularly for data on language experience. Nevertheless, the analysis plan was retained as its primary purpose was to model trajectories across the available longitudinal data.

Table 1*Participant Country of Birth*

Country of Birth	Frequency (n)	Percentage (%)
Australia	1424	68.23
UK/Ireland	426	20.41
Other European	75	3.59
Italy	38	1.82
Poland	32	1.53
Germany	22	1.05
The Netherlands	17	.82
South Africa	10	.48
New Zealand	9	.43
Southeast Asia	8	.38
Yugoslavia	8	.38
Greece	7	.34
Middle East	6	.29
United States / Canada	3	.14
South America	2	.10

Note. Country of Birth entries which reflect only region-level information are limited by the reporting within source data and cannot be further disaggregated.

Table 2*Participant Nationality*

Nationality	Frequency (n)	Percentage (%)
Australian	1835	87.93
English	162	7.76
Other European	46	2.20
Other UK	33	1.58
Not reported	5	.24
Other	3	.14
Asian	2	.10
Aboriginal or Torres Strait Islander	1	.05

Table 3*Reported Primary Interpreter*

Reported Primary Interpreter	Frequency (n)	Percentage (%) of full sample
Son or Daughter	27	1.29
Other Relative	6	.29
Other Household Member	2	.10
Neighbour	1	.05
Other Informal	1	.05
Other Formal, Free Service	1	.05

Measures

Our analysis focused on the two measures of objective cognition and two measures of subjective cognition which were most consistently administered throughout the waves of data collection (Figure 2). Measures were deemed to be consistently administered if they were administered: 1) at baseline; and, 2) in 7 or more of the 13 waves of data collection. These measures were selected to ensure sufficient longitudinal coverage and statistical power, allowing for reliable assessment of cognitive trajectories over time. Importantly, the final selected measures capture distinct dimensions of cognition: objective versus subjective performance, linguistic versus non-linguistic processing, and cognitive versus affective domains. This approach enabled us to examine how multilingual experience may differentially influence performance across these key axes while maintaining comparability across participants and waves. Details of these scales across dimensions are provided below and in Table 4.

Measures Administered Across Waves

[illegible]

Table 4*Breakdown of Measures Across Dimensions*

Measure	Subjective / Objective	Cognitive / Affective	Linguistic / Non-linguistic
Philadelphia Centre Geriatric Morale Scale (PCGMS)	S – self-report of outlook, agitation, loneliness	A – affective, mood	Survey
Metamemory in Adulthood (MIA)	S – self-report of beliefs about memory	C/A – cognitive complaints with affective components (worry, anxiety)	Survey
Boston Naming Test (BNT)	O – performance-based behavioural task	C – lexical retrieval, semantic processing	Linguistic
Digit Symbol (WAIS)	O – performance-based behavioural task	C – processing speed, visuomotor integration	Non-Linguistic

The Philadelphia Geriatric Centre Morale Scale. The Philadelphia Geriatric Centre Morale Scale was designed to measure perceived morale and affect in elderly people (82,83). This scale was divided into three subscales: 1) Agitation: characterises anxiety or distress experienced by respondents, e.g., “I get upset easily”; 2) Attitudes to own ageing: measures respondents’ perceptions of the changes taking place in their life, e.g., “Things keep getting worse as you get older”; and 3) Loneliness and dissatisfaction: measures satisfaction with their degree of social interaction, e.g., “You feel lonelier than you used to feel”. Participants responded by indicating whether they ‘agree’ or ‘disagree’ with 15 statements relating to their morale. Responses to all statements were recoded to ‘0’ or ‘1’, whereby ‘1’ was reflective of higher morale. As a result, statements 4, 5, 7, 14, and 15 were reverse-coded.

The Meta-Memory in Adulthood Scale (MIA). The Metamemory in Adulthood Questionnaire was devised to assess multiple dimensions of self-perceived memory (84). Three of the original 7 subscales were adapted for use in ALSA: 1) Capacity: Measure of memory self-

efficacy, e.g., “Remembering the plots of stories and novels is easy for me”; 2) Task: Measure of knowledge of memory processes, e.g., “For most people, facts that are interesting are easier to remember than facts that are not”; and 3) Locus: Measure of internal sense of control over memory, e.g., “Even if I work on it, my memory ability will go downhill.” The MIA used in ALSA was comprised of 42 statements measuring the respondents’ perceptions about their own memory. Item responses were provided on a Likert scale from 1 (‘Strongly agree’), to 5 (‘Strongly disagree’). As higher scores would normally represent good memory performance and internal control over memory, recoding was conducted to calculate total scores. Variables that are recoded are named accordingly (e.g. miata017 becomes rtask017). Subscale calculation used both the recoded and raw data variables as necessary.

Boston Naming Test. The Boston Naming Test (BNT) is a measure of lexical retrieval or naming ability designed for use with aphasic populations and individuals with other cognitive impairments affecting language comprehension and production (85). The BNT involves showing participants 15 line-drawings which range in difficulty and frequency. Participants were shown each target stimulus and asked to identify each item within a 20-second interval per trial. Correct responses were numerically recorded as a score of ‘1’. If an incorrect or incomplete response was provided, the examiner provided either a phonemic cue to indicate the initial sound of the target word, or a stimulus cue to direct participants who misappraised the object. If participant errors persisted, a score of ‘0’ was recorded for that item. BNT total scores were calculated to reflect the overall number of cues provided and successfully named items.

Digit Symbol Substitution Task. The Digit Symbol Substitution Task (DSST) is a subscale of the Wechsler Adult Intelligence Scale—Revised (WAIS-R) and assesses participants’ executive function, attention, associative learning, motor speed, and visuo-

perceptual function (86–88). The DSST requires participants to learn symbol-number pairs (digits 1-9) with reference to a key before responding to a sequence of blank symbols by providing the corresponding numbers. Participants are given 90 seconds to complete as many items as possible from left to right in chronological order. Correct responses are given a score of '1' while incorrect responses return a score of '0'. Total scores are provided for the overall number of correct items and error commissions.

Data Preprocessing and Statistical Approach

Data consolidation across waves and category-specific data files was performed using Python 3.12. Data were initially merged into separate datasets per wave, before being consolidated into a single long-form dataset to facilitate analysis. Where multiple variables existed within the same wave, they were aligned to ensure consistency across the dataset. Naming conventions were standardised per variable and all duplicate or redundant entries were reviewed.

Data preprocessing was conducted using the TIDAL (Trajectories of Individual Data Across Lifecourse) (89) framework in R Version 4.4.2, which facilitates the restructuring of longitudinal datasets from wide to long format (digital tool is accessible at <https://tidal-modelling.github.io/assets/pdf/Instructions.pdf>). Following the TIDAL guidelines, variables representing repeated measures across time (e.g., questionnaire scores at different waves) were selected alongside participant identifiers and relevant covariates. The tool was used to systematically tidy and reshape the data, such that each row represented a unique observation per individual per timepoint. This transformation enabled the inclusion of time-varying information (e.g., wave-specific scores) and time-invariant variables (e.g., sex, birth country) in a single long-

format dataset appropriate for subsequent statistical modelling. TIDAL also performed validation checks to ensure structural consistency, such as alignment of time variables and score columns, and flagged any inconsistencies for correction before analysis (89).

We employed longitudinal Generalised Additive Mixed Models (GAMMs) to examine the relationships between multilingual status and trajectories of performance across measures throughout ageing. In longitudinal biomedical research, it is common for outcomes to exhibit non-linear trajectories over time—a complexity that traditional methods like repeated measures ANOVA or linear mixed-effects models (LMEMs) fail to capture fully due to their reliance on linear trends (90–93). Mundo et al. (92) demonstrated that such linear assumptions can bias results and lead to unreliable inferences when the true trends are non-linear. This limitation underscores the need for a more flexible modelling framework capable of fitting the true shape of the data without imposing restrictive assumptions. Generalised Additive Mixed Models (GAMMs) bridge this gap by allowing data-driven smooth functions to model relationships between predictors and outcomes, while still accommodating the incomplete observations and correlated structure inherent in longitudinal data (91,92). As evidenced by Mundo et al. (92), GAMMs accurately recover non-linear patterns, even with substantial missing data, making them particularly well-suited for real-world biomedical studies where measurement schedules vary and response shapes are unknown. GAMMS are also considered apt for examining multilingual experience data (90,94). In multilingualism and second language acquisition studies, developmental patterns often exhibit non-linear trajectories, such as U-shaped learning curves or gradual improvements that plateau and then increase again (90,94). Standard linear models are not sensitive to such complexities, while GAMMs are specifically designed to model non-linear relationships through smooth terms that flexibly fit curves to the data without assuming a

specific polynomial structure. GAMMs support mixed-effects structures, which are critical in multilingualism research where data are often nested (e.g., repeated measures within participants). This allows the researcher to account for both individual variability (random effects) and complex, dynamic relationships in the dependent variables (e.g., cognitive scores, language performance) as they change over time or stages of development. GAMMS are rigorous, transparent, and reproducible, making them particularly well-suited for the current study (90). Their ability to flexibly model complex, real-world data structures such as non-linear trajectories and individual variability makes them especially effective for use in psycholinguistics, cognitive neuroscience, and longitudinal research more broadly (90). Overall, GAMMS' aptitude for data-driven modelling of developmental processes without imposing strict parametric assumptions made it an ideal tool to provide accurate and nuanced interpretations of longitudinal change. Prior to modelling, data were restricted to non-missing observations on the outcome variables at each wave to ensure valid estimation within the GAMMs framework. This preprocessing step resulted in a complete longitudinal structure for the analytic sample, with no variation in the number of observed waves per participant and, consequently, no observable dropout process within the data used for modelling. All scripts that were authored by members of the research team (written by OM, edited by AS) and used to conduct the data analysis are available at <https://osf.io/j86gy/overview>.

Results

A series of GAMMS models were fitted to examine longitudinal changes in scores on each measure's subscales as a function of multilingual status, timepoint, and baseline age, with random intercepts for participants to account for within-person dependence across measurement waves. Here, age was included to capture cross-sectional variation at baseline, while time

captured intra-individual change over the waves. For the current analyses, multiple model configurations were computed for each outcome variable to determine the most appropriate fit. Despite flexible models being effective in capturing nonlinear trajectories, excessive flexibility may introduce artificial fluctuations (95). The current analysis employed a principled modelling strategy, beginning with simpler models and progressively increasing complexity to provide staged improvements in model fit and interpretability. This approach required evaluation of competing models using diagnostic criteria (AIC, Explained Deviance, Adjusted R^2), assessing residual patterns and predictive accuracy, and ensuring that added model complexity aligned with theoretical expectations (95). Model results were interpreted based on the best determined fit. The model specifications are summarised in Table 5. The core research question was whether there was evidence supporting Model 2, such that there was a differential trajectory over time depending on multilingual status (see Table 5).

Table 5*Model Specifications*

Model	Equation	Focus	Key Terms Added	Research Question
M0 – Baseline Model	$Task \sim s(Time, k=5) + s(ID, bs="re")$	Establish baseline longitudinal trends and intra-individual differences.	Includes smooth terms for Time; random intercept for ID.	Does task performance change nonlinearly over time and within participants?
M1 – Age, Time, Multilingual Status	$Task \sim MultilingualStatus + s(Time, k=5) + s(Age) + s(ID, bs="re")$	Establish longitudinal trends for time, age and Multilingual Status.	Includes smooth terms for Time and Age; random intercept for ID.	Does task performance change nonlinearly over time or with age, and is there a main effect of multilingual status?
M2 – Age, Time × Multilingual Interaction	$Task \sim MultilingualStatus + s(Time, by=MultilingualStatus, k=5, bs="fs") + s(Age) + s(ID, bs="re")$	Examine differential time trajectories.	Group-specific smooths of Time by Multilingual Status, with separate terms for monolinguals and multilinguals.	Do multilinguals and monolinguals show different trajectories of performance across time?

*Subjective Affective Measures**The Philadelphia Geriatric Centre Morale Scale (PGCMS).*

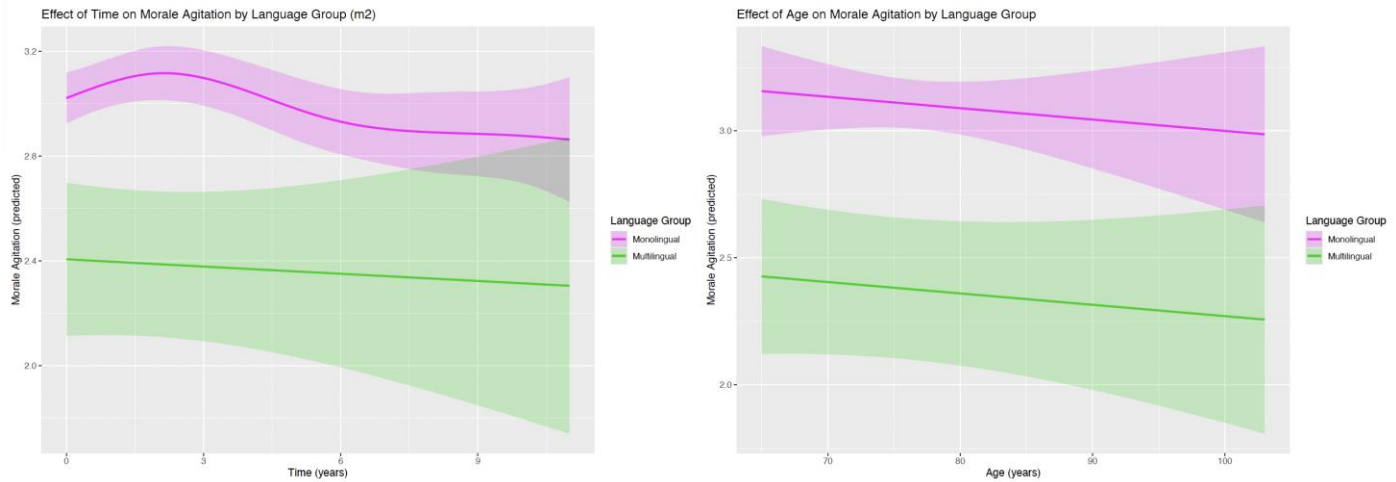
Agitation. For PGCMS Agitation scores, the final model (m2) had the lowest AIC, albeit marginally, indicating it demonstrated the most appropriate trade-off between model complexity and fit (Table 6). The model diagnostics shown in the Figure suggest that adding both linear and nonlinear effects captured systematic trends that the simpler models missed without overfitting.

Table 6*PGCMS Agitation Models*

Model	AIC	Explained Deviance	Adj. R ²
m0	9687.00	75.8%	0.63
m1	9667.17	76.0%	0.63
m2	9665.08	76.0%	0.63

The m2 model provided a strong overall fit (adjusted $R^2 = .63$, deviance explained = 76.0%, REML = 5472). Main effects using parametric term revealed that monolingual participants generally exhibited less agitation (higher morale scores) than multilinguals, $t = 4.38$, $\beta = 0.64$, $p < .001$. The smooth interaction term of Time $\times$ Monolingual Status was significant, $F(3.51) = 3.96$, $\text{edf} = 3.07$, $p = .008$, while the smooth of Time $\times$ Multilingual Status was not significant ($p = .731$). Modelling using smooth terms was not significant for baseline age, $F(1.00) = 0.50$, $\text{edf} = 1.00$, $p = .479$. The m2 model further included a random intercept for ID (s(ID)) to account for repeated measures within individuals over time. This term was highly significant, $F(1510.00) = 3.52$, $\text{edf} = 1103.54$, $p < .001$, indicating substantial between-person variability in baseline agitation levels, even after controlling for multilingual status, time, and age. The significance of ID reaffirms that including individual-level random effects significantly improves model fit and captures within-participant correlation across waves.

Modelling of time and baseline age effects by language group are visualised in Figure 3. The time plot suggests that multilinguals maintained more stable agitation levels across waves, while monolinguals showed a steeper early decline. Despite this, overall performance was better for monolinguals as compared to multilinguals at all time points, indicating an affective cost for multilinguals. Interactive three-dimensional representations of these variable relationships, as well as for all subsequent outcome measures, are available at <https://osf.io/j86gy/overview>.

Figure 3*PCGMS Agitation by Age and Time*

Note. Main effects of time (left) and age (right).

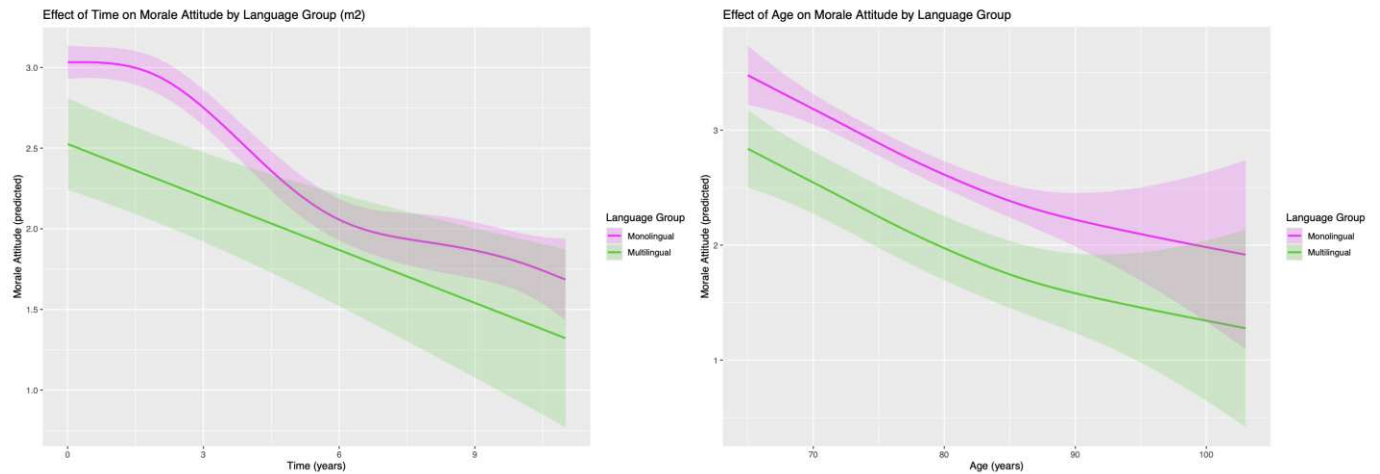
Attitudes to Own Ageing. For PGCMS scores on Attitudes to Own Ageing, the m2 model provided the best fit (AIC = 9447.70, adjusted $R^2 = 0.62$, deviance explained = 74.9%, REML = 5301.1; Table 7).

Table 7*PGCMS Attitudes to Own Ageing Models*

Model	AIC	Explained Deviance	Adj. R^2
m0	10057.75	67.8%	0.62
m1	9450.56	74.9%	0.62
m2	9447.70	74.9%	0.62

Monolingual participants generally exhibited more positive attitudes towards their own ageing (higher scores) than multilinguals as per parametric analysis, $t = 3.35$, $\beta = 0.47$, $p < .001$. The smooths of Time $\times$ Multilingual Status were significant for both monolinguals, $F(3.93) = 93.15$, $\text{edf} = 3.69$, $p < .001$, and multilinguals, $F(1.01) = 17.61$, $\text{edf} = 1.01$, $p < .001$, suggesting that despite lower scores overall, multilinguals demonstrated more linear, stable decline trajectories over time for attitudes towards their own ageing. Modelling using smooth terms was

also significant for age, $F(2.16) = 35.29$, $\text{edf} = 2.00$, $p < .001$, indicating a negative linear slope as participants aged. The m2 model further included a random intercept for ID (s(ID)) to account for repeated measures within individuals over time. This term was highly significant, $F(1500.00) = 3.06$, $\text{edf} = 1058.90$, $p < .001$, indicating substantial between-person variability in participants' baseline attitudes towards their own ageing, even after controlling for multilingual status, time, and age. Variable relationships are plotted in Figure 4, indicating visibly more stable trajectories for multilingual people over time than for monolinguals, as well as generally worse attitudes towards one's own ageing for multilinguals compared to monolinguals at all time points.

Figure 4*PCGMS Attitudes Towards Own Ageing by Age and Time*

Loneliness and Dissatisfaction. For Loneliness and Dissatisfaction scores, the m2 model provided the best fit (AIC = 8633.87, adjusted $R^2 = 0.55$, deviance explained = 69.2%, REML = 4805.4; Table 8).

Table 8*PGCMS Loneliness and Dissatisfaction Models*

Model	AIC	Explained Deviance	Adj. R^2
m0	8978.32	64.3%	0.55
m1	8644.09	69.0%	0.55
m2	8633.87	69.2%	0.55

Monolingual participants generally exhibited less self-rated loneliness and dissatisfaction (higher scores) than multilinguals on parametric analysis, $t = 3.75$, $\beta = 0.42$, $p < .001$. The smooths of Time $\times$ Monolingual Status, $F(3.80) = 48.39$, $\text{edf} = 3.45$, $p < .001$, and Multilingual Status were both significant, $F(3.28) = 5.50$, $\text{edf} = 2.81$, $p < .001$, suggesting highly nonlinear trajectories of self-reported loneliness and dissatisfaction over time. Modelling using smooth terms was also significant for age, $F(1.00) = 44.35$, $\text{edf} = 1.00$, $p < .001$, indicating a negative

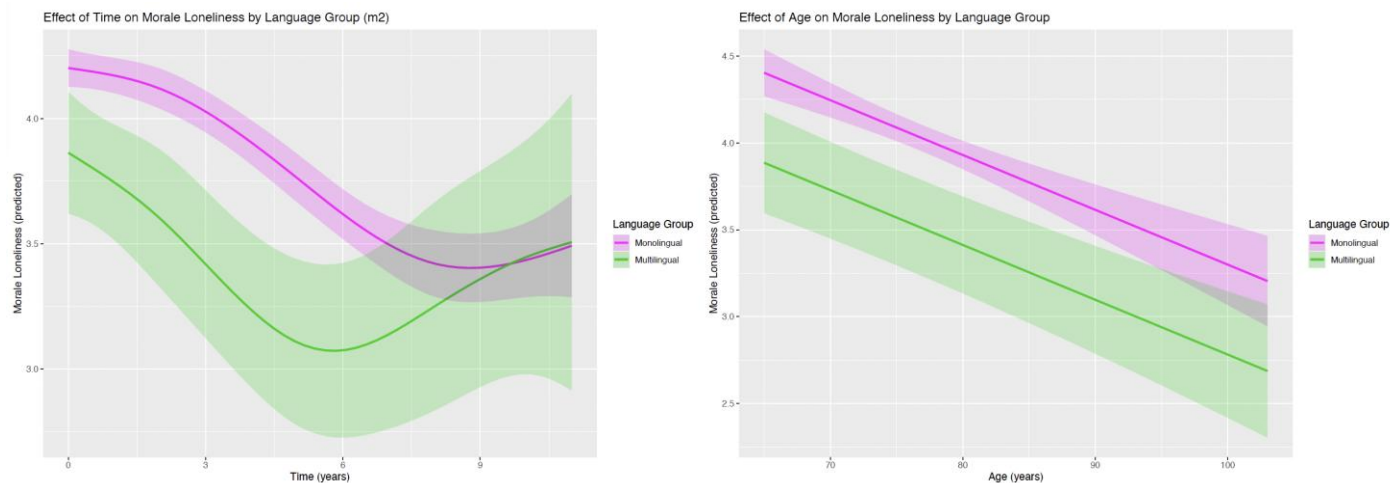
linear slope as participants aged. ID was also significant, $F(1519.00) = 2.36$, $\text{edf} = 1005.20$, $p < .001$, indicating substantial between-person variability in participants' baseline levels of

loneliness and dissatisfaction, even after controlling for multilingual status, time, and age.

Variable relationships are plotted in Figure 5. Multilingual people exhibited more pronounced nonlinear trajectories over time, beginning with higher loneliness (lower morale scores) relative to monolinguals, but showing an apparent reversal of this trend by the final measurement.

Figure 5

PCGMS Loneliness and Dissatisfaction by Age and Time



Subjective Cognition Measures

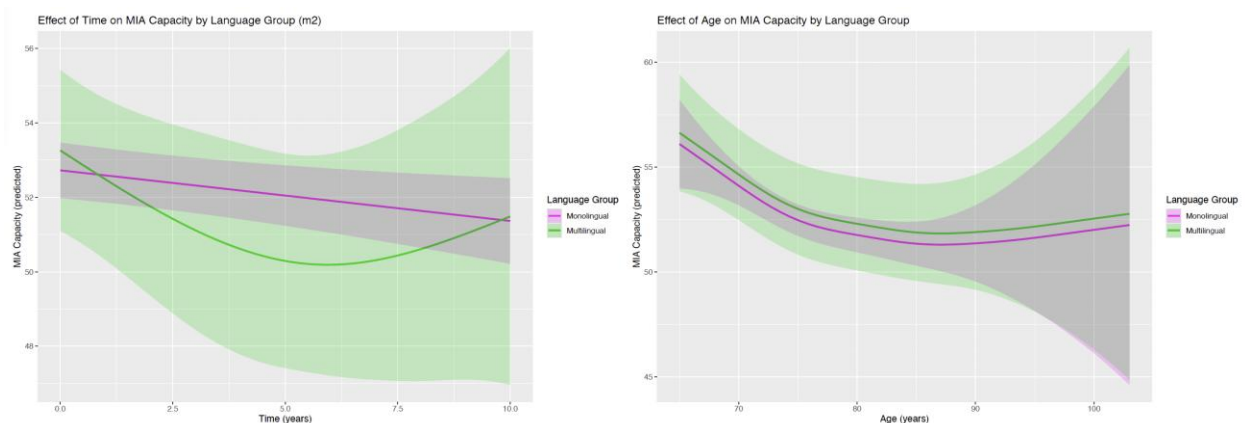
The Meta-Memory in Adulthood Scale (MIA).

MIA Capacity. For MIA Capacity scores, the m2 model provided the best fit (AIC = 11478.79, adjusted $R^2 = 0.76$, deviance explained = 88.5%, REML = 6437.7; Table 9).

Table 9*MIA Capacity Models*

Model	AIC	Explained Deviance	Adj. R ²
m0	11514.24	88.2%	0.76
m1	11489.05	88.4%	0.76
m2	11478.79	88.5%	0.76

Overall, Multilingual Status did not demonstrate a significant main effect on MIA Capacity scores, $p = .841$. Despite this, the smooth of Time $\times$ Monolingual Status was significant, $F(1.01) = 6.56$, $\text{edf} = 1.01$, $p = .01$, suggesting relatively linear decline trajectories of self-reported memory capacity over time. The smooth of Time $\times$ Multilingual Status was nonsignificant, $F(2.04) = 2.79$, $\text{edf} = 1.79$, $p = .06$ (Figure 6). Modelling using smooth terms was significant for Age, $F(2.62) = 7.40$, $\text{edf} = 2.47$, $p < .001$, indicating a negative linear slope as participants aged. ID was also significant, $F(1223.00) = 4.57$, $\text{edf} = 958.37$, $p < .001$, indicating substantial between-person variability in participants' baseline memory capacity, even after controlling for multilingual status, time, and age. Variable relationships are shown in Figure 6. Although multilingualism was not a significant predictor, highly nonlinear patterns were evident.

Figure 6*MIA Capacity by Age and Time*

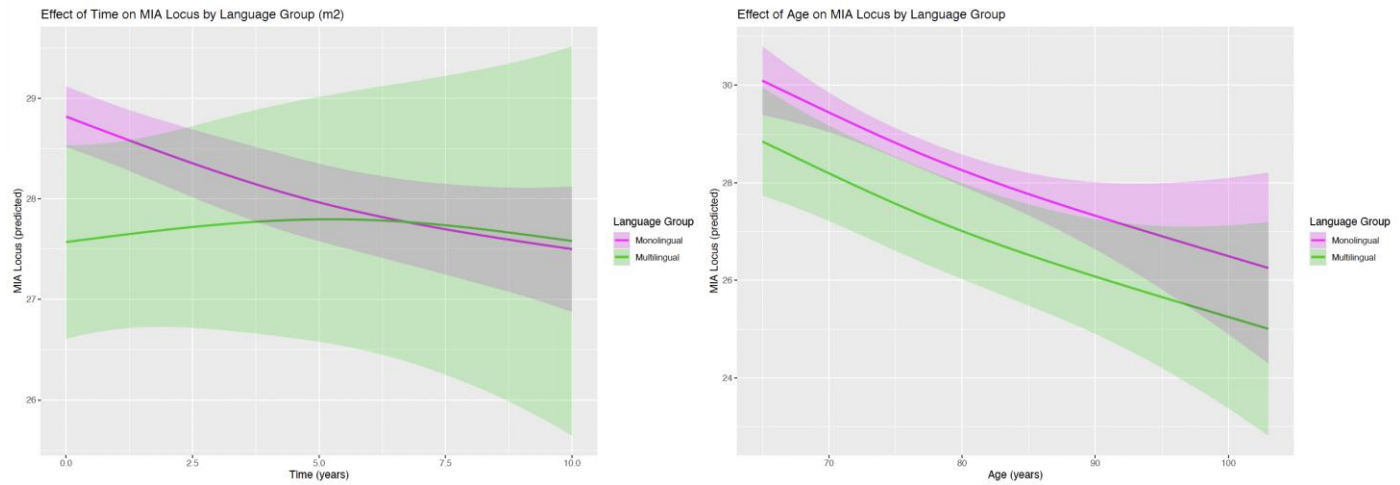
MIA Locus. For MIA Locus scores, the m2 model provided the best fit (AIC = 9990.39, adjusted $R^2 = 0.68$, deviance explained = 83.4%, REML = 5558.1; Table 10).

Table 10

MIA Locus Models

Model	AIC	Explained Deviance	Adj. R^2
m0	10072.32	82.4%	0.68
m1	9992.59	83.4%	0.68
m2	9990.39	83.4%	0.68

Multilingual Status did not demonstrate a significant main effect on MIA Locus scores, $p = .09$. The smooth of time by multilingual status was also not significant, $p = .842$. Despite this, the smooth of time by monolingual status was significant, $F(1.87) = 16.18$, $\text{edf} = 1.60$, $p < .001$, indicating that monolingual participants' internal sense of control over their own memory nonlinearly declined over time. Modelling using smooth terms was significant for age, $F(1.52) = 19.51$, $\text{edf} = 1.42$, $p < .001$, indicating a negative linear slope as participants aged. ID was also significant, $F(1311.00) = 3.11$, $\text{edf} = 939.97$, $p < .001$, indicating substantial between-person variability in participants' baseline memory control, even after controlling for multilingual status, time, and age. Variable relationships are plotted in Figure 7. Monolinguals showed a steeper decline with ageing as compared with the multilingual group. Although monolinguals initially rated their memory control higher, multilinguals reported marginally better internal locus of control over their memory by the final measurement timepoint.

Figure 7*MIA Locus by Age and Time*

MIA Task. For MIA Task scores, the m1 model provided the best fit (AIC = 10977.48, adjusted $R^2 = 0.57$, deviance explained = 74.7%, REML = 5859.1; Table 11), indicating relatively similar trajectories for language groups over time.

Table 11*MIA Task Models*

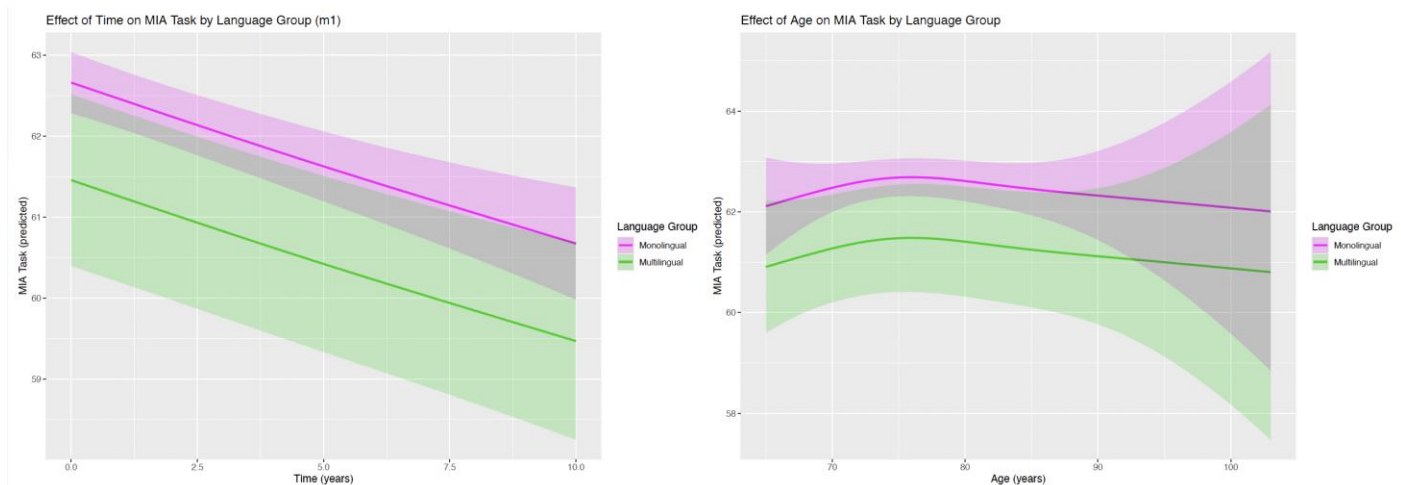
Model	AIC	Explained Deviance	Adj. R^2
m0	11068.43	72.6%	0.57
m1	10977.48	74.7%	0.57
m2	10979.99	74.7%	0.57

Monolingual participants generally felt they had better knowledge about memory processes (higher scores) than multilinguals, $t = 2.24$, $\beta = 1.20$, $p = .025$, across timepoints. Modelling using smooth terms was significant for time, $F(1.25) = 28.23$, $\text{edf} = 1.14$, $p < .001$, indicating a negative linear slope as participants aged. Smooth term modelling was not significant for baseline age, $F(2.17) = .53$, $\text{edf} = 1.96$, $p = .513$. ID was also significant, $F(1303.00) = 1.91$, $\text{edf} = 807.08$, $p < .001$, indicating substantial between-person variability in

participants' baseline memory control, even after controlling for multilingual status, time, and age. Variable relationships are visualised in Figure 8. Both monolingual and multilingual trajectories over time appeared relatively linear and similar to each other, with nonsignificant, nonlinear patterns apparent for baseline age.

Figure 8

MIA Task by Age and Time



Objective Linguistic Cognition Measures

Boston Naming Test (BNT).

Cued Recall. For BNT Cued Recall scores, the m0 model provided the best fit (AIC = 10664.93, adjusted $R^2 = 0.80$, deviance explained = 91.5%, REML = 6804.8; Table 12).

Table 12

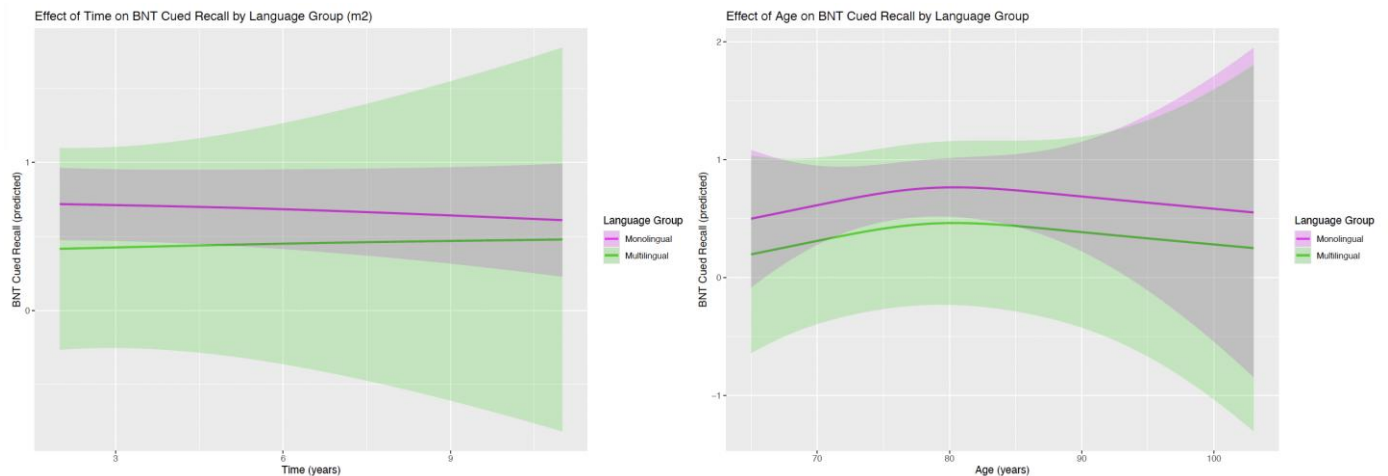
BNT Cued Recall Models

Model	AIC	Explained Deviance	Adj. R^2
m0	10664.93	91.5%	0.80
m1	10671.70	91.5%	0.80
m2	10677.02	91.5%	0.80

Across models, parametric analyses for multilingual status, time and age revealed no significant main effects on BNT Cued Recall scores (all $p > .05$). The smooths of time by monolingual status ($p = .648$), multilingual status ($p = .955$) and age ($p = .657$) were also not significant, suggesting that multilingual experience did not significantly affect cued recall performance over time. Modelling using smooth terms was significant for ID, $F(1730.00) = 6.15$, $\text{edf} = 1511$, $p < .001$, indicating high between-person variability in participants' baseline cued recall, even after controlling for multilingual status, time, and age on m1 and m2. The similar trajectories for both language groups are visualised in Figure 9, indicating no robust declines over time or with age for either group, consistent with the m0 model.

Figure 9

BNT Cued Recall by Age and Time

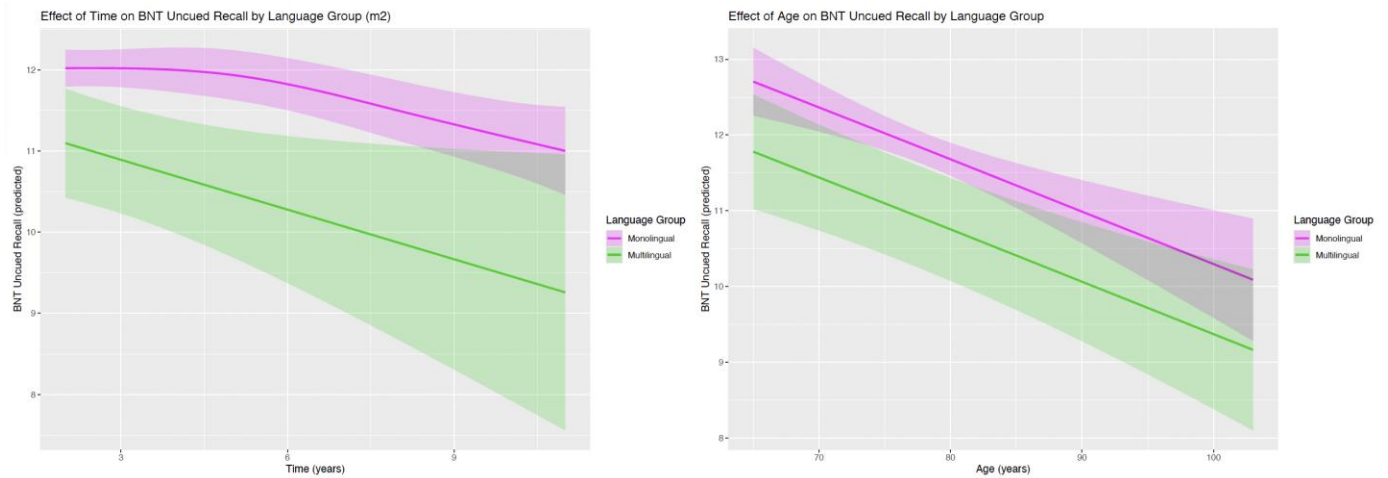


Uncued Recall. For BNT Uncued Recall scores, the m2 model provided the best fit (AIC = 12935.65, adjusted $R^2 = 0.60$, deviance explained = 78.5%, REML = 7165; Table 13).

Table 13*BNT Uncued Recall Models*

Model	AIC	Explained Deviance	Adj. R ²
m0	12995.04	77.8%	0.60
m1	12940.99	78.5%	0.60
m2	12935.65	78.5%	0.60

Parametric main effects analyses indicated that monolingual participants were able to recall more items uncued than their multilingual counterparts, $t = 3.21$, $\beta = 1.15$, $p = .001$. The smooth of time by monolingual status was significant, $F(2.37) = 6.61$, $\text{edf} = 2.02$, $p < .001$, as was time by multilingual status, $F(1.01) = 4.64$, $\text{edf} = 1.00$, $p = .03$. Modelling using smooth terms was also significant for age, $F(1.03) = 20.22$, $\text{edf} = 1.02$, $p < .001$, indicating a negative linear slope as participants aged. ID was also significant, $F(1728.00) = 2.23$, $\text{edf} = 1210.93$, $p < .001$, indicating high between-person variability in participants' baseline uncued recall, even after controlling for multilingual status, time, and age. Variable relationships are shown in Figure 10. Compared to multilinguals, monolinguals showed better performance at all timepoints as well as more nonlinear trajectories over time, potentially indicating a less pronounced rate of decline.

Figure 10*BNT Uncued Recall by Age and Time**Objective Non-Linguistic Cognition Measures**Digit Symbol Substitution Task (DSST).*

DSST Correct. For Digit Symbol Correct scores, the m2 model provided the best fit (AIC = 23653.64, adjusted $R^2 = 0.47$, deviance explained = 37.3%, REML = 11873; Table 14).

Table 14*Digit Symbol Correct Models*

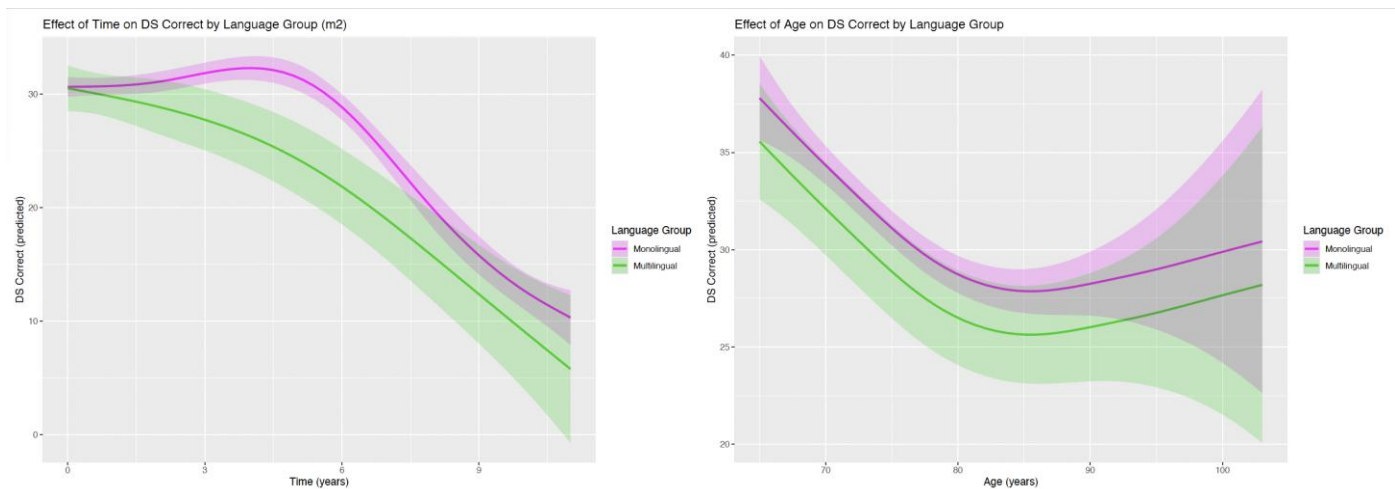
Model	AIC	Explained Deviance	Adj. R^2
m0	24267.95	13.1%	0.47
m1	23654.88	37.3%	0.47
m2	23653.64	37.3%	0.47

Parametric analyses revealed a significant main effect of multilingual status on Digit Symbol Correct scores ($p = .003$). The smooths of age, $F(3.99) = 32.61$, $\text{edf} = 3.33$, $p < .001$, time by multilingual status, $F(2.73) = 24.19$, $\text{edf} = 2.28$, $p < .001$, and time by monolingual status, $F(3.98) = 130.00$, $\text{edf} = 3.84$, $p < .001$, were significant, suggesting that executive cognition and processing speed accuracy nonlinearly varied with multilingual experience over

time and across baseline age. Modelling using smooth terms was significant for ID, $F(1685.00) = 0.33$, $\text{edf} = 387.76$, $p < .001$, indicating high between-person variability in participants' baseline cued recall, even after controlling for multilingual status, time, and age. Variable relationships for each language group are visualised in Figure 11, illustrating the difference in trajectories between monolinguals and multilinguals. Multilinguals appeared to demonstrate stable patterns of decline over time, while monolinguals showed a delayed onset of decline.

Figure 11

Digit Symbol Correct by Age and Time



DSST Errors. For Digit Symbol Error scores, the m1 model provided the best fit (AIC = 54345.73, adjusted $R^2 = 0.03$, deviance explained = 3.0%, REML = 27151; Table 15).

Table 15

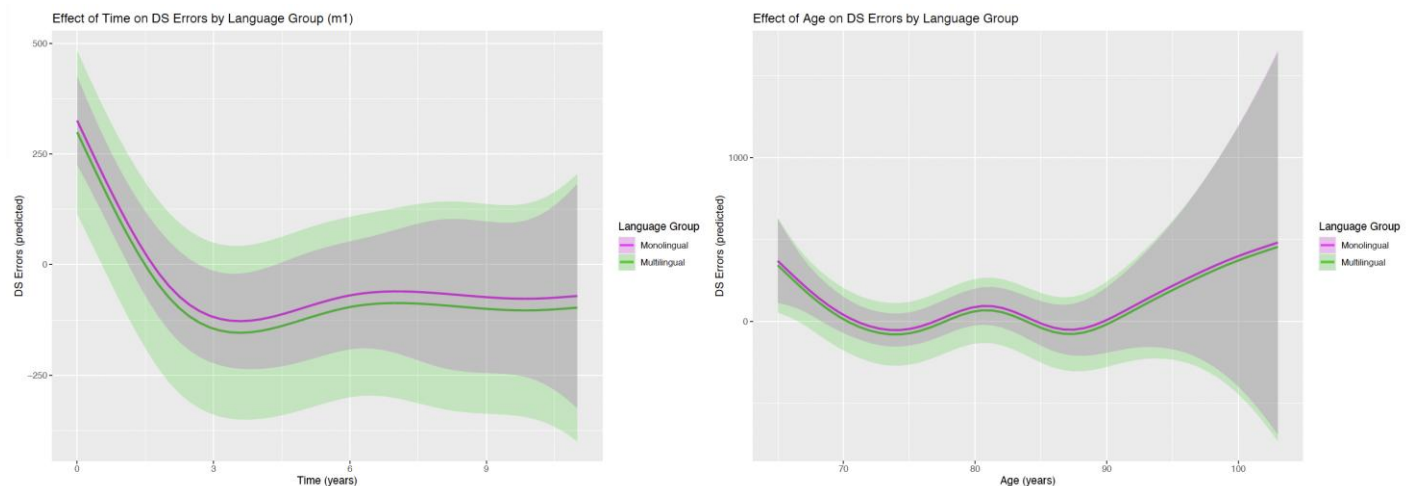
Digit Symbol Error Models

Model	AIC	Explained Deviance	Adj. R^2
m0	54415.44	0%	0.03
m1	54345.23	3.0%	0.03
m2	54349.57	3.0%	0.03

Parametric analyses revealed a nonsignificant main effect for multilingual status on Digit Symbol Correct scores ($p > .05$). The smooths of time, $F(3.71) = 17.36$, $\text{edf} = 3.31$, $p < .001$, and age, $F(5.78) = 2.63$, $\text{edf} = 4.75$, $p = .02$, were significant, indicating that executive cognition and processing speed errors nonlinearly varied over time and across baseline age, showing early declines and then stability for both language groups. Modelling using smooth terms was not significant for ID, $p = .488$. The similar trajectories for each language group are visualised in Figure 12, consistent with the m1 model.

Figure 12

Digit Symbol Errors by Age and Time



Discussion

The present study aimed to examine the relationship between multilingual experience and cognitive functioning across the later adult lifespan using large-scale longitudinal data from the Australian Longitudinal Study of Ageing (ALSA). By modelling both objective and subjective measures across cognitive/affective and linguistic/non-linguistic axes with GAMMS, the study explored whether multilingualism was associated with differences in change over repeated

observations. Consistent with recent calls for nonlinear modelling approaches to ageing data , this study evaluated complex time- and age-dependent trajectories to capture intra- and inter-individual variability across the lifespan. Three primary hypotheses were tested: a) Multilingual participants would demonstrate lower levels of subjective memory concern than their monolingual counterparts, with this difference becoming more pronounced at older ages (i.e., a significant Multilingualism $\times$ Age interaction on subjective cognitive outcomes); b) Multilingual participants would demonstrate both affective and non-linguistic cognitive performance advantages over time (i.e., a significant Multilingualism $\times$ Time interaction); and c) Multilingual participants would demonstrate poorer performance than their monolingual counterparts on lexical cognitive tasks.

Principal Findings

Contrary to the study hypotheses, the analyses provided limited evidence for any cognitive or affective advantages of multilingualism in ageing. Across most models, multilingual status was not associated with improved cognitive outcomes or slower decline trajectories, and in fact, where there were differences, they were in the opposite direction such that multilinguals showed poorer subjective cognition and affect than monolinguals. While significant effects of time and baseline age were consistently observed across measures—reflecting expected age-related changes—multilingualism did not interact robustly with these variables. Notably, small but interpretable differences emerged across time for specific domains of subjective affective wellbeing, non-linguistic executive cognition and subjective memory, however, these differences were not always in the expected direction. Across most measures, monolinguals consistently outperformed multilinguals, and these group differences were largely maintained longitudinally. Multilingual participants showed no superiority in level of performance; rather, they exhibited

limited domain-specific benefits regarding longitudinal trajectory shape, including greater temporal consistency in attitudes towards ageing despite lower overall scores, and a reduction of an initial disadvantage in loneliness and dissatisfaction that resulted in a relative crossover at the final assessment. This pattern of results suggests that multilingualism may selectively influence the stability of cognitive-affective trajectories, rather than producing large differences in overall performance or scores. Despite the limited evidence indicating longitudinal stability associated with multilingual experience, overall performance was poorer for multilinguals, pointing to a nuanced, domain-specific effect of multilingual experience that is best understood as comprising both measurable costs and benefits, rather than any uniform advantage.

Hypothesis A, which predicted that multilingual participants would demonstrate lower levels of subjective memory concern than monolinguals and that this difference would become more pronounced with age, was not supported. Across MIA subscales, monolinguals exhibited lower overall subjective cognitive concern, with this pattern persisting across baseline age. Although multilingual participants exhibited lower initial scores, a different longitudinal trajectory was observed for MIA Locus scores that resulted in convergence with, but not improvement beyond, monolingual performance by the final wave. These findings do not support a multilingual advantage in subjective memory and instead align with a trade-off account: Multilingual experience appeared to confer measurable costs for subjective memory and modest, domain-specific convergence over time that did not offset the broader pattern of disadvantage.

Hypothesis B, which proposed that multilingual participants would demonstrate both affective and non-linguistic cognitive advantages over time received partial support. Monolingual participants reported generally higher morale across subscales of Agitation, Attitudes to Own Ageing, and Loneliness and Dissatisfaction. Multilingual participants did not

demonstrate superior affective or cognitive performance; however, they exhibited more stable longitudinal trajectories in self-reported attitudes to ageing. Similarly, for Loneliness and Dissatisfaction and memory-related locus of control on the MIA, multilingual participants began with poorer scores but showed greater convergence with monolinguals over time. Importantly, these trajectory differences reflected attenuation of initial disadvantages rather than improvement beyond monolingual levels. These findings suggest that multilingual experience may be associated with selective resilience on self-reported affective and self-regulatory domains in the context of otherwise poorer overall functioning. Although age-related decline was evident across all cognitive and affective measures, multilingual participants demonstrated less fluctuation over time, which may indicate constrained, domain-specific resilience rather than broad cognitive or affective advantage.

Finally, Hypothesis C, predicting that multilinguals would demonstrate a disadvantage on linguistic cognitive tasks, was supported: Performance on the BNT was poorer for multilinguals, consistent with other research which has identified lexical retrieval disadvantages in multilinguals. Overall, these findings suggest that multilingualism's influence on cognitive ageing is subtle, domain-specific, and likely mediated by individual and contextual factors across the lifespan, rather than representing a uniform protective effect.

Affective Wellbeing and Morale

The PGCMS results highlight important distinctions in how multilingualism relates to affective and attitudinal aspects of ageing. Monolingual participants reported higher morale, reflected in lower agitation and loneliness and more positive attitudes towards their own ageing. Multilingual participants, in contrast, started with substantially lower baseline scores on Agitation and Attitudes to Own Ageing, and this difference was largely maintained across time.

For Loneliness and Dissatisfaction, however, multilinguals exhibited a different pattern:

Although initially reporting higher loneliness, their scores showed increasing convergence with monolinguals over successive waves. These findings provide conflicting evidence relative to prior work suggesting that multilingualism contributes to emotional regulation stability rather than superior wellbeing (69,70,79). Communicating in multiple languages may provide opportunities for cognitive enrichment as well as social connection, representing not only a useful cognitive resource, but a meaningful affective or socioemotional experience (71,96).

Navigating multiple linguistic and cultural frameworks could, therefore, contribute to reductions in variability in affective trajectories over time (71,96). Nonetheless, these potential regulatory effects occur in the context of generally lower affective wellbeing for multilingual participants, underscoring that any benefits are subtle, constrained, and do not outweigh the baseline costs.

The differences in morale could also reflect broader sociocultural and migration-related factors. Many older multilinguals in the ALSA sample likely represent first-generation migrants whose experiences of linguistic and cultural adaptation may involve ongoing psychosocial challenges, especially given the operationalisation of multilingualism as having a first language other than English, which was the closest indication of multilingual status available in the dataset. These contextual influences, including cultural distance and reduced access to community networks, could explain the lower baseline morale among multilinguals. It could also be possible that multilinguals had lower expectations for their cognition and overall wellbeing than monolinguals, potentially because of socioeconomic factors or cultural attitudes.

Nonetheless, the longitudinal patterns observed in this group may indicate subtle, domain-specific adaptability built through lifelong cross-cultural negotiation (97). Thus, the morale findings may not directly reflect cognitive differences but rather the socioemotional context in

which multilingualism develops and is maintained, in the Australian setting where English speaking monolingualism represents the majority.

Subjective Cognitive Function and Metamemory

Metamemory, as assessed by the MIA subscales, provides a window into how individuals perceive, monitor, and evaluate their own cognitive processes, and particularly, the extent of subjective memory concerns. The current findings indicated no evidence for multilingual advantages in metamemory perceptions but there was some evidence for differential trajectories over time. For example, multilinguals demonstrated a converging trajectory with monolinguals over time on MIA Locus scores, suggesting they maintained greater perceived control over memory at later ages, despite an initial baseline disadvantage. These findings are consistent with research linking multilingual experience to enhanced metacognitive monitoring and cognitive control (66,98–101), even when objective performance differences are minimal.

Importantly, the models captured nonlinear changes across age, showing that subjective perceptions of memory control and capacity appeared to fluctuate dynamically over the lifespan. Multilinguals' more stable trajectories on perceived locus of control as compared with other MIA subscales may indicate a preserved sense of cognitive self-efficacy—a factor strongly associated with reduced cognitive anxiety and slower functional decline in later life (102). However, overall levels of perceived memory control and capacity were not higher for multilinguals, and the analyses did not reveal robust main effects of multilingual status across MIA subscales. These findings align with work suggesting that cognitive advantages of multilingualism may not exist or are restricted to very specific and undetermined circumstances (41,42). It may also be possible that potential benefits, if and where they do occur, may be

dependent on individual differences in language proficiency, frequency of use, and sociocultural engagement. Overall, the results do not support a protective effect of multilingualism on cognitive or affective outcomes: any apparent stability in subjective memory is subtle, domain-specific, and does not translate into overall cognitive or affective advantages.

Objective Cognitive Functioning

The results for the objective cognitive measures were consistent with the null or mixed findings reported in large-scale meta-analyses and reviews of the literature (44,97). On the Boston Naming Test, multilingual participants showed disadvantages on uncued recall relative to monolinguals. This pattern likely reflects the multilingual lexical access cost, whereby managing multiple lexical systems can slow retrieval in single-language contexts (74). Importantly, in prior research, these differences did not imply overall cognitive disadvantage; instead, they illustrated a trade-off between lexical retrieval speed and other cognitive processes such as control and flexibility (74). In the current study, these disadvantages appeared to be extinguished when cues were provided to elicit recall: cued recall performance did not differ significantly between groups, suggesting that when retrieval demands were supported, multilinguals performed equivalently to monolinguals, suggesting that, like purported multilingual advantages, multilingual disadvantages may only emerge in specific circumstances and on specific tasks.

Similarly, for the Digit Symbol Substitution Task, a non-linguistic task which indexes processing speed, executive function and attention, a significant effect of multilingualism was only observed for accuracy scores, where multilinguals performed worse when compared with monolinguals, though the difference between groups reduced over time. Both time and age significantly predicted DSST performance, consistent with expected age-related slowing in

cognitive processing. The absence of a consistent multilingual effect contributes to the body of literature showing no effects of multilingual experience on cognitive tasks (41,42). The findings could alternatively suggest that any potential cognitive reserve conferred by multilingualism may not reliably extend to tasks which rely heavily on aspects of perceptual-motor coordination—abilities that decline with age. These findings underscore the domain-specific nature of multilingualism's cognitive effects and highlight the importance of careful task selection when assessing potential differences (103).

Theoretical Implications

Taken together, the findings from subjective and objective cognitive, affective, linguistic and non-linguistic measures provide a nuanced, trajectory-based picture of the potential impacts of multilingual experience on ageing. While the hypothesised broad protective effect was not supported, there was some evidence that multilingualism may impact the temporal dynamics of specific domains rather than cognitive and affective outcomes overall. Across most measures, multilingual participants tended to perform worse than monolinguals, yet selective patterns emerged over time in certain affective and self-regulatory domains. These longitudinal patterns may reflect domain-specific associations between multilingual experience and aspects of adaptive ageing, potentially supporting stability in emotional and self-regulatory processes rather than conferring broad enhancements in cognitive performance.

This interpretation aligns with the reserve modulation hypothesis (104), which proposes that multilingualism influences the deployment of existing cognitive resources rather than increasing their quantity. In other words, multilinguals may not possess greater cognitive capacity, but they may use some cognitive resources more efficiently or flexibly, allowing them

to maintain performance under changing task or environmental demands (105). Nonetheless, the broader pattern of data suggests that multilingualism confers a range of costs and limited, domain-specific benefits for cognition and affect. Overall, these data support prior work proposing that cognitive advantages may be overstated and instead highly restricted to certain contexts, domains and measures (41,42,44,74,97).

From a theoretical standpoint, these results contribute to an evolving understanding of how lifelong language experience interacts with cognitive ageing. The data suggest that multilingualism's influence is neither globally protective nor completely absent, but contingent on the domain and life stage being examined. The selective, domain-specific stability observed on some measures—such as self-reported memory control or affective attitudes—among multilinguals suggests that multilingual experience supports some regulatory mechanisms, such as emotional regulation, self-monitoring, and attentional control, that underpin adaptive ageing. However, the absence of widespread advantages challenges simplistic claims of a “bilingual advantage” and supports more nuanced, context-sensitive models. In fact, the results indicated costs for multilinguals across measures. For example, group differences were evident on the Boston Naming Task for uncued but not cued recall, with disadvantages emerging under effortful lexical retrieval despite performance being preserved when semantic cues were provided (74). These patterns suggest that multilingual experience entails both costs and limited, domain-specific benefits rather than a uniform advantage.

Limitations and Future Directions

Several limitations of the current study should be acknowledged. First, the ALSA cohort did not directly measure multilingual experience. Because we were restricted to the variables

already collected in this existing dataset, Language Background Other Than English (LBOTE) was used as the closest available proxy, classifying participants dichotomously (multilingual vs. monolingual) according to whether their first language was other than English, which would imply multilingualism in the Australian context. This classification is blunt, and it lacks detail on the number of languages, proficiency, age of acquisition, context of acquisition or use, frequency of language use, switching, and sociocultural engagement—all variables shown to modulate cognitive outcomes (106). As an indirect measure, the proxy measure (LBOTE) may also have introduced noise into the comparison. It is likely to have missed multilingual individuals whose first language was English, increasing the heterogeneity within the “monolingual” sample. Overall, this coarse classification likely attenuated true variability in language experience and may explain the small or null effects observed. The present results may therefore reflect an average effect across a highly heterogeneous multilingual population by failing to appropriately capture important within-group differences.

These findings highlight the need to distinguish between proficiency-based and usage-based effects of multilingualism. More comprehensive language assessment, as well as more qualitative data about individuals’ experiences being multilingual, is important for contextualising how effects may vary across different multilingual contexts and mapping potential nuances in terms of where effects may be comparatively stronger or weaker. Such experience-based data may also help to understand why our multilingual participants appeared to have poorer affective wellbeing in terms of morale and loneliness. Future studies integrating sociolinguistic, neural, and behavioural metrics could clarify these interaction patterns and explore the mechanisms by which multilingualism contributes to cognitive resilience. Examples of integrative future research directions could be mixed-methods approaches combining

behavioural tasks like those used in the current study with qualitative data about people's beliefs surrounding their language acquisition and use, or even combined behavioural-neural experimental designs using continuous language measures to strategically test for effects.

Future research should also adopt direct and multidimensional language measures—such as language entropy, diversity indices, and self-reported usage patterns—to capture the complexity of multilingual experience more accurately (97,103). This shift has been pioneered more recently in cross-sectional research utilising tools such as the Language History Questionnaire, which utilises detailed demographic, social and linguistic data to produce numerical indices of overall language diversity, immersion and proficiency (107). Including these granular measures of multilingual experience, embedded consistently across waves, would allow meaningful comparison within and across datasets and allow researchers to test mechanistic questions about how specific dimensions of multilingual experience relate to cognitive and affective ageing trajectories.

In addition, the cognitive tasks were all administered in English, which may have introduced linguistic bias against participants with limited proficiency or who had an interpreter. This limitation is particularly relevant for tasks involving lexical retrieval (e.g., BNT), where performance is closely tied to vocabulary access. Employing nonverbal or culturally neutral tasks, or adjusting analyses for English proficiency, would strengthen causal inferences regarding language-related effects. Other task-level limitations also constrained the scope of the analysis. In particular, the administration of cognitive measures was inconsistent across waves, resulting in limited coverage of cognitive domains. Although a range of measures were available within the ALSA dataset, only those administered most consistently across the greatest number

of waves were selected. This decision ensured adequate longitudinal power but consequently limited the breadth and representativeness of cognitive domains assessed.

While the ALSA dataset offers exceptional longitudinal depth, cohort effects may confound interpretations. Many older multilinguals in this sample are likely first-generation migrants to Australia who experienced varying levels of educational and occupational opportunity. Overall, most participants were Australian-born and predominantly used English to communicate, which may limit generalisability to culturally and linguistically diverse (CALD) populations. This should be considered when interpreting findings, as CALD groups may show different patterns of language knowledge, use, and cognitive adaptation. Educational background was also not captured in the current sample, which largely limits the confidence with which we can reliably draw conclusions about the cognitive and affective effects of multilingual experience *per se*. Observed differences may reflect the intersection of ranging social, educational, economic, and cultural variables, for example, migration history and associated lifestyle variables, rather than purely language or cognitive differences alone. Future studies should integrate more diverse sampling and other detailed demographic- and migration-related measures (e.g., acculturation, social support, language environment) to disentangle these influences and capture variability in multilingual experience across sociocultural contexts.

Despite the use of advanced nonlinear modelling, residual unmeasured confounds may remain: variables such as physical health, depressive symptoms, and lifestyle engagement—factors known to correlate with both language use and cognitive function (79,108)—were not modelled in the current analyses. Incorporating these predictors would clarify whether multilingualism exerts independent or mediated effects on ageing trajectories. While the analysis method was considered principled for longitudinal modelling, a further limitation was the small

number of monolingual participants, particularly in later waves. For instance, although monolinguals comprised approximately 90% of the sample at baseline, attrition left few individuals in this group by the final wave. This limits statistical power and makes trajectory estimates for small subgroups less reliable. Consequently, while the current findings provide preliminary indications that multilingual experience confers costs and benefits for cognition and affect, more controlled and targeted research with larger, balanced samples is needed to confirm these effects. Longitudinal ageing studies should aim for their cohorts to reflect population norms and target recruitment to ensure greater diversity.

Future work should extend these analyses to younger and midlife cohorts to better characterise developmental trajectories, particularly since the present sample is restricted to older adults (65–103 years), which limits direct inference across earlier stages of the lifespan. It could be possible that changes are observable in midlife or at even earlier timepoints. Integrating ecological assessments, such as language switching frequency and social network diversity, would provide further value to elucidate how real-world multilingual engagement influences cognitive resilience over time. These cognitive and behavioural investigations could be further complemented by neuroimaging or neurophysiological measures, such as functional MRI, EEG, MEG, or fNIRS. Although optional, these approaches may detect subtle differences in brain function between multilinguals and monolinguals, even in the absence of observable differences in cognitive performance (109,110). Such measures could provide additional insight into whether comparable behavioural performance is supported by differences in neural efficiency, flexibility or patterns of recruitment. Longitudinal neuroimaging could further examine whether multilingual experience is associated with different patterns of neural change or compensatory recruitment across ageing.

Conclusion

In summary, this longitudinal analysis of the Australian Longitudinal Study of Ageing provides a detailed, trajectory-based view of how multilingualism might relate to cognitive and affective functioning across objective/subjective and linguistic/non-linguistic axes. No broad protective effects of multilingualism were observed. Instead, the data suggest that multilingual experience is associated with both costs and benefits for cognition and affect over the lifespan. Across most measures, multilinguals demonstrated poorer performance than monolinguals, with greater longitudinal consistency observed only on loneliness and dissatisfaction, attitudes towards ageing, and memory-related locus of control subscales. These highly selective, domain-specific findings challenge the notion of a uniform “multilingual advantage” and instead support a more nuanced view in which multilingualism may contribute to benefits for some domains and costs for others. While multilingualism was associated with disadvantages across most measures, including subjective memory and task-based recall, it was also linked to modest, domain-specific patterns consistent with adaptive ageing in certain affective and self-regulatory outcomes.

By leveraging advanced, flexible nonlinear statistical modelling techniques, the present study advances understanding of individual differences in ageing trajectories and demonstrates the value of considering dynamic change rather than static group means. Multilingualism, as a complex and context-dependent life experience, may not provide uniform protection against cognitive decline, but instead appears to involve trade-offs that selectively shape cognitive and affective trajectories over time. Continued longitudinal and mechanistic research will be essential to clarify when, how, and for whom multilingual experience fosters adaptive ageing.

Declarations

Ethics Approval and Consent to Participate

Institutional ethics approval from the Western Sydney University Human Research Ethics Committee was waived in accordance with their policy for projects with negligible risk using pre-existing data (EX2022-10). Participants from the original ALSA cohort provided extended consent in line with Flinders University ethics board requirements.

Consent for Publication

Not applicable.

Availability of Data and Materials

The data that support the findings of this study are available from the Centre for Ageing Studies at Flinders University (<https://sites.flinders.edu.au/alsa/>) but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of the Centre for Ageing Studies.

Declaration of Competing Interests

The authors report no competing interests.

Funding

This research was supported by Candidature Support funding from Western Sydney University.

CRediT Authorship Contribution Statement

OM was responsible for conceptualisation (formulating the research questions and framing the scope of the review), investigation, software, data curation, formal analysis, visualisation, and writing – original draft and review and editing. CJ and CH both provided supervision and writing – review and editing. CP and AS assisted with formal analysis, and writing – review and editing.

Acknowledgements

Not applicable.

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