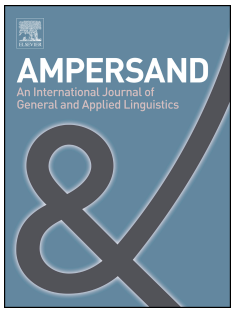

A cross-sectional developmental approach to bilingualism: Exploring neurocognitive effects across the lifespan

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A cross-sectional developmental approach to bilingualism: Exploring neurocognitive effects across the lifespan

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Abstract

This article summarises over ten years of research on the effects of multilanguage acquisition on cognitive development (and decline) across the lifespan conducted by our lab. We adopted a developmental approach to research on bilingualism with the aim of building developmental trajectories of components of executive functions and metacognition. We examined the performance of over 900 individuals from the age of 8 to 80 years, half of them multilinguals. They were all tested individually with a battery of behavioural tasks and a large number of adult participants underwent structural magnetic resonance imaging (MRI). For all participants we collected biographical, linguistic, and socio-economic data.

Taken together, our studies show that behavioural performance across multiple cognitive indicators does not differ between multilingual and monolingual groups when they are carefully matched on potential confounding covariates such as socio-economic status and language experience, and that the evidence base against a multilingual advantage is disproportionately robust when sample size is comparatively large. Nevertheless, we have also identified possible differences in the functional architecture of higher-level cognition across these groups, indicating that the process of acquiring a second language may alter the distributed networks underpinning cognitive control. Our findings have contributed to a better understanding of the effects of multilingualism on cognitive and metacognitive processes across the lifespan. They have shown that multilingual acquisition is neither detrimental nor advantageous to domain-general cognitive development but may nevertheless promote functional and structural adaptation in the service of control of linguistic interference.

Introduction

There is a growing interest in bilingualism/multilingualism and multicultural diversity. External factors such as migration have contributed to ever greater diversity within populations. However, there are many open questions that embrace different sectors in our societies, including education, workforce, health and well-being. Does promoting socio-cultural diversity enhance cognitive capacity and flexible behaviour across the lifespan? Are multilingual school children a resource or a challenge to the delivery of good learning outcomes in education? Are multilingual adults an economic resource or a drain for the workforce? These questions demand a clear answer which is underpinned by science. Our research has been heavily inspired by historical debates among philosophers, linguists, psychologists and educators in which second language acquisition, especially in children, was considered detrimental for cognitive development. For cognitive psychologists like us, research on bilingualism has offered the unique opportunity to study the interactions between the language system and other domain-general cognitive abilities, and help develop theoretical models that can embrace complexity in the effects of multilanguage acquisition on the human brain.

From very early – and flawed - studies arguing that bilingual children were cognitively disadvantaged in comparison to monolingual peers (e.g., Saer, 1923), to more recent research conducted across three decades indicating a range of advantages, it is perhaps not surprising this has encouraged confusion among the general public. On one hand, still today in our professional contacts with parents and teachers, we frequently find parents who are very concerned about raising their children as multilinguals, and educators who discourage them to do so, with the (wrong) assumption that '*two languages in a single mind will delay their "normal" cognitive and linguistic development'* – a statement that, sadly, in some cases has been endorsed by respected colleagues and experts in early years language acquisition.

On the other hand, we also find people who hold the opinion that learning two languages can lead to a kind of immunity against age-related neurodegenerative disorders such as dementia. We suggest that this *advantage* vs. *disadvantage* dichotomy is fundamentally false, and that it is the responsibility of the scientific community to ensure that evidence in this debate is presented fairly and objectively. Learning a second language (or more) is not a "disease"; for many of us it is the inevitable consequence of our life experiences. It is therefore demonstrably the case that being able to speak multiple languages is unequivocally positive for social, cultural and professional reasons (Antoniou, 2019). The so-called *bilingual advantage*, however, refers to evidence that bilingual speakers may be some faster and, in some cases, more accurate than monolinguals in performing classical nonverbal executive function tasks measuring the ability to control visual and auditory interference, shifting from one task to another, and updating information in working memory (see the work of Miyake and colleagues, 2000, for a clear account on the components of executive function).

From a theoretical perspective, second language acquisition offered the unique opportunity to explore underlying processes and interactions between linguistic and general cognitive abilities. We also recognised the impact that this line of research has had (and continues to have) in education, culture, social policies and practices and in other aspects of multicultural life.

When we started our investigations, the predominant view was in favour of the *bilingual advantage* and many publications provided evidence that bilingual children, adults and older adults outperformed aged-matched monolinguals in a range of cognitive nonverbal tasks (e.g., Bialystok & Martin, 2004; Bialystok et al., 2005; Costa et al., 2008). One key question in bilingual research is how bilingual speakers control language production, that is, how they select the language they intend to speak. There is robust empirical evidence that, in the bilingual mind, both languages are active at the same time (e.g., Dijkstra et al., 1998; Filippi et al., 2013; Wu & Thierry, 2010). Therefore, speakers of two or more languages will need to resolve the competition between them in order to communicate effectively, which means controlling the

selection process through, perhaps, the suppression of the unwanted language and focused engagement with the language they want to speak. This interpretation is central to the Inhibitory Control Model (ICM - Green, 1986; 1998), which proposes that during the phase of speech planning, a general control mechanism is in charge of the speaker's communicative goals. This control process inhibits the non-target language and activates the target one, as a sort of cognitive *traffic light*. On the supposition that bilingual speakers habitually switch between languages, *executive function* mechanisms must be deployed for language control processes and, as a result of this cognitive overtraining, bilingualism may enhance cognitive control abilities beyond the language system (i.e., for nonverbal thought and action). This process, therefore, provides a candidate mechanism that drives a *bilingual advantage* in some executive functions.

A bilingual advantage has predominantly been reported in studies using paradigms in the visual domain, that is, with tasks using only visual stimuli. We found this surprising, because an obvious feature of bilingual behaviour is to disentangle *auditory* messages. In order to fill this gap in the literature, our early studies focussed on the auditory domain, specifically by measuring monolinguals' and bilinguals' selective attention and their ability to filter out verbal interference when comprehending speech (Filippi et. al., 2012; 2015). This work incorporated both behavioural and neuroimaging methods. We then extended our investigation to focus on visuo-spatial working memory and metacognitive processing. Over the course of the years, we came to the realisation that our early work, like that of many others at that time, was providing only a small-scale snapshot of some possible positive effects of bilingualism without directly incorporating age as a key variable of interest. There is evidence, for example, that bilingual/monolingual discrepancies in cognitive test performance are wider in older relative to younger adult groups (for a meta-analysis see Ware et al., 2020; although earlier meta-analyses fail to support this claim (Lehtonen et al., 2018; Donnelly et al., 2019). Therefore, we decided to design our more recent projects by using a developmental approach based on

large-scale cross-sectional examination embracing the whole lifespan while carefully matching all comparison groups on important covariates, including measures of socio-economic status. Our primary goal was to determine under which conditions a bilingual advantage appears in empirical investigations, for which kind of bilinguals, and on which cognitive skills/tasks (cf. Festman, 2021; Leivada et al., 2021).

Control of interference

The first study we conducted employed a group of 20 Italian/English proficient bilingual adults (mean age 32 years old) based in the UK, who acquired English once the acquisition of their native language (Italian) was complete – often referred to in the literature as *late bilinguals*. We adapted a sentence comprehension task in noise used in cross-linguistic **(**e.g., Bates et al., 2001), clinical (e.g., Dick et al., 2007) and developmental research (Leech et al., 2007). The participants were required to identify the agent in a sentence while ignoring linguistic interference that was presented simultaneously in both ears (technically, this paradigm is called *diotic listening*). The target sentences were divided in *canonical*, (i.e., subject-verb-object) and *non-canonical* (i.e., object-verb-subject) syntactic structures, where the former were deemed as *easy to comprehend* (i.e., not particularly demanding in terms of language processing) and the latter more demanding to process due to the position of the subject at the end of the sentence. The target sentences were paired with competing speech in Italian and in English, always presented by the opposite sex (e.g., target = male; interference = female and vice versa). There were also blocks of sentences without interference, used as baseline control trials (for more details about the task design, please refer to Filippi et al., 2012).

The accuracy scores obtained by the bilingual groups were compared with a group of 20 Italian monolinguals based in Italy and matched by age and socio-economic status. We predicted that all participants would show poorer performance when comprehending sentences in the presence of interference and in particular with interference in the more dominant language

(Italian). On the basis of previous research on executive function, we also predicted that bilingual speakers would be more efficient in inhibiting irrelevant information and, therefore, would be more accurate than monolingual speakers in comprehending the target sentences. As shown in Figure 1, we found that bilinguals were indeed reliably better than monolinguals in filtering out interference (p <.001), but the effect was only present when the task was more demanding, that is, when they had to comprehend non-canonical sentences.

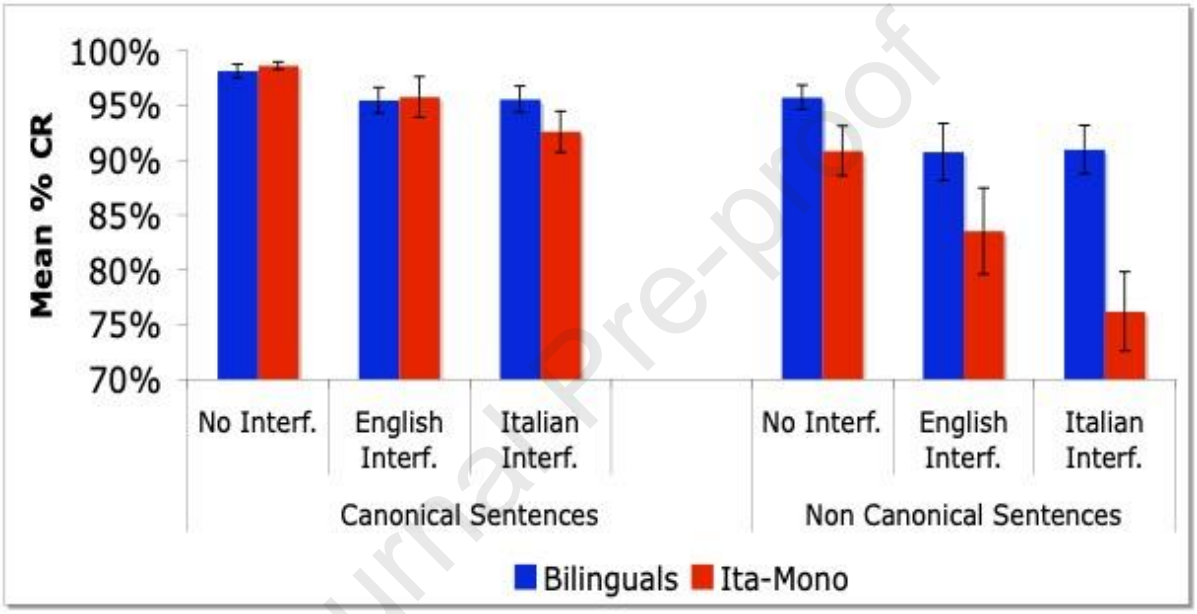

Figure 1: Bilingual and monolingual speakers' performance (CR=Correct Responses) in the sentence comprehension task. Bars show standard error.

Within the bilingual group, we also found that the level of proficiency measured with a standardised test, the Bilingual Verbal Ability Test (BVAT Muñoz-Sandoval et al., 1998), was a reliable predictor of best performance (Figure 2).

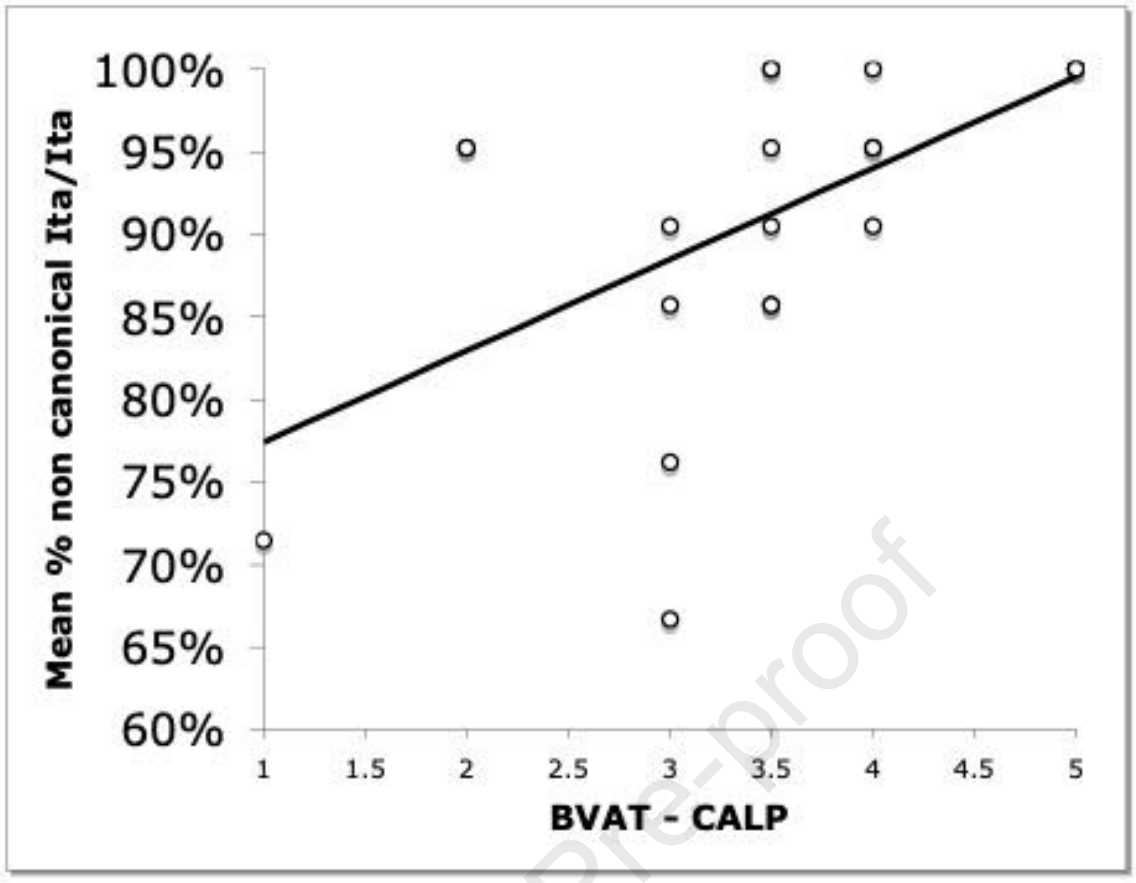

Figure 2: Bilingual level of proficiency mregressed against the performance in the sentence comprehension task. BVAT: Bilingual Verbal Ability Test – CALP: Cognitive-Academic Level of Proficiency (Muñoz-Sandoval, et al., 1998)

A follow up study conducted with children produced similar results (Filippi et al., 2015). The task was adapted to be administered to bilingual children who were acquiring English plus an additional language simultaneously. Their age ranged from 7 to 11 years . The target sentences were all in English, the language that all children used at school, and the interference was either in English or in Greek, a language that none of the bilingual children could comprehend. The key result indicated that the bilingual children's ability to control verbal interference improved through development (Figure 3). The same analysis conducted with a control group of English monolingual children did not show the same pattern: their performance did not improve across development.

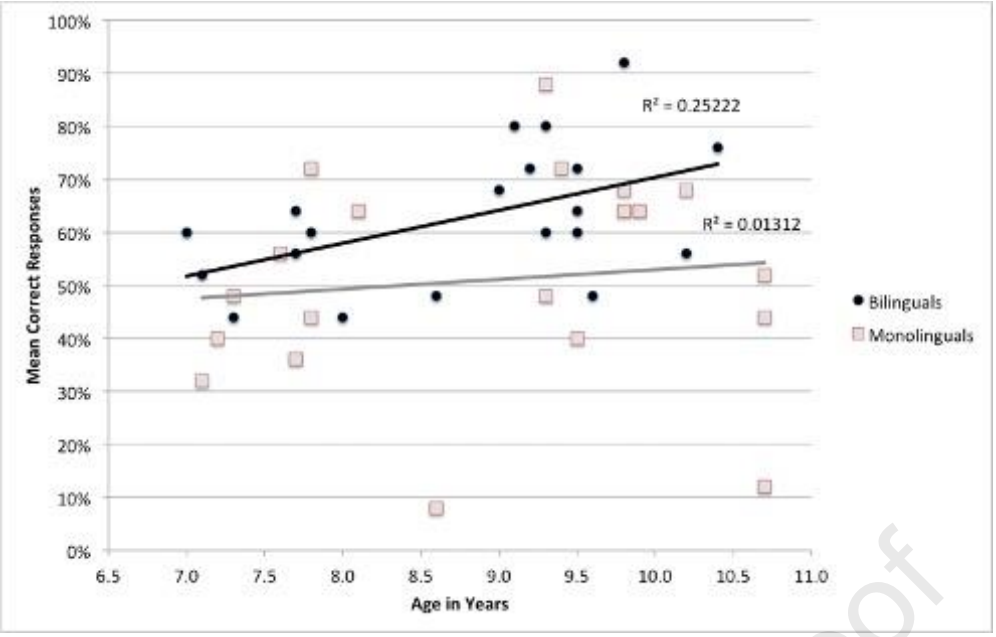

Figure 3: Regression analysis of bilingual and monolingual children indicating a positive effect of bilingualism on the control of verbal interference across development.

Taken together, both studies showed a positive effect of second language acquisition in the control of verbal interference. They also showed that language proficiency in adulthood and age in the children's development were both reliable predictors of better inhibitory control in the auditory domain (see also Ouzia & Filippi, 2016, for a review), results that seemed to be compatible with a bilingual advantage account.

Visuo-spatial working memory

We extended our investigation to visuo-spatial working memory using the change-blindness task with a group of young bilingual university students (mean age 21 years old) who learnt English as a second language and had different linguistic backgrounds, and whose performance was compared against a group of age- and SES-matched monolinguals (Kerrigan et al., 2014). They were shown a series of coloured pictures with scenes from everyday life. Each picture was paired with a slightly modified image in which one element was missing. The two pictures were presented in alternation until the participants were able to identify the change. The key results indicated a very clear pattern: bilingual speakers were significantly faster than

monolinguals in identifying the missing object in the picture. The study, therefore, provided more evidence that tasks requiring attentional control, whether in the visual or auditory domain or containing either verbal or nonverbal materials, were performed more efficiently by bilingual speakers than age- and SES-matched monolinguals.

Metacognitive processing

On the assumption that the observed bilingual advantage in executive function operates in a broader range of cognitive abilities, we investigated metacognitive performance in groups of second language learners and English monolingual adults (Folke at al., 2016). Metacognition refers to the ability to evaluate one's own cognitive processes and it is often associated in the literature with executive function (see Bright et al., 2019, for a review). Our prediction was therefore directed to a possible positive effect of bilingualism in metacognitive processing. Across two separate experiments involving 123 individuals in total, we found the reverse effect: bilingual participants showed a metacognitive *deficit* compared to age- and SES-matched monolinguals. These findings were at odds with our previous studies and suggested that, on one hand, this line of investigation may be complicated by the difficulty in controlling for multiple candidate explanatory variables that may operate across group comparisons and, on the other hand, that the impact of second language acquisition on cognition was much more complex than we initially thought.

Bilingualism and ageing

So far, our studies had focussed on children, young and middle-aged adults. However, some studies have reported possible positive effects of bilingualism on *cognitive reserve*, that is, factors that can potentially reduce the detrimental effects of ageing on cognition. These studies offered some evidence that bilingualism may protect the brain from neurodegenerative disorders such as Alzheimer's disease, delaying onset by approximately 4 years (e.g., Alladi et al., 2013; Bialystok et al., 2007; Craik et al., 2010; Schweizer et al., 2012; Woumans et al.,

2015). With this in mind, we investigated the effects of long-term use of multiple language in older age (Papageorgiou et al., 2018). In collaboration with the University of the Third Age, we targeted 74 healthy retired individuals with a mean age of 70 years. Half of these participants were bilingual and had been exposed to their second language for an average of 56 years. They were compared with an age- and SES-matched group of English monolinguals on tests of executive function typically employed in research on bilingual cognition: the Simon task (e.g., Bialystok et al., 2004) and the Tower of London test (e.g., Cox et al., 2016), along with the change-blindness task we had already used with younger participants (Kerrigan et al., 2014). Across all tasks and using both traditional and Bayesian statistical methods, the two groups showed statistically comparable performance.

A developmental approach to bilingual research

Our studies on the relationship between second language acquisition and executive function produced contradictory results, but also contained some potential limitations. First, they were relatively small-scale studies with a small number of participants; second, direct comparison across each published study was complicated due to heterogeneity in linguistic experience, age of second language exposure/acquisition and inconsistency in the test battery administered. These issues and others (including failure to control for immigration status and cultural factors) have been raised by a number of critics who have challenged the validity of much of the evidence base for the bilingual advantage hypothesis (e.g., Antón et al., 2014; Duñabeitia et al., 2014; Paap, Johnson & Sawi, 2015; Paap & Greenberg, 2013; Morton & Harper, 2007).

In order to move forward and towards a more solid understanding of the theoretical and practical implications of bilingualism on cognitive development and decline, we subsequently adopted a neuroconstructivist developmental approach (e.g., Karmiloff-Smith 1998) to the field of second language acquisition (see Filippi et al., 2018 for a review).

We designed our subsequent studies with the aim of building and comparing developmental trajectories of bilingual and monolingual cognition across the lifespan. We calibrated the experimental tasks in a way that they could be performed by participants with age ranging from 7 to 80 years. Linguistic experiences were collected, through individual questionnaires, and we also acquired socio-economic status data. We built a database of more than 900 individuals (bilinguals and monolinguals) and, within the bilingual population, we specifically targeted those who were raised from birth in bilingual households and learned both languages simultaneously, and those who learned a second language within the first 5 years of life. A large subset of individuals (N=87) underwent structural MRI acquisition allowing mapping of behavioural performance to grey matter density and white matter connectivity in monolingual and bilingual participants. In the following sections we illustrate the results of our recent findings based on this larger set of data.

Building on our observation of a bilingual advantage in the control of auditory verbal interference during the processing of syntactically complex sentences, and in the context of recent critical reports around perceived methodological shortcomings in the broad literature on *the bilingual advantage*, we conducted a new study with a considerably larger sample of children, incorporating additional experimental conditions within a developmental framework (Filippi et al., 2020).

Two-hundred and nine children aged between 7 and 12 (132 monolinguals and 77 bilinguals) undertook the oral sentence interpretation task described above, which was modified to include both non-verbal and verbal interference conditions. For the nonverbal conditions, congruent trials incorporated the sound of the agent animal (i.e., the animal performing the 'bad action') and incongruent trials incorporated the sound of the object (i.e., the 'victim' of that action). A neutral condition of unrelated sounds (e.g., a train, a telephone, etc.) was also employed. On the basis of our earlier study (Filippi et a., 2015) we predicted a bilingual advantage in the

ability to process complex (i.e., non-canonical) sentences in the context of familiar language interference. However, our earlier, smaller-scale findings were not supported: comparable performance was demonstrated across the monolingual and bilingual groups on all verbal and nonverbal interference conditions, reinforced by the inclusion of computed Bayes factors. Cluster analysis identified three performance-based clusters, driven principally by age, with older participants performing comparatively better than younger participants on the sentence interpretation task and background measures of fluid intelligence, working memory and English vocabulary knowledge. This pattern held for both groups, such that there was similar representation of monolinguals and bilinguals in each of these clusters. Overall, and within each cluster, key indicators for successful verbal and nonverbal interference control were background cognitive ability and socioeconomic status, irrespective of linguistic status (monolingual/bilingual).

To make sense of the inconsistency in the support for our primary hypothesis across the earlier (2015) and more recent (2020) studies we considered a range of factors. The experimental procedure for the sentence interpretation task differed only with respect to the inclusion of a non-verbal interference condition, the sample characteristics were similar, and groups were matched on candidate alternative explanatory factors (including socioeconomic status). However, the sample size was more than five times larger in our more recent study, and also incorporated Bayesian methods alongside cluster analysis to identify meaningful patterns of association among our variables of interest. Consistent with other recent, comparatively large sample studies (e.g., Duñabeitia et al., 2014, Paap & Greenberg, 2013) and with several meta-analyses (e.g., Lehtonen et al., 2018; Van den Noort et al., 2019), our data indicate that the reported bilingual advantage in cognitive control is highly sensitive to sample size and that the increased statistical power of larger scale studies challenges the viability of the underpinning theory that bilingualism directly serves the enhancement of executive control.

Nevertheless, this study was focused on a relatively constrained age range (7 to 12 years) and in order to further address the implications of multilingual acquisition on cognitive control we therefore adopted a broader, developmentally informed study of executive function in individuals aged 7-80 years of age (Filippi et al., 2022). We included tests of inhibition (Simon and go/no-go tasks), planning and problem solving (Tower of London), verbal working memory (digit span forwards and backwards), verbal fluency (letter and category), fluid intelligence (Raven's Matrices) and receptive vocabulary (British Picture Vocabulary Scale; BPVS-III - Dunn, et al., 1997). Our sample consisted of 154 children (77 monolinguals, 77 multilinguals) and 170 adults (86 monolinguals, 84 multilinguals), with no significant differences overall or within each age band on our measures of socioeconomic status, sex, or age.

Consistent with our 2015 study, age was the primary driver of performance across our tasks in children, and this was the case for both the linguistic and non-linguistic measures. Age-related trajectories were similar in the monolingual and multilingual groups, with the exception of a shallower improvement in planning abilities (on the Tower of London task) between the ages of 7 and 15 in multilingual children. No performance advantages or additional disadvantages were observed in the multilingual group. In adults, we observed some evidence for a steeper deterioration with age in inhibitory control reaction times on the go/no go task in monolinguals, thereby offering some evidence that multilingualism may offset age-related decline in inhibitory control. Nevertheless, statistically comparable performance was observed on all other measures.

Despite limited evidence for group differences in performance on our measures, exploratory factor analysis provided evidence that early acquisition of a second language modulates the functional architecture underpinning cognitive control mechanisms. Thus, verbal fluency was strongly associated with fluid intelligence and working memory in monolinguals while in

multilinguals there was a strong verbal fluency factor on which other measures of executive function, including fluid intelligence and working memory showed low or marginal loadings, both in child and adult groups. On this basis, we tentatively claim that early multilanguage acquisition encourages functional convergence and divergence among mechanisms serving high-level cognition but that these effects do not manifest as reliable performance advantages or disadvantages.

Building on our earlier study of metacognitive processing (Folke et al., 2016), we have also explored developmental interdependencies of metacognition and executive function across the lifespan. To the extent that metacognition incorporates domain-general active cognitive control as well as passive monitoring (e.g., Flavell, 1979; Nelson & Narens, 1990, 1994), there is considerable conceptual overlap with models of executive function (e.g., Baddeley, 1986, 2002; Norman & Shallice, 1986): both systems are concerned with top-down mechanisms that monitor and modulate thought and action in the service of meeting behavioural goals. Our earlier work, which demonstrated a metacognitive *disadvantage* in our multilingual participants, therefore ran counter to our predictions informed by the bilingual advantage hypothesis.

With sample size increased from 62 young adults to 330 participants from 7 to 80 years of age we were able to broaden our focus and embrace a lifespan perspective on interdependencies of executive and metacognitive abilities (Filippi et al., 2020). In contrast to our earlier findings, we observed neither advantage nor disadvantage in metacognitive processing (on the same task) across our multilingual and monolingual groups, with comparable performance observed in all age bands (children, young adults, middle-aged adults and older adults). Despite similarities in conceptualisation of the two systems, exploratory factor analysis indicated that metacognitive ability was independent from mechanism(s) supporting performance on classic tests of executive function and working memory (including Raven's Matrices, Simon test,

Tower of London and digit span). Our measure of metacognitive ability showed negligible loadings on the latent variables underpinning performance on these tests, with over 99% of the variance identified as unique. Confirmatory evidence that metacognitive efficiency does not depend on mechanisms serving working memory and executive function (at least in the context of our visual perception-based discrimination task) emerged from analysis of the trajectories of performance across the lifespan. While acknowledging limitations around drawing developmental inferences from cross-sectional data, we observed a steep gradient of improvement on tests of executive function/working memory between childhood (7-12) and young adulthood (18-35) which was followed by a shallow decline to middle adulthood (36-55) and a steep performance decline in older participants (56-80). Metacognitive ability showed a rather different trajectory across our age groups, with a relatively shallow gradient of improvement from childhood through early adulthood, reaching optimal performance in middle adulthood, although this was followed by a similar sharp decline in older participants.

On balance our recent investigations, which incorporate markedly larger samples than typically employed in this literature, provide a body of evidence that challenges the viability of the bilingual advantage hypothesis. As such, our work is consistent with recently published meta-analyses which report essentially zero evidence for a positive impact of multilingual acquisition on domain-general executive function once publication bias and alternative candidate explanatory variables are accounted for (e.g., von Bastian et al., 2017; Donnelly et al., 2019; Lowe et al., 2021, Monnier et al., 2021, Paap, 2019).

In summary, our exploration of developmental trajectories of high-level cognition indicates comparable performance in monolingual and multilingual participants, and this observation held in childhood and in early, middle and older adult age groups. Nevertheless, we also identified group differences in the functional architecture of executive functions as measured

by tests of working memory, verbal fluency, nonverbal fluid intelligence, planning and problem solving, and response inhibition (Filippi et al., 2022).

To determine whether evidence for functional adaptation underpinned by multilingual acquisition might be associated with *cortical* differences between multilingual and bilingual groups, we conducted a structural imaging study using voxel-based morphometry. Specifically, we returned to our earlier study described above, which indicated that an area of the cerebellum, the right posterior paravermis, is involved in control of verbal interference (Filippi et al., 2011). This earlier study was conducted with highly-proficient bilinguals only, and we therefore elected to undertake a new, larger study which employed the same sentence interference task but also incorporated a group of 41 monolingual participants matched closely with a new group of 46 bilingual participants (Filippi et al., 2020).

Despite comparable performance on our experimental task, we identified robust group effects in our region of interest (ROI), the posterior paravermis (and, unlike our earlier study, this was observed bilaterally). Specifically, a direct group comparison revealed i. significantly more grey matter volume in bilinguals than monolinguals in the ROI (right hemisphere only) and ii., significantly greater volumetric grey matter sensitivity in bilinguals over monolinguals within our ROI (bilaterally) when processing syntactically complex sentences against unfamiliar linguistic interference. Our findings indicate that multilingual acquisition may encourage adaptation of the distributed networks underpinning language, despite the absence of demonstrable effects at the behavioural level once alternative explanatory variables are controlled. We suggest that these findings are intuitively appealing and coherent with our evidence for changes in the functional interdependencies among a range of working memory/executive mechanisms underpinned by early multilanguage acquisition.

Our recent work on the impact of language experience on attention to faces in infancy indicates that bilingual environments may alter the development of visual attention capture and maintenance for faces in the service of adaptation to multilingual social communication (Mercure et al., 2018; 2022). These findings, we argue, also contribute to the evidence base that differences in language experience contribute to the emergence of functional interdependencies, and that these in turn are likely to alter the distributed neural networks underpinning domain-general cognitive control.

Concluding comments

Our body of published research on the impact of multilanguage acquisition on cognitive control incorporates diverse and sometimes contrasting findings. Our earlier work presents evidence consistent with the bilingual cognitive advantage hypothesis, yet our more recent studies, which incorporate more sophisticated analyses and far larger samples, indicate that there is no reliable domain-general cognitive advantage associated with multilanguage acquisition. Our position, reinforced by several recently published meta-analyses (Donnelly et al., 2019; Lehtonen et al., 2018; Lowe et al., 2021; Monnier et al., 2021; Paap, 2019; von Bastian et al., 2017) is that the evidence base for there being a general advantage in executive function is too small and variable to warrant further serious debate. It is time to accept that small sample studies are likely to lack the statistical power required to reliably detect effects generalisable to the wider population, which in this literature has been compounded by the challenges in adequately controlling confounding covariates such as socioeconomic and immigration status (see, for example, Lowe et al., 2021; Morton, 2015). In those comparatively few studies with significantly larger sample sizes, including our own, the result, almost without exception, is a failure to reject the null hypothesis. Bayes factors are increasingly included in such studies, and they serve to reinforce the ratio of probability towards the null hypothesis (i.e., that there

are no meaningful differences between monolingual and bilingual performance on measures of executive function and cognitive control).

In our view, the debate on whether or not there is a general cognitive advantage *caused* by the process of acquiring and using a second language is so polarised that it apparently attracts an impulsive refusal to accept statistically reliable and empirically sound evidence if it does not support the theory. On the opposing side, we still hear expert researchers in early language acquisition and education publicly stating that "…*children who are acquiring English as a second language, even coming from advantaged backgrounds, will take between 5-7 years to become competent academically with the language*". This is no way for science to progress, it misleads public understanding, and it encourages decision-making that is not grounded in evidence.

Our data indicate that multilanguage acquisition does modulate the functional and structural architecture of networks associated with high-level executive control, but also that these group differences do not reliably lead to benefits at the behavioural level. This failure to identify group differences might relate to test sensitivity or some other methodological reason, but we suggest that the weight of evidence against the bilingual advantage hypothesis as currently presented is statistically overwhelming.

Rather than persisting with straightforward comparisons of discrete 'bilingual/multilingual' and 'monolingual' groups, we recommend that the emphasis should now be on language experience as a continuum. While heterogeneity in definitions and levels of bilingualism is increasingly recognised in the literature, less attention has been directed toward monolingualism. We might even question whether the strictly defined category 'monolingual' reliably exists in in this literature outside of studies of pre-school children. Most 'monolingual' participants in published articles are likely to have studied one or more foreign language for

several years, yet the literature continues to present language status as a monolingual/bilingual dichotomous variable. Such an approach is likely to lead to noisy and unreliable data, made more problematic by the small sample sizes typically employed.

Through treating language experience as a continuum it will better capture the diversity in linguistic experience, the context in which each language was learned (and for what purpose), amount of exposure to second languages in 'monolinguals', etc. Objective measures of linguistic skills should also be more routinely acquired in addition to self-ratings (for a discussion of these points see Takahesu Tabori et al., 2018). We encourage development of longitudinal studies in addition to cross-sectional designs, particularly in early school age and infancy, along with wider sampling and control of important alternative explanatory factors such as age of acquisition, language use and socioeconomic status (SES), particularly targeting the more disadvantaged populations.

On this point, in one of our recent studies (Naeem et al., 2018), we found that SES was a significant modulator of executive function performance. By comparing the cognitive performance of low and high SES individuals, we found that low-SES bilinguals outperformed low-SES monolinguals in the Simon task, that is, they responded faster when resolving the cognitive conflict presented in the task itself. However, high-SES bilinguals' and monolinguals' performance was comparable. These results raise the possibility that a multilingual experience may not be important in high-SES populations, but may help offset the negative impact that impoverished environments have on cognitive development. This area is largely understudied and certainly deserves further exploration on a larger scale. Pre-registration of research design, hypotheses and analyses, and the sharing of data is encouraged to ensure good practice, encourage replication studies, and to counteract publication and confirmation bias.

We also need better theory which clearly identifies the mechanisms and conditions under which advantages operating in one domain (e.g., interference control during linguistic processing) transfer to domain-general executive function. This theory is currently missing and there is, therefore, no extant explanation for *how* or *why* enhanced skills in language-specific selection, inhibition and/or control should generalise to advantages in overall executive function (for an excellent discussion of this issue, see Blanco-Elorrieta & Caramazza, 2021). Our recent studies suggest that early multilingual acquisition influences the interdependencies among various subcomponents of executive function and may also lead to modulation of the distributed cortical networks associated with control of linguistic interference. Intuitively, then, there may be effects which operate at the behavioural level (either as an advantage or disadvantage in overt task performance). To date, however, the accumulation of empirical evidence, properly analysed, supports the claim that there is no *general* cognitive advantage for bilinguals. Without an adequate, testable model that clearly delineates the transfer mechanisms and the underlying assumptions, we suggest that the bilingual advantage hypothesis has outlived its usefulness in progressing our understanding of bilingual cognition. More than that, when we consider how influential this model has been, and continues to be, among the general public, educators and policy makers it is crucial to ensure that the inferences we draw follow the evidence. It is time to move on from simplistic models for which the underpinning assumptions have neither been clearly articulated nor empirically proven.

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Declaration of interests

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

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: