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Language Diversity Across Home and Work Contexts Differentially Impacts Age- and Menopause-Related Declines in Cognitive Control in Healthy Females

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Menopause is associated with declines in cognitive control. However, there is individual variability in the slope of this decline. Recent work suggests that indices of cognitive control are mediated by communicative demands of the language environment. However, little is known about how the impact of bilingual experience generalizes across the lifespan, particularly in females who exhibit steeper cognitive decline due to increasing age and menopausal transition. Thus, we investigated whether diversity of language use in distinct communicative contexts modulated the effects of aging and menopause on cognitive control in an adult lifespan sample of healthy females. We performed robust linear regressions on a sample of 120 females (age range 20–65 years) to characterize age- ($n = 120$) and menopause-related ($n = 59$) declines in cognitive control (as assessed by the Wisconsin Card Sorting Test) and to determine whether they are modulated by different facets of bilingual language experience, including the diversity of language use (i.e., language entropy) in home and workplace environments. Workplace but not home language diversity modulated age- and menopause-related declines in cognitive control, suggesting that females may compensate for decline by virtue of adapting to the externally imposed demands of the language environment. These findings have implications for identifying which aspects of bilingual experience may contribute to cognitive reserve in healthy aging.

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Public Significance Statement
The novel findings of this study provide value to understanding the trajectory in age- and menopause-related decline in cognitive control that is experienced by females and how particular aspects of bilingual language experience may, in turn, mitigate these effects.

Keywords: females, menopause, bilingualism, language diversity, cognitive control

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Healthy aging is associated with declines in cognitive control, that is, one's ability to accomplish goal-directed behaviors using complex neurocognitive skills, such as inhibition and attention (Ferguson et al., 2021). However, there is significant individual variability in the slope of age-related decline in cognitive control (de Frias et al., 2009; Goh et al., 2012; Wilson et al., 2002), and not all adults exhibit the same degree of cognitive decline (e.g., Rhodes, 2004). For example, at a coarse level, there is evidence that female biological sex is associated with higher baseline levels of cognitive control but a faster rate of age-related cognitive decline, particularly in cognitive control, compared to males (Levine et al., 2021). Notably, biological sex differences in lifetime exposures to the gonadal sex hormones (i.e., estrogen and testosterone) may modulate neuroendocrine function and differentially impact the effect of age on cognitive control in females compared to males (Bale & Epperson, 2015; Gurvich et al., 2018; Rubinow & Schmidt, 2019). This divergence reaches a critical point at midlife when females experience menopause (El Khoudary et al., 2019). The menopausal transition[1] at midlife has been associated with declines in cognitive control (e.g., verbal fluency and working memory) in some, albeit not all females (Berent-Spillson et al., 2012; Brinton, 2009; Jacobs et al., 2016; Rentz et al., 2017; Sherwin & Henry, 2008; Weber et al., 2013). Menopause is defined as experiencing 12 months of amenorrhea due to a loss of ovarian follicular function and declines in blood estrogen levels (Harlow et al., 2012). Females with ovaries also experience declines in centrally circulating estradiol-17β (E2), which has been shown to modulate brain function in regions important for cognitive control (i.e., prefrontal cortex; Russell et al., 2019; Shanmugan & Epperson, 2014; Sommer et al., 2018). Thus, it has been hypothesized that menopause-related declines in estrogens, particularly centrally circulating E2, may contribute to declines in cognitive control in some females (Russell et al., 2019). However, existing evidence on the effects of menopause on cognitive control is contentious, particularly due to the paucity of longitudinal data and mixed findings (see Morgan et al., 2018 for review). Moreover, all females with ovaries experience estrogen declines with menopause, but not all females experience declines in cognitive control (Jacobs et al., 2016; Rentz et al., 2017). These findings highlight the need for a greater understanding of what factors may contribute to individual differences in cognitive control in females at midlife.

The construct of cognitive reserve aims to explain why there are individual differences in cognitive control with age (Cabeza et al., 2018; Duncan et al., 2018; Stern, 2002; Stern & Barulli, 2019). Cognitive reserve refers to how individual differences in biological, environmental, and lifestyle factors may help support one's ability to maintain normal levels of cognitive function with age in the presence of age-related brain pathology or injury (Tucker & Stern, 2011). Cognitive reserve is thought to build up through cognitively stimulating life experiences, such as educational attainment, literacy, and physical activity (Sattler et al., 2012). Of interest here, bilingualism is often offered as a lifestyle factor having the potential to impact cognitive reserve (for reviews, see Bialystok, 2021; Gallo et al., 2022; Heredia et al., 2020; Liu & Wu, 2021; Mendez, 2019; Zhang et al., 2021). This hypothesis presumes that bilinguals' lifelong experience managing language control demands (e.g., resolving cross-language competition when speaking or comprehending in contextually sensitive ways) stimulates domain-general cognitive control processes. This experiential stimulation, in turn, is believed to forestall behavioral cognitive declines despite neural declines (e.g., brain atrophy) typical of advancing age (Bialystok, 2021; Gold et al., 2013; cf., García-Pentón et al., 2016).

While the evidence for bilingualism as a contributor to cognitive reserve is fairly consistent at the level of brain structure and function (see DeLuca et al., 2019; Pliatsikas et al., 2021, for reviews; cf., de Bruin et al., 2021 for methodological criticism), the behavioral evidence is less understood. Studies comparing different groups of monolinguals and bilinguals on cognitive control tasks have often reported complex dynamic interactions of language experience on age-related cognitive decline. We illustrate this in the context of the Wisconsin Card Sorting Test (WCST; Mueller & Piper, 2014), in which participants are instructed to classify cards according to a particular sorting rule (e.g., color, number, or figure). Here, performance yields several outcome variables sensitive to age-related decline and are presumed to measure different cognitive control components (Barceló, 2001; Rhodes, 2004).

Among the most common measures from the WCST, categories completed (CC) reflect a global performance. For example, in one study, Kousaie et al. (2014) compared the number of CC in the WCST in three different groups of speakers: monolingual francophones, monolingual anglophones, and French–English bilinguals who were immersed in either a predominantly francophone context (Québec City) or a bilingual context (Ottawa). Contrary to expectations, they found that monolingual francophones from Québec City completed more categories on the WCST than monolingual anglophones and bilinguals from Ottawa. This finding suggests a role for the language environment (i.e., language use/exposure across different interactional contexts) in differentially modulating cognitive control performance in healthy older adults.

A second and perhaps more sensitive WCST measure of age-related deficits in cognitive control is perseverative errors (PEs). PEs are hypothesized to reflect a failure to engage in appropriate

[1] Menopause is generally staged as premenopausal (regular menstrual cycle), perimenopause (transition period, variable length of menstrual cycle, or interval of amenorrhea for ≥60 days), and postmenopausal (amenorrhea for ≥12 months; see Harlow et al., 2012 for more details).

cognitive control processes required to inhibit previous sorting rules. Age-related increases in PEs suggest cognitive inflexibility or difficulties with inhibitory control via working memory systems (Head et al., 2009). Interestingly, some work suggests that PEs on the WCST are associated with unique characteristics of second language (L2) learning and bilingual language use (e.g., Festman & Münte, 2012). Among young adults, it has been shown that simultaneous interpreters (Yudes et al., 2011) and bilinguals immersed in an L2 environment (Xie & Antolovic, 2022) make fewer PEs compared to bilinguals whose habits of language use are relatively less cognitively demanding. It is an ongoing question to identify and characterize how specific bilingual language experience give rise to adaptive changes across the lifespan (Claussenius-Kalman & Hernandez, 2019; Navarro-Torres et al., 2021).

Returning to the topic of sex differences in cognitive reserve, little is known about whether lifelong bilingualism impacts females and males in a manner that differentially moderates age-related declines in cognitive control. In a first preliminary study (Subramaniapillai et al., 2019) we systematically investigated whether and how different aspects of bilingual language experience (i.e., age of L2 acquisition, nonnative language usage, and number of languages known), age, and biological sex impacted cognitive control performance, as assessed by the WCST. Overall, the study found that females with greater nonnative language usage made fewer PEs across the adult lifespan. Interestingly, these bilingual effects on cognitive control were not seen in males. These results suggest that bilingual experience may affect females and males differently, thus offering possible explanations for prior conflicting findings on this point.

A second potential reason for inconsistency across previous studies is that bilingualism (i.e., language experience) is often treated as a unitary construct that may be simply present or absent (Baum & Titone, 2014; de Bruin, 2019; Gullifer & Titone, 2020; Luk & Bialystok, 2013). However, bilingualism is a multidimensional and complex life experience (Beatty-Martínez & Titone, 2021, 2023; Gullifer & Titone, 2021; Gullifer et al., 2021; Titone & Tiv, 2023). Bilinguals differ in when they learn a L2, relative to a first language (L1)—a construct known as L2 age of acquisition (AoA). In addition, bilinguals also differ in terms of where they live and the demands placed on them to use each language within and across distinct communicative contexts, irrespective of when those languages were learned (Beatty-Martínez & Titone, 2021; Beatty-Martínez, Navarro-Torres, Dussias et al., 2020; Dussias et al., 2019; Green & Abutalebi, 2013; Gullifer & Titone, 2021). Importantly, these dimensions of bilingual experience often covary with other factors known to impact cognitive control, such as socioeconomic status (Alladi et al., 2013; Bak, 2016; Bialystok et al., 2007; Woumans et al., 2015).

Only a handful of studies have examined how specific aspects of bilingual language experience potentially mitigate age-related cognitive decline. Some work has found that an earlier L2 AoA may be particularly important for building up cognitive reserve, given that people who acquire an L2 earlier in life also have a longer history of using more than one language (e.g., for review, see Hernandez et al., 2018; Luk et al., 2011; Perquin et al., 2013). However, more recent research has identified other experiential factors whose impact on cognitive control may exceed that of AoA (e.g., Beatty-Martínez & Titone, 2021, 2023; Beatty-Martínez, Navarro-Torres, Dussias et al., 2020). This emerging work emphasizes bilingual language diversity, where more balanced use of the multiple languages is associated with better cognitive function in aging (Pot et al., 2018; Chan et al., 2020). Such perspectives assume that bilinguals' habits of language use are homogeneously distributed across their communicative contexts such as the workplace and home environment. While this may be the case in some language environments (e.g., Beatty-Martínez et al. 2021), it is not true of others (e.g., Beatty-Martínez et al., 2020; Tiv et al., 2022; Wigdorowitz et al., 2022). Critically, bilinguals living in more linguistically diverse environments differentially use their languages across different communicative contexts (Anderson et al., 2018; DeLuca et al., 2019; Tiv et al., 2020) with important implications for language processing and cognitive control engagement tendencies (Beatty-Martínez, Navarro-Torres, Dussias et al., 2020; Beatty-Martínez & Titone, 2023; Gullifer et al., 2018; Titone & Tiv, 2023).

For example, in the highly multilingual city of Montréal, linguistic diversity is greatly influenced by social environmental forces, ranging from interpersonal interactions to higher-order regional policies on language protection and promotion. For example, many workplace contexts require knowledge and exclusive or joint use of French in particular professional contexts. The implication is that such policies may mediate both interpersonal and ecological language dynamics, promoting greater linguistic diversity in the workplace compared to other interactional contexts. In contrast, these kinds of externally directed communicative demands need not apply at home where language choice may be under full control of the speaker (Gullifer et al., 2021). Such variability is a systematic reflection of the complex and dynamic nature of bilingual language experience (Navarro-Torres et al., 2021; Titone & Tiv, 2023).

In line with Canadian Census in Montréal (Government of Canada—Statistics Canada, 2017), workplace contexts exhibit higher linguistic diversity, indicative of more varied language use, compared to the home environment (Gullifer & Titone, 2020). Importantly, estimates of bilingual language diversity align with self-reported language ratings differentially across such social contexts (Gullifer & Titone, 2020). As a field, we are still in the early stages of understanding the cognitive consequences of distinct interactional experiences across different communicative contexts. However, these differences are potentially important because communicative contexts that impose different language demands will stimulate different language regulation strategies (Green & Abutalebi, 2013). For example, if the workplace demands that people speak one language, people will need to proactively dampen activation of their other known language(s). In contrast, if language choice in the home context is more at the discretion of the speaker, people will experience less of a proactive control demand (Beatty-Martínez, Navarro-Torres, Dussias et al., 2020; Gullifer et al., 2018).

Thus, in this article, we expand on our previous findings (Subramaniapillai et al., 2019) by richly characterizing bilinguals' diversity of language use within and across distinct communicative contexts. To this end, we make use of language entropy (Gullifer & Titone, 2020; referred to here as speaking entropy because of the particular data examined), a continuous measure of language-related uncertainty computed as a function of the probability with which a particular language will occur within a given communicative context. Speaking entropy values range continuously, allowing for the assessment of language use that falls in between fully compartmentalized (i.e., where there is low language-related uncertainty) and perfect balance (i.e., where there is high language-related uncertainty; see Gullifer & Titone, 2018 for a documented R package). Thus, rather than a measure of language proficiency[2] or L2 exposure alone (i.e., nonnative language usage), speaking entropy allowed us to investigate the relative diversity in language use within different communicative contexts, such as in the home, where the demands on language use are presumably up to the speaker, and the workplace, where interactional demands are mediated externally.

Additionally, because Subramaniapillai et al. (2019) observed a beneficial effect of bilingual language experience exclusively in females, the present study included an adult lifespan sample of only females. Accordingly, we aim to address the gaps in the existing literature by providing valuable insights into the complexities of aging in females, by investigating the nuanced effects of menopause on cognitive control.

To these ends, we systematically investigated whether chronological and reproductive aging (i.e., menopause) impact cognitive control and whether bilingual language experience as a contributor to cognitive reserve (i.e., L2 AoA and speaking entropy in the home and workplace environments) modulates cognitive control as a function of age and menopause.

Our specific predictions were:

1. This female sample will experience a greater decline in cognitive control performance with increasing age and postmenopausal status.
2. Given the externally mediated nature of the communicative demands in the workplace, greater speaking entropy in the workplace but not home environment will have a beneficial effect on WCST performance.

Method

Participants

This study is part of a larger ongoing project investigating the impact of sex, menopausal status, and risk factors for sporadic late-onset Alzheimer's disease on the neural correlates of episodic memory. The study was conducted at the Douglas Brain Imaging Centre and was approved by the Research Committee Board at the Douglas Mental Health University Institute. Medical exclusion criteria included a lifetime history of substance misuse, neurological insult/disease (i.e., stroke, traumatic brain injury), severe psychiatric illness, Type 2 diabetes and reported smoking more than 40 cigarettes per day. Moreover, participants who had either uncontrolled hypertension, high cholesterol, glaucoma, macular degeneration, or had a concussion leading to a loss of consciousness for more than 1 min in the past 5 years were excluded from the study.

From the larger study ($n = 276$), a subset of 203 participants met the following inclusion criteria: female, less than 65 years of age, acquired L2 before the age of 18, scored <21 on the Becks' Depression Inventory-II (indicative of moderate to severe symptoms of depression), scored <23 on the Beck's Anxiety Inventory (indicative of moderate to severe symptoms of anxiety), and scored >26 on the Mini-Mental State Exam (indicative of a greater risk of developing dementia). Participants were excluded if they had a L1 ($n = 60$) and/or L2 ($n = 9$) that was not English or French, they completed less than two categories on the WCST (indicative of poor overall performance on the task; $n = 9$), or had an indeterminant menopausal status ($n = 5$).

These procedures left a total of 120 healthy females aged 20–65 years old ($M_{\text{age}} = 44.17$, $SD_{\text{age}} = 12.62$) in the final analyses. All participants were French–English or English–French bilinguals, who self-reported good health and had at least high school education ($M_{\text{education}} = 15.27$ years, range: 11–20 years). For the menopause analyses, we excluded females who were under the age of 40 ($n = 41$), as we were interested in middle-aged females. We also excluded females who were categorized as perimenopausal ($n = 20$), as this is the transition period between pre- and postmenopause. Thus, the final sample size for the menopause analyses consisted of 59 middle-aged females, aged from 40 to 65 years old ($M_{\text{age}} = 52.40$, $SD_{\text{age}} = 7.95$). Participant background characteristics and WCST performance measures are summarized in Table 1.

Materials and Procedures

Eligible participants were contacted by phone and invited to participate in person in a behavioral testing session. Participants selected the language of study instruction and administration (i.e., English or French). As part of the behavioral session, participants completed the WCST (Mueller & Piper, 2014) and the Language and Social Background Questionnaire (LSBQ; Anderson et al., 2018). All participants were compensated for their time.

Cognitive Reserve

Bilingual Language Experience. To assess bilingual language experience, we gathered information on participants' L2 AoA as well as the proportion of French and English use in the home and workplace (i.e., home and work speaking entropy) to characterize bilinguals' diversity of language use within and across distinct communicative contexts.

Speaking entropy is based on the Shannon entropy (H) as implemented in the languageEntropy R package (see Gullifer & Titone, 2018), where lower entropy values indicate lower language diversity (i.e., more compartmentalized language use), whereas higher entropy values indicate greater language diversity (i.e., more integrative language use; Gullifer & Titone, 2020). The following equation was used

$$H = -\sum_{i=1}^{n} P_i \log_2 (P_i). \tag{1}$$

Here, n represents the number of languages spoken (e.g., $n = 2$), and P_i represents the proportion that language$_i$ is used within the specific interactional context. Twelve percent of participants (15 from the whole sample; two from the premenopause group and 11 from the postmenopause group) reported being unemployed and were excluded from analyses involving work speaking entropy.

Education. As part of the LSBQ, education level was collected based on the highest number of years completed, where 20 was the maximum level (i.e., having completed a PhD or MD). We included years of education as a control variable in the analyses to proxy for socioeconomic status.

[2] Notably, language entropy is related, yet independent, from other metrics of language experience such as proficiency as an individual could report being equally proficient in two languages and yet use them in either a highly integrated or compartmentalized manner within a given context (Gullifer & Titone, 2020).

Table 1
Mean Background and Wisconsin Card Sorting Test Performance Measures (and Standard Error) by Group

Sample demographics and outcomes	Whole sample	Premenopausal middle-aged females	Postmenopausal middle-aged females
Sample size (n)	120	26	33
Age (years)	44.17 (1.15)	44.49 (0.25)	58.64 (0.68)
Education (years)	15.27 (0.21)	16.02 (0.48)	14.61 (0.45)
L2 AoA (years)	7.03 (0.36)	7.62 (0.52)	7.88 (0.71)
Home speaking entropy	0.23 (0.03)	0.22 (0.08)	0.14 (0.06)
Work speaking entropy	0.52 (0.04)	0.49 (0.07)	0.44 (0.08)
WCST-CC	7.85 (0.12)	8.08 (0.29)	7.27 (0.31)
WCST-PEs	15.62 (0.68)	15.00 (1.76)	18.03 (1.27)

Note. L2 AoA = second language age of acquisition; WCST = Wisconsin Card Sorting Test; CC = completed categories; PEs = perseverative errors.

Menopausal Stage

All participants completed a reproductive questionnaire to obtain information regarding their last menstrual period as well as regularity of menses. These questions were used to apply the Stages of Reproductive Aging Workshop (STRAW; Harlow et al., 2012) criteria for menopausal categorization. For the current study, staging categories were condensed as premenopausal (STRAW categories −5 to −3a) and postmenopausal (STRAW +1a to +2) in a middle-aged sample.

WCST

To evaluate cognitive control, a computerized version of the WCST (Mueller & Piper, 2014) was administered, using the Psychology Experiment Building Language (PEBL) Version 0.13 (retrieved from https://pebl.sourceforge.net as the Berg's Card Sorting Test). In this task, participants are instructed to sort a target card to one of four reference cards based on specific attributes (e.g., sorting the cards by color, shape, or number). The participant must infer the correct operative rule through limited feedback (i.e., accuracy feedback based on correct or incorrect card sort). Each participant is required to apply the established rule for 10 subsequent trials to achieve a completed category (i.e., apply a set rule). Once ten consecutive cards have been sorted correctly, the sorting rule changes without notice and the participant must adapt to and apply a new rule. The task is completed once the participant successfully sorted through the nine categories or advanced through 128 card sort trials. For this study, we focused on two WCST measures: the number of CC reflecting global performance (i.e., participants' ability to not only shift but also form and maintain a set of sorting rules) and PEs (i.e., participants' inability to ignore previously valid sorting rule and shift to a new one), which more specifically relates to cognitive inflexibility and reduced inhibitory control.

Statistical Analysis

A series of robust linear regressions with maximum-likelihood estimation in RStudio (Version 1.2.5033) using the rlm function in the MASS package (Venables & Ripley, 2004) were conducted. Robust regressions use iteratively reweighted least squares to mitigate the influence of large residuals (e.g., outliers), allowing us to utilize all available observations.

To explore the impact of bilingual factors and age on cognitive control, we constructed two regression models to predict the number of WCST-CC and the number of WCST-PEs. The first analysis examined effects of language experience and age across the entire sample. The second analysis examined the effects of language experience and menopause status and was exclusively conducted with a middle-aged subsample. This two-analysis approach was an explicit and considered methodological decision to minimize the influence of age. This is because menopause and age are inherently linked (i.e., by-definition, on average premenopausal women are younger than postmenopausal women), making "statistically controlling" for age near impossible. The very strong correlation of .89 ($p < .001$) between age and menopause status (pre- vs. postmenopause) in our middle-age sample affirms the inherent connection between these two variables. For these reasons, adding age to the menopause models introduces substantial collinearity, which increases the uncertainty of the estimated coefficients. As a proof of concept, additional analyses taking age into account as a covariate were conducted, and our main findings remained unchanged (see Tables S13 and S14 in the online supplemental materials).

Our language variables of interest were L2 AoA as a proxy measure for historical language exposure and speaking entropy as a measure of bilinguals' diversity of language use within home and work contexts. We evaluated the main effects and interactions between age and each bilingual language experience measured individually while statistically controlling for age and number of years of education (a proxy for socioeconomic status) as covariates, as well as the interaction between the two variables. Thus, regarding R syntax, the specific models fitted were:

$$\text{Model 1: WCST} \sim \text{Age} \times \text{Home Speaking Entropy} + \text{Age} \times \text{L2 AoA} + \text{Age} \times \text{Education}. \quad (2)$$

$$\text{Model 2: WCST} \sim \text{Age} \times \text{Work Speaking Entropy} + \text{Age} \times \text{L2 AoA} + \text{Age} \times \text{Education}. \quad (3)$$

To minimize the effects of age and further explore the impact of bilingual language factors and menopausal status (premenopause and postmenopause) on cognitive control, we constructed two additional regression models including only middle-aged females. The middle-aged sample consisted of 59 females ($n = 26$ premenopause and $n = 33$ postmenopause), aged 40–65 years ($M = 52.45$, $SD = 7.89$). We evaluated the main effects and interactions between menopausal status and each bilingual language experience, measured individually while statistically controlling for menopausal status and number of years of education as covariates, as well as the interaction between the two variables. The specific models fitted were:

$$\text{Model 3: WCST} \sim \text{Menopausal Status} \times \text{Home Speaking Entropy} + \text{Menopausal Status} \times \text{L2 AoA} + \text{Menopausal Status} \times \text{Education.} \quad (4)$$

$$\text{Model 4: WCST} \sim \text{Menopausal Status} \times \text{Work Speaking Entropy} + \text{Menopausal Status} \times \text{L2 AoA} + \text{Menopausal Status} \times \text{Education.} \quad (5)$$

Across the models, all fixed effects were continuous, apart from menopausal status, which was deviation coded as -0.5 (premenopausal) and $+0.5$ (postmenopausal). All continuous fixed effects were scaled to z scores in order that model intercepts reflect average performance. Interactions that were statistically significant were examined by rescaling continuous predictors 1 *SD* above/below the mean to examine the effect of one predictor (e.g., age) at high and low values of the other continuous predictor (e.g., education; Aiken et al., 1991). In the case of significant interactions involving a categorical predictor (e.g., menopausal status), simple effects were examined by refitting models with default (dummy) variable coding and changing the reference level. Note that rescaling and releveling procedures in multiple regression analysis do not reduce statistical power and/or inflate the Type I error rate (Irwin & McClelland, 2001). Instead, the model simply reestimates the parameters with a different reference point, providing a different interpretation of the coefficients while keeping the variance constant (Gelman & Hill, 2006; for similar approaches see Beatty-Martínez et al., 2020; Kheder & Kaan, 2021; Navarro-Torres et al., 2023). Figures 1 and 2 present the interaction plots for the results.

Transparency and Openness

The supplemental materials, anonymized data files, and R scripts used for this article can be downloaded at the Open Science Framework repository: https://osf.io/pkxuz. This study's design and analysis were not preregistered.

Results

Descriptive Results

In terms of language experience, participants varied in their reported diversity of language use. Speaking entropy values ranged from completely compartmentalized to fully integrated and most notably, they varied across home and workplace environments. Overall, participants reported greater language diversity in work contexts relative to the home environment (see Table 1 for means and standard errors). These findings are consistent with the previously observed distinction between home and work speaking entropy for French–English bilinguals living in Montréal (Gullifer & Titone, 2020; Gullifer et al., 2021; Tiv et al., 2020), validating the need to assess bilinguals' habits of language use within and across distinct communicative contexts. Correlations with age, years of education, bilingual experience variables, and all WCST performance measures (CC and PEs) are displayed in Figure S1 in the online supplemental materials.

How Does Bilingual Language Experience Contribute to WCST Performance?

Models 1 and 2 examined the relationship between bilingual variables (i.e., L2 AoA and speaking entropy) and age. The models differed in that the former considered interactions between age and speaking entropy in the home environment, whereas the latter examined interactions between age and speaking entropy in the workplace. Models 3 and 4 were fitted to the middle-aged pre-/postmenopause subgroups. These models shared the same specifications as Models 1 and 2 respectively but examined whether the effects of bilingual variables vary as a function of menopausal status. Tables 2 and 3 summarize the regression outputs from Models 1–4 on the number of CC and the number of PEs, respectively. Estimates from follow-up simple slope analyses are reported in the main text. Full simple slope analysis outputs are outlined (see Tables S1–S4 in the online supplemental materials for CC and Tables S5–S8 in the online supplemental materials for PEs). Results from these models are visualized in Figures 1 and 2 (see Figures S6 and S7 in the online supplemental materials for effects plots with individual data points).

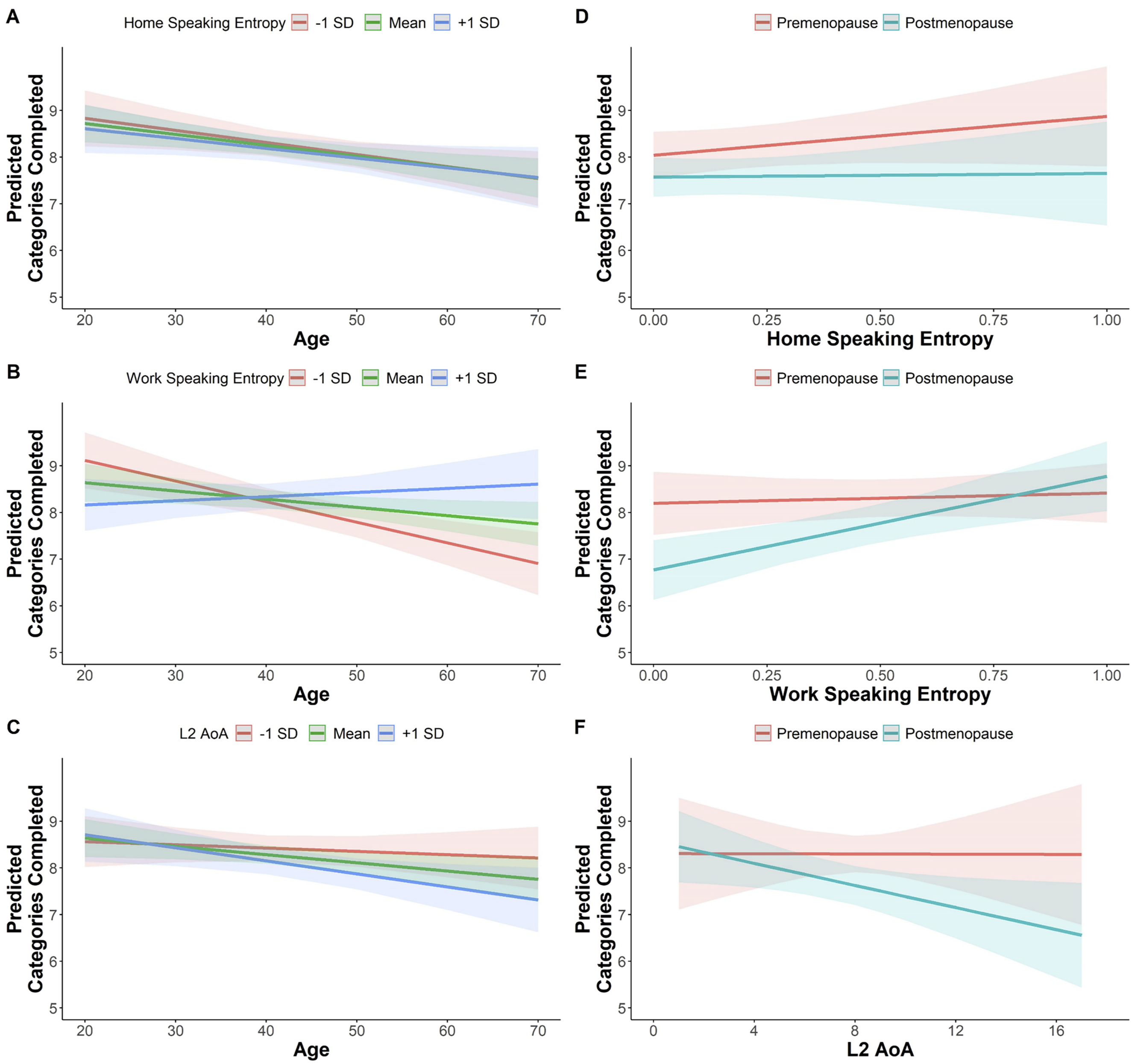
CC

Models 1 and 2: Effects of Bilingual Language Experience and Age on CC

The number of CC serves as an indicator of global performance, where a higher score reflects a greater ability to form, maintain, and shift a set of sorting rules. Consistent with previous findings, we found that increased age and fewer years of education were associated with fewer CC on the WCST. Furthermore, although there were no main effects or interactions involving home speaking entropy (Figure 1A) or L2 AoA (Figure S2 in the online supplemental materials), Model 2 revealed a significant interaction between age and work speaking entropy (Figure 1B). To explore this interaction, we refitted Model 2 using the rescaling method described previously. Here, we rescaled the standardized work speaking entropy predictor by creating two new variables. The first variable added 1 *SD* to all entropy values so that the model intercept (i.e., the zero point on the scale) represents the lower end of the continuum. Similarly, the second variable subtracted 1 *SD* from all entropy values so that the model intercept represents the higher end of the continuum. In this way, any main effects of age represent effects for participants on the lower and higher end of the work speaking entropy continuum respectively. This follow-up simple slopes analysis indicated that the age effect was significant only for low work speaking entropy participants ($\beta = -.36$, $SE = 0.10$, $t = -3.70$, $p < .001$) but not for those on the higher end of the continuum ($\beta = .06$, $SE = 0.10$, $t = 0.61$, $p = .540$). When resolving the interaction by age, significant effects of work speaking entropy were observed for older ($\beta = .32$, $SE = 0.11$, $t = 2.75$, $p = .006$) but not younger participants ($\beta = -.11$, $SE = 0.09$, $t = -1.21$, $p = .226$). Critically, these effects were observed over and above the effects of education, and there were no significant effects of L2 AoA (Figure 1C). These results thus suggest that greater work speaking entropy mitigates the age-related decrease in the number of CC on the WCST.

Figure 1

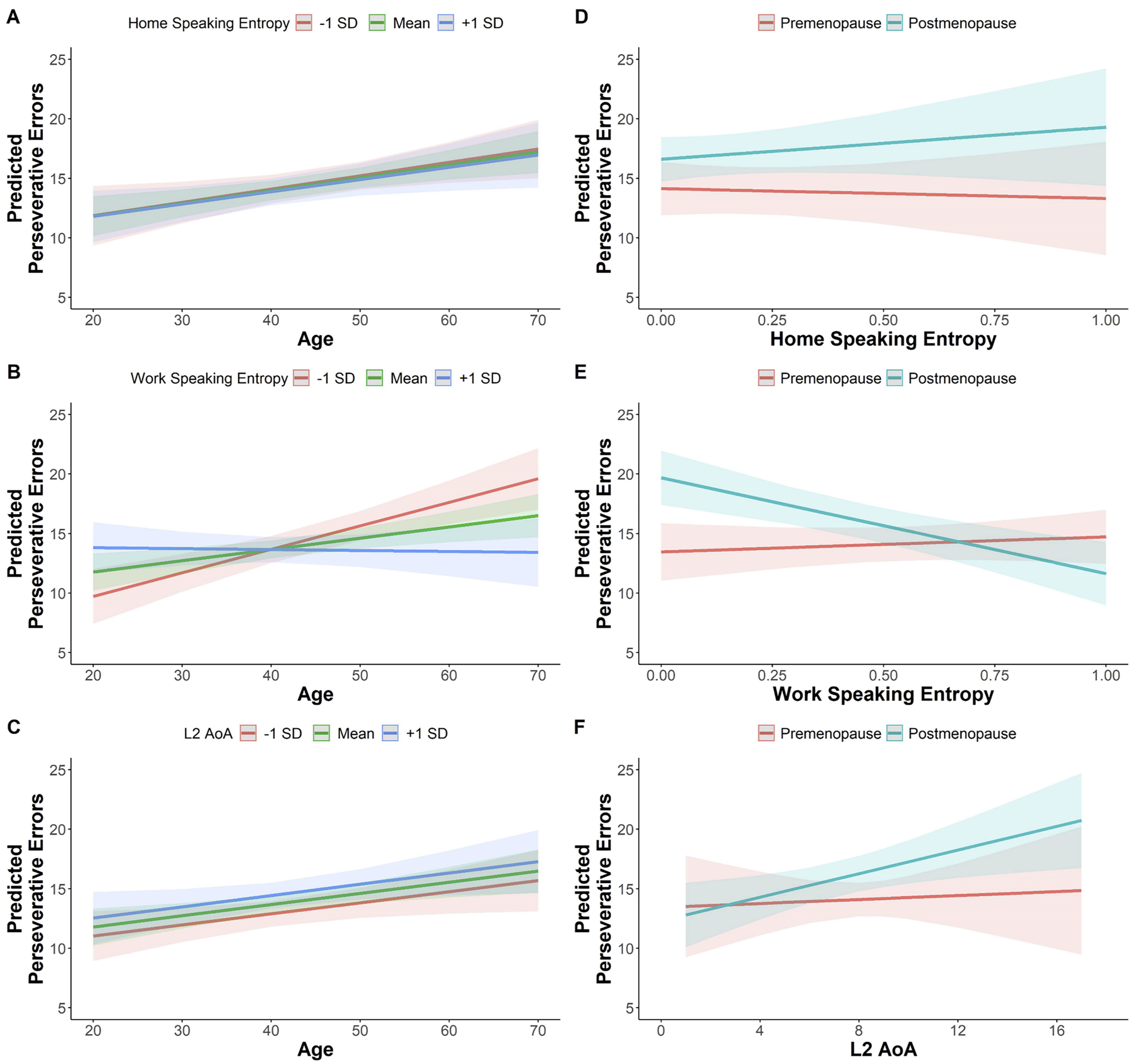
Effects Plots Demonstrating the Interactions Between Bilingual Language Experience Variables and Age (Left) and Menopausal Status (Right) on the Number of CC on the WCST



Note. Left: marginal effects of age and bilingual language experience on the number of CC on the WCST. (A) Effect of age at low (−1 *SD*), mean, and high (+1 *SD*) levels of home speaking entropy (Model 1). (B) Effect of age at low (−1 *SD*), mean, and high (+1 *SD*) levels of work speaking entropy (Model 2). (C) Effect of age at low (−1 *SD*), mean, and high (+1 *SD*) levels of L2 AoA (Model 2; see Figure S2 in the online supplemental materials for equivalent interaction terms in Model 1). Right: marginal effects of bilingual language experience and menopausal status on the number of CC on the WCST. (D) Effect of home speaking entropy in premenopausal and postmenopausal participants (Model 3). (E) Effect of work speaking entropy in premenopausal and postmenopausal participants (Model 4). (F) Effect of L2 AoA in premenopausal and postmenopausal participants (Model 4; see Figure S3 in the online supplemental materials for equivalent interaction terms in Model 3). Some participants were excluded from analyses examining work speaking entropy because they reported being unemployed at the time of testing (Valid *N* whole sample = 105; middle-aged subgroup = 46). Shaded areas represent 95% confidence intervals. WCST = Wisconsin Card Sorting Test; L2 AoA = second language age of acquisition; CC = categories completed. See the online article for the color version of this figure.

Figure 2

Effects Plots Demonstrating the Interactions Between Bilingual Language Experience Variables and Age (Left) and Menopausal Status (Right) on the Number of PEs on the WCST



Note. Left: Marginal effects of age and bilingual language experience on the number of PEs on the WCST. (A) Effect of age at low (−1 *SD*), mean, and high (+1 *SD*) levels of home speaking entropy (Model 1). (B) Effect of age at low (−1 *SD*), mean, and high (+1 *SD*) levels of work speaking entropy (Model 2). (C) Effect of age at low (−1 *SD*), mean, and high (+1 *SD*) levels of L2 AoA (Model 2; see Figure S4 in the online supplemental materials for equivalent interaction terms in Model 1). Right: Marginal effects of bilingual language experience and menopausal status on the number of PEs on the WCST. (D) Effect of home speaking entropy in premenopausal and postmenopausal participants (Model 3). (E) Effect of work speaking entropy in premenopausal and postmenopausal participants (Model 4). (F) Effect of L2 AoA in premenopausal and postmenopausal participants (Model 4; see Figure S5 in the online supplemental materials for equivalent interaction terms in Model 3). Some participants were excluded from analyses examining work speaking entropy because they reported being unemployed at the time of testing (valid *N* whole sample = 105; middle-aged subgroup = 46). Shaded areas represent 95% confidence intervals. WCST = Wisconsin Card Sorting Test; PEs = perseverative errors; L2 AoA = second language age of acquisition. See the online article for the color version of this figure.

Table 2

Estimated Standardized Beta Coefficients (Effect Sizes) for Age (Models 1 and 2) and Menopausal Status (Models 3 and 4) Models on the Number of Categories Completed on the WCST

	Age models							
	Model 1 (home entropy)				Model 2 (work entropy)			
Effects	β (*SE*)	95% CI	*t*	*p*	β (*SE*)	95% CI	*t*	*p*
Intercept	**.19** (**0.07**)	[0.05, 0.33]	**2.69**	**.007**	**.21 (0.07)**	**[0.08, 0.34]**	**3.20**	**.001**
Age	**−.19 (0.07)**	[−0.33, −0.05]	**−2.60**	**.009**	**−.14 (0.07)**	**[−0.26, −0.01]**	**−2.06**	**.040**
Home entropy	−.03 (0.08)	[−0.18, 0.11]	−0.44	.657	—	—	—	—
Work entropy	—	—	—	—	.08 (0.07)	[−0.06, 0.22]	1.12	.264
L2 AoA	−.14 (0.07)	[−0.29, 0.00]	−1.93	.054	−.10 (0.07)	[−0.24, 0.03]	−1.53	.126
Education	**.16 (0.07)**	**[0.01, 0.30]**	**2.12**	**.034**	.13 (0.07)	[−0.00, 0.27]	1.91	.057
Age: home entropy	.02 (0.07)	[−0.12, 0.16]	0.26	.792	—	—	—	—
Age: work entropy	—	—	—	—	**.20 (0.07)**	**[0.07, 0.34]**	**2.89**	**.004**
Age: L2 AoA	−.10 (0.07)	[−0.23, 0.04]	−1.43	.151	−.08 (0.06)	[−0.21, 0.05]	−1.25	.212
Age: education	.09 (0.08)	[−0.07, 0.26]	1.08	.281	.10 (0.08)	[−0.05, 0.26]	1.30	.194
	Menopause models							
	Model 3 (home entropy)				Model 4 (work entropy)			
Effects	β (*SE*)	95% CI	*t*	*p*	β (*SE*)	95% CI	*t*	*p*
Intercept	.15 (0.12)	[−0.08, 0.38]	1.31	.191	.14 (0.10)	[−0.05, 0.33]	1.43	.152
Menopause group	−.35 (0.23)	[−0.81, 0.10]	−1.52	.129	−.35 (0.20)	[−0.74, 0.03]	−1.80	.072
Home entropy	.09 (0.12)	[−0.14, 0.32]	0.79	.430	—	—	—	—
Work entropy	—	—	—	—	**.25 (0.10)**	**[0.05, 0.45]**	**2.50**	**.012**
L2 AoA	−.09 (0.14)	[−0.37, 0.18]	−0.66	.512	−.12 (0.11)	[−0.34, 0.10]	−1.07	.286
Education	.21 (0.13)	[−0.03, 0.46]	1.69	.091	.20 (0.10)	[−0.01, 0.41]	1.91	.056
Meno: home entropy	−.15 (0.23)	[−0.61, 0.30]	−0.65	.515	—	—	—	—
Meno: work entropy	—	—	—	—	**.40 (0.20)**	**[0.01, 0.80]**	**2.01**	**.044**
Meno: L2 AoA	−.33 (0.28)	[−0.88, 0.23]	−1.16	.246	−.24 (0.23)	−[0.68, 0.21]	−1.04	.296
Meno: education	.13 (0.25)	[−0.36, 0.63]	0.53	.599	.05 (0.21)	[−0.36, 0.46]	0.26	.799

Note. Significant results are displayed in boldface. Some participants were excluded from analyses examining work speaking entropy because they reported being unemployed at the time of testing (Model 2 valid $N = 105$; Model 4 valid $N = 46$). WCST = Wisconsin Card Sorting Test; L2 AoA = second language age of acquisition; CI = confidence interval.

Models 3 and 4: Effects of Bilingual Language Experience and Menopausal Status on CC

Regression models of the middle-aged subgroup showed similar relationships to those observed in the age analysis based on the whole sample. That is, although Model 3 indicated no main effects or interactions involving home speaking entropy (Figure 1D) or L2 AoA (Figure S3 in the online supplemental materials), Model 4 revealed a significant interaction between work speaking entropy and menopausal status (Figure 1E). Follow-up simple slopes analyses revealed that, at low levels of work speaking entropy, participants in the postmenopause group completed fewer categories compared to participants in the premenopause group ($\beta = -.76$, $SE = 0.29$, $t = -2.64$, $p = .008$). However, this group effect was not significant at high levels of work speaking entropy ($\beta = .05$, $SE = 0.27$, $t = 0.18$, $p = .854$). Examining the work speaking entropy effect on the number of WCST CC for each group separately further revealed a positive association for participants in the postmenopause group ($\beta = .45$, $SE = 0.15$, $t = 3.09$, $p = .002$), but not for participants in the premenopause group ($\beta = .49$, $SE = 0.14$, $t = 0.36$, $p = .719$). Importantly, the effects of work speaking entropy were independent of years of education or L2 AoA (Figure 1F). Together, these results suggest that greater work speaking entropy buffers against decreased cognitive performance associated with natural menopausal transition.

PEs

Models 1 and 2: Effects of Bilingual Language Experience and Age on PEs

The number of PEs serves as an index of cognitive control where a lower score reflects a greater ability to switch to a new sorting category following feedback from a previous trial as well as to inhibit a previously established rule. Consistent with previous findings, we found that increased age and fewer years of education were associated with greater PEs on the WCST. Like CC, no main effects or interactions were observed with home speaking entropy (Figure 2A) or L2 AoA (Figure S4 in the online supplemental materials). However, Model 2 revealed a significant interaction between age and work speaking entropy (Figure 2B). As with the number of CC, we explored this interaction by refitting Model 2 using the same rescaling method whereby any main effects of age represent effects for participants on the lower and higher end of the work speaking entropy continuum, respectively (see Tables S5–S8 in the online supplemental materials for full outputs). This follow-up simple slopes analysis indicated that the age effect was significant only for low work speaking entropy participants ($\beta = .31$, $SE = 0.08$, $t = 3.83$, $p < .001$) but not for those on the higher end of the work speaking entropy continuum ($\beta = -1.01$, $SE = 0.09$, $t = -0.15$, $p = .877$). When resolving the interaction by age, significant effects of work speaking entropy

Table 3
Estimated Standardized Beta Coefficients (Effect Sizes) for Age (Models 1 and 2) and Menopausal Status (Models 3 and 4) on the Number of PEs on the WCST

	Age models							
	Model 1 (home entropy)				Model 2 (work entropy)			
Effects	β (*SE*)	95% CI	*t*	*p*	β (*SE*)	95% CI	*t*	*p*
Intercept	**−.16 (0.06)**	**[−0.27, −0.04]**	**−2.70**	**.007**	**−.19 (0.06)**	**[−0.30, −0.08]**	**−3.37**	**.001**
Age	**.18 (0.06)**	**[0.07, 0.30]**	**3.08**	**.002**	**.15 (0.06)**	**[0.04, 0.26]**	**2.63**	**.009**
Home entropy	−.02 (0.06)	[−0.14, 0.10]	−0.29	.771	—	—	—	—
Work entropy	—	—	—	—	−.04 (0.06)	[−0.16, 0.08]	−0.60	.549
L2 AoA	.11 (0.06)	[−0.01, 0.23]	1.79	.074	.10 (0.06)	[−0.01, 0.22]	1.71	.087
Education	**−.12 (0.06)**	**[−0.24, −0.00]**	**−2.01**	**.044**	−.08 (0.06)	[−0.20, 0.04]	−1.34	.179
Age: home entropy	−.01 (0.06)	[−0.13, 0.11]	−0.13	.900	—	—	—	—
Age: work entropy	—	—	—	—	**−.16 (0.06)**	**[−0.28, −0.04]**	**−2.66**	**.008**
Age: L2 AoA	.05 (0.06)	[−0.06, 0.16]	0.90	.367	.00 (0.06)	[−0.11, 0.11]	0.02	.982
Age: education	−.09 (0.07)	[−0.23, 0.04]	−1.34	.179	−.08 (0.07)	[−0.22, 0.05]	−1.21	.227
	Menopause models							
	Model 3 (home entropy)				Model 4 (work entropy)			
Effects	β (*SE*)	95% CI	*t*	*p*	β (*SE*)	95% CI	*t*	*p*
Intercept	−.14 (0.10)	[−0.34, 0.05]	−1.43	.152	**−.17 (0.08)**	**[−0.31, −0.02]**	**−2.19**	**.028**
Menopause group	.38 (0.20)	[−0.01, 0.77]	1.89	.059	.22 (0.15)	[−0.07, 0.52]	1.47	.142
Home entropy	.04 (0.10)	[−0.16, 0.23]	0.39	.694	—	—	—	—
Work entropy	—	—	—	—	**−.15 (0.08)**	**[−0.30, 0.00]**	**−1.96**	**.050**
L2 AoA	.12 (0.12)	[−0.11, 0.36]	1.04	.300	.12 (0.09)	[−0.06, 0.29]	1.32	.186
Education	−.16 (0.11)	[−0.37, 0.05]	−1.52	.130	−.13 (0.08)	[−0.29, 0.03]	−1.64	.101
Meno: home entropy	.15 (0.20)	[−0.24, 0.54]	0.74	.458	—	—	—	—
Meno: work entropy	—	—	—	—	**−.42 (0.15)**	**[−0.72, −0.11]**	**2.68**	**.007**
Meno: L2 AoA	.20 (0.24)	[−0.27, 0.67]	0.83	.405	.16 (0.17)	[−0.18, 0.51]	0.94	.346
Meno: education	−.05 (0.21)	[−0.47, 0.37]	−0.25	.801	.01 (0.16)	[−0.30, 0.33]	0.08	.936

Note. Significant results are displayed in boldface. Some participants were excluded from analyses examining work speaking entropy because they reported being unemployed at the time of testing (Model 2 valid $N = 105$; Model 4 valid $N = 46$). L2 AoA = second language age of acquisition; WCST = Wisconsin Card Sorting Test; CI = confidence interval; PEs = perseverative errors.

were observed for older (β = −.20, $SE = 0.09$, $t = -2.17$, $p = .030$), but not younger participants (β = .13, $SE = 0.08$, $t = 1.57$, $p = .177$). Critically, effects of work speaking entropy were observed over and above the effects of education, and there were no significant effects of L2 AoA (Figure 2C). Thus, consistent with our results on the number of CC, these results suggest that greater work speaking entropy mitigated the age-related increases in the number of PEs on the WCST.

Models 3 and 4: Effects of Bilingual Language Experience and Menopausal Status on PEs

Regression models of the middle-aged subgroup showed similar relationships to those observed in the age analysis based on the whole sample. That is, although Model 3 indicated no main effects or interactions involving home speaking entropy (Figure 2D) or L2 AoA (Figure S5 in the online supplemental materials), Model 4 revealed a significant interaction between menopausal status and work speaking entropy (Figure 2E). Follow-up simple slopes analyses revealed that, at low levels of work speaking entropy, participants in the postmenopause group made more PEs compared to participants in the premenopause group (β = .64, $SE = 0.22$, $t = 2.89$, $p = .004$). However, this group effect was not significant at high levels of work speaking entropy (β = −.19, $SE = 0.21$, $t = -0.91$, $p = .362$). Examining the work speaking entropy effect on the number of WCST PEs for each group separately further revealed a positive association for participants in the postmenopause group (β = −.36, $SE = 0.11$, $t = -3.18$, $p = .001$), but not for participants in the premenopause group (β = .06, $SE = 0.11$, $t = 0.53$, $p = .594$). Importantly, the effects of work speaking entropy did not depend on age of L2 acquisition (Figure 2F). Together, these results again suggest that greater work speaking entropy provides a buffer against decreased cognitive performance associated with natural menopausal transition.

Discussion

The present study characterized how diversity of language use in distinct communicative contexts modulates the effects of aging and menopause on cognitive control in an adult lifespan sample of healthy females. Using robust linear regression, we systematically investigated the interactions between chronological age, menopausal status, as well as continuous measures of bilingual language experience on WCST performance, while also controlling for years of education, a robust contributor of cognitive reserve (Lövdén et al., 2020).

The Impact of Chronological Age and Menopausal Status on WCST Performance

Consistent with previous findings (Subramaniapillai et al., 2019), we observed that with increased age, females completed fewer categories and made more PEs overall on the WCST. The results also showed that cognitive control abilities declined with postmenopausal status in the middle-age sample, particularly with reported low work entropy. These findings thus corroborate existing evidence indicating that aging and menopause are associated with decreased cognitive performance in healthy adult females. The findings of this study provide important insights into changes in cognitive control in females at midlife, and specifically the importance of considering individual differences and lifestyle factors (e.g., speaking entropy) in cognitive aging in females.

One important challenge to consider when distinguishing the effect of healthy aging versus menopause on cognitive control is that cognitive aging and menopause intersect temporally and are intricately linked. To address this concern, we carefully selected a middle-aged cohort for our menopause analyses. Moreover, we conducted additional analyses, taking age into account as a covariate, and our main findings remained unchanged (see Tables S13 and S14 in the online supplemental materials). Nevertheless, it is critical to consider the interconnected nature of these variables when investigating menopause and cognitive health.

The Impact of Bilingual Language Experience on WCST Performance

Building from our previous findings (Subramaniapillai et al., 2019), this study applied speaking entropy, a measure of diversity of current language use in the highly multilingual city of Montréal, Canada. By examining speaking entropy within the home and workplace separately, this work provides insight into how distinct communicative contexts may impose different demands on language use with implications for cognitive control. Specifically, our results showed that greater speaking entropy in the workplace, but not in the home environment, mitigated the effects of aging and menopause on WCST performance. Critically, this pattern of results held above and beyond differences in years of education and L2 AoA.

One possible explanation for the effect of work speaking entropy is that participants overall reported greater language diversity in the workplace than in the home environment. However, as we have argued elsewhere (Beatty-Martínez & Titone, 2021), high linguistic diversity can be achieved through different means, depending not only on bilinguals' proclivity to codeswitch, but also on their propensity to experience dynamic and diverse interactional demands requiring bilinguals to proactively monitor and regulate their languages. While our measure of speaking entropy cannot dissociate between these kinds of interactional experiences, the emerging evidence seems to suggest that it is not higher levels of language diversity per se that mediates cognitive control in bilingual speakers. Instead, the environmental pressures associated with deciding how each language might be used in a specific communicative context.

We propose that what distinguishes work from home speaking entropy relates to the ways in which interactional demands are mediated. In the home environment, the choice of using one language over the other, or both (e.g., via codeswitching), may be more voluntary or opportunistic (e.g., Beatty-Martínez, Navarro-Torres, & Dussias, 2020). In contrast, workplace environments impose increased demands and proactive monitoring of the appropriate language in each scenario (e.g., "What language[s] does the interlocutor speak?," "Is it appropriate to codeswitch?," "Am I required to speak French exclusively?," etc.).

While more research is needed, the results of this study suggest that greater experience managing language-related uncertainty under such circumstances may trigger an adaptive response for bilingual females that may compensate age- and menopause-related decline. This interpretation is consistent with recent studies examining proactive control reliance as a function of the demands of bilinguals' context of language use. For example, Zhang and colleagues compared Mandarin-English bilinguals who underwent intensive language switching training in either the L1 environment (Zhang et al., 2021) or while abroad in an L2-immersion context (Zhang et al., 2021). For L1-immersed bilinguals, language switching training led to an increased reliance on proactive control, suggesting that language training may mediate the recruitment of cognitive control during language processing. L2-immersed bilinguals also showed a stronger reliance on proactive control, but critically, these proactive control effects were observed at pretest, suggesting that they are the consequence of the increased demands on language regulation associated with experience of L2-immersion.

As a second illustration, Beatty-Martínez, Navarro-Torres, Dussias et al. (2020) compared picture naming performance of two groups of highly proficient Spanish–English bilinguals living in different language environments. One group lived in Puerto Rico, a predominantly L1-speaking context but where codeswitching is prevalent and comes at little-to-no interactional cost. The second group was immersed in a predominantly L2-speaking context in the United States where bilinguals had to proactively monitor opportunities to use L1. Despite both groups exhibiting high levels of language diversity, the results showed that picture naming performance and how it related to cognitive control ability, depended on the demands of bilinguals' interactional context. For bilinguals in Puerto Rico, there was no pattern of association between picture naming and cognitive control skill, but for bilinguals in the U.S. context, greater reliance on proactive control related to better picture naming performance in the L1. The implication is that bilinguals differ by virtue of the demands that are placed on them to regulate their languages. Further work is needed to identify sex differences in how interactional demands relating to bilingual language experience may differentially contribute to increased cognitive reserve across the adult lifespan.

An alternative explanation for the work entropy effect may be due to the difference in sample size between home and work models given that some participants were unemployed at the time of testing and thus did not report on their habits of language use in the workplace. To address this possibility, we reran all home speaking entropy analyses including only bilinguals who reported being employed. The results remained unchanged (see Tables S9–S12 in the online supplemental materials).

The use of speaking entropy is a potential strength of this study as previous investigations could not accurately account for the subtle differences in language use within distinct communicative contexts. In most past research, measures relating to language experience are generally treated as a uniform construct. The current findings suggest that the expertise bilingual speakers gain in their everyday conversational practices will differentially affect cognitive control, and that measures relating to historical bilingual experience may not necessarily provide a comprehensive understanding of such dynamics. Critically, this point may have been masked entirely had we collapsed across communicative contexts or relied on conventional bilingual language variables extracted from standard language questionnaires such as proficiency self-ratings.

Constraints on Generality

It is worth considering the constraints on the generalizability of this study (Simons et al., 2017). To examine menopause and language diversity on WCST performance, this study exclusively focused on a subsample of females at midlife (40–65 years) to minimize age-related confounds. This potentially limits generalizability to this group and age range. The study also utilized the computerized version of the WCST, a widely used measure sensitive to cognitive control. Thus, alternative tasks or noncomputerized versions may yield different results. Moreover, this study has limitations characteristic of all cross-sectional studies. Accordingly, future longitudinal studies would provide a more comprehensive understanding of the relationships between age, menopause, bilingual language use, and cognitive control. Lastly, to control sociolinguistic variability, the study focused exclusively on English–French and French–English bilingual in a highly multilingual city that has a single official language. This potentially limits generalizability to other samples that share similar sociolinguistic characteristics (e.g., the impact of work entropy may be reduced in locations that are less inherently multilingual).

Notably, the current findings may not generalize to other bilingual phenotypes (Beatty-Martínez & Titone, 2021) who may differ in terms of the communicative demands they face. Interactional effects on cognitive control have been observed previously in young adult bilinguals in linguistically diverse contexts requiring proactive monitoring of the appropriateness of using each of their languages (Gullifer et al., 2018, 2023; Gullifer & Titone, 2021). The current findings add a further dimension to this discussion by demonstrating that females, who are most vulnerable to age- and menopause-related changes in cognitive control, may compensate for cognitive declines by virtue of adapting to the externally imposed demands of the language environment. Taken together, these findings highlight the need to richly characterize bilinguals' interactional demands across distinct communicative contexts. Given the paucity of work on female-specific issues, our findings provide great value to understanding the trajectory in age- and menopause-related decline in cognitive control that is experienced by females and how particular aspects of bilingual language experience may, in turn, compensate for these effects.

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