Bilingualism: Language and Cognition

cambridge.org/bil

Research Article

Cite this article: Fyndanis V, Cameron S, Hansen PB, Norvik MI, Simonsen HG (2023). Multilingualism and verbal short-term/working memory: Evidence from academics. *Bilingualism: Language and Cognition* **26**, 490–503. https://doi.org/10.1017/S1366728922000621

Received: 5 January 2022
Revised: 5 September 2022
Accepted: 5 September 2022
First published online: 28 November 2022

Keywords:
bilingualism; multilingualism; verbal working memory; verbal short-term memory

Address for correspondence:
Valantis Fyndanis,
Department of Rehabilitation Sciences
Cyprus University of Technology
15 Vragadinou Street, ZT3 Building, 1st Floor
3041 Limassol, Cyprus
Email: c.fyndanis@cut.ac.cy

Multilingualism and verbal short-term/working memory: Evidence from academics

Valantis Fyndanis[1,2], Sarah Cameron[2], Pernille Bonnevie Hansen[3,2], Monica I. Norvik[2,4,5] and Hanne Gram Simonsen[2]

[1]Department of Rehabilitation Sciences, Cyprus University of Technology, Limassol, Cyprus; [2]MultiLing/Department of Linguistics and Scandinavian Studies, University of Oslo, Oslo, Norway; [3]Department of Humanities, Inland Norway University of Applied Sciences, Hamar, Norway; [4]Department of Language and Literature, Norwegian University of Science and Technology, Trondheim, Norway and [5]Department of Speech and Language Disorders, Statped, Oslo, Norway

Abstract

To date, the evidence regarding the effect of bilingualism/multilingualism on short-term memory (STM) and working memory (WM) capacity is inconclusive. This study investigates whether multilingualism has a positive effect on the verbal STM and WM capacity of neurotypical middle-aged and older individuals. Eighty-two L1-Norwegian sequential bilingual/multilingual academics were tested with tasks measuring verbal STM/WM capacity. Degree of bilingualism/multilingualism for each participant was estimated based on a comprehensive questionnaire. Different measures of bilingualism/multilingualism were used. Data on potentially influencing non-linguistic factors were also collected. Correlation and regression analyses showed that multilingualism impacts both verbal STM and verbal WM. In particular, all analyses showed that number of known foreign languages was the strongest predictor of verbal STM and WM capacity. The results are discussed in light of recent studies on the impact of bilingualism on STM/WM and on recent proposals regarding the mechanism underlying so-called bilingual advantage.

1. Introduction

The investigation of the impact of bilingualism or multilingualism[1] on speakers' cognitive abilities has been one of the most popular lines of research in cognitive psychology and related fields. Most studies have addressed whether bilingualism/multilingualism enhances executive functions (EFs), and – inspired by Miyake, Friedman, Emerson, Witzki, Howerter, and Wager's (2000) and Miyake and Friedman's (2012) work on EFs – primarily focused on three EFs: inhibition, switching, and updating. Many studies reported a "bilingual advantage" in EFs (see review by Bialystok, 2017, and references therein). Cognitive benefits of bilingualism have been reported for healthy children, younger and older adults, with the clearest effects reported for children and older adults (Bialystok, 2017, and references therein), as well as for people with neurological conditions. For instance, in two retrospective studies, Bialystok, Craik, and Freedman (2007) and Alladi, Bak, Duggirala, Surampudi, Shailaja, Shukla et al. (2013) found that bilingualism delays the onset of symptoms of dementia by 4–4.5 years.

For a long time, it was believed that the mechanism underlying the bilingual advantage was related to inhibition. When we speak, all the languages of bilingual/multilingual speakers are activated (Colomé, 2001; Costa, Caramazza & Sebastián-Gallés, 2000; Kroll, Dussias, Bice & Perrotti, 2015), and therefore, bilinguals/multilinguals need to inhibit the non-target languages (e.g., Green, 1998). It has been argued that this practice with inhibition of the non-target language(s) trains and enhances domain-general inhibition, which results in bilinguals outperforming monolinguals on nonverbal tasks tapping into inhibition and related EFs. In other words, the bilingual advantage results from practice with inhibition of the non-target language, which strengthens inhibitory control on a domain-general level (Bialystok, 2009, and references therein).

The implicit or explicit assumption of the studies that advocated this hypothesis was that inhibition of the non-target language(s) is predominantly involved in speaking. However, not only bilinguals with high productive proficiency in their languages, but also bilingual infants and 2-year old toddlers show a bilingual advantage in EFs such as inhibition/ conflict resolution and switching, and in related cognitive functions such as visual attention (e.g., Kovács & Mehler, 2009; Pons, Bosch & Lewkowicz, 2015; Poulin-Dubois, Blaye, Coutya & Bialystok, 2011; Singh, Fu, Rahman, Hameed, Sanmugam, Agarwal, Jiang, Chong, Meaney & Rifkin-Graboi, on behalf of the GUSTO Research Team, 2015). Since both the productive proficiency and language production of infants and 2-year-old toddlers is very limited, inhibition may not be the source of the bilingual advantage (Bialystok, 2017). In fact, Bialystok (2017) has recently argued that the mechanism that underlies the bilingual advantage is related to executive attention, not inhibition. In particular, in a recent narrative review (Bialystok, 2017), she stated that "lifelong bilingualism impacts a set of processes subsumed under the category of executive attention. Beginning in infancy, the attention system is adapted to the particular demands of a bilingual environment, and these adaptations become apparent in cognitive performance across the life span. […] Attention begins to develop at birth and evolves throughout childhood so it is well positioned to provide the basis for a set of findings that extend across the entire life span" (pp. 250-251). Recently, this position gained empirical support from Comishen and Bialystok (2021), who tested 64 young adults (33 English-speaking monolinguals and 31 bilinguals) with an n-back task with increasing levels of difficulty (0-back, 1-back, 2-back, 3-back) while EEG was recorded. Increasing task difficulty resulted in greater declines in accuracy performance for monolinguals than for bilinguals, while ERP analyses showed more effortful processing in monolinguals than bilinguals across conditions, indicating that bilinguals have greater attentional resources available compared to monolinguals. The fact that studies focusing on infants and 2-year-old toddlers report data consistent with the bilingual advantage suggests that not only speaking but also listening to more than one language might confer a cognitive advantage.[2] To the best of our knowledge, the impact of the amount of writing or reading in more than one language on cognitive abilities has not been explored thus far.

It was long believed that only the lifelong bilingual experience confers a bilingual advantage (e.g., Bialystok, 2017, and references therein). However, recent studies have shown that even shorter periods of bilingual experience can have a positive impact on cognition (e.g., Bak, Vega-Mendoza & Sorace, 2014; Vega-Mendoza, West, Sorace & Bak, 2015). Moreover, it appears that both simultaneous and sequential bilingualism lead to better cognitive performance (op. cit.).

Although many studies reported evidence for the bilingual advantage (see, for example, Bialystok, 2017, and references therein; van den Noort, Struys, Bosch, Jaswetz, Perriard, Yeo et al., 2019, and references therein), several recent studies have failed to detect enhanced EFs in bilinguals (see, for example, the meta-analytic review by Lehtonen, Soveri, Laine, Järvenpää, de Bruin & Antfolk, 2018, and references therein; note that Lehtonen et al.'s (2018) review included adults only). Several studies (e.g., Paap & Greenberg, 2013; Paap, Johnson & Sawi, 2015; Paap, Myuz, Anders, Bockelman, Mikulinsky & Sawi, 2017; Duñabeitia, Hernández, Antón, Macizo, Estévez, Fuentes & Carreiras, 2014) have also pointed out methodological caveats or flaws in studies reporting evidence for a bilingual advantage. For instance, there have been several studies reporting a bilingual advantage in EFs in which monolingual and bilingual groups were not matched on a number of factors that may affect cognitive performance. One factor that has been emphasized is that of immigrant status. Some studies (e.g., Bialystok et al., 2007; see also Bak, 2016 for a discussion on this) have used bilingual groups consisting mainly of immigrants and compared them with monolingual groups consisting of non-immigrants. However, as pointed out by Fuller-Thomson and Kuh (2014), immigrant groups may have cognitive advantages which are not attributable to bilingualism, but rather to other factors. It has been found that, when socioeconomic status is controlled for, non-immigrants have worse morbidity and mortality outcomes than immigrants, which might be attributed to self-selection: it may be that those who migrate are, on a general basis, healthier than those who don't. This effect, dubbed "the healthy migrant effect", also extends to cognitive functioning in later life (Hill, Angel & Balistreri, 2012), while emigration might act as an environmental factor that enriches people's lifestyle and contributes to cognitive reserve (Mondini et al., 2014). Thus, it may be that what has been interpreted as a bilingual advantage in immigrant groups is rather an advantage connected to migration in some way. Other factors that may impact cognitive performance include socioeconomic status, educational level, and aspects of lifestyle such as physical activity, and playing instruments and/or games (see Valian, 2015, and references therein).

Another problem with the bilingual advantage is that of publication bias. That is, studies reporting null results were/are less likely to be published than studies reporting significant results (de Bruin, Treccani & Della Sala, 2015). Indeed, Lehtonen et al.'s (2018) meta-analytic review, which included correction for publication bias, found no evidence for a bilingual advantage in EFs.

An equally serious methodological limitation to the studies on the impact of bilingualism/multilingualism on cognitive abilities is that, although bilingualism/multilingualism should be treated as a continuous variable (e.g., Luk & Bialystok, 2013), the vast majority of studies have treated bilingualism as a categorical variable. (Some of the few studies treating bilingualism/multilingualism as a continuous variable include Bialystok & Barac, 2012; Boumeester, Michel & Fyndanis, 2019; Chung-Fat-Yim, Sorge & Bialystok, 2020; and Sorge, Toplak & Bialystok, 2017).

In this line of research, less attention has been paid to the effect of bilingualism/multilingualism on short-term memory (STM) capacity and working memory (WM) capacity. STM is the capacity for storing, but not manipulating, a small amount of items in mind for a short period of time (seconds), whereas WM is the capacity for storing AND MANIPULATING a small amount of items for a short period of time (e.g., Baddeley, 1992). It should be noted that STM and WM are closely related to EFs (e.g., Baddeley & Hitch, 1974; Engle, 2002; McCabe, Roediger, McDaniel, Balota & Hambrick, 2010).

A recent comprehensive meta-analysis by Grundy and Timmer (2017), which was based on 88 effect sizes, 27 independent studies, and 2901 participants, provided evidence that bilinguals have a greater STM/WM capacity than monolinguals, reporting a significant small to medium population effect size of 0.20. Larger effects were found in children than in young adults and older adults. Grundy and Timmer (2017) also found that bilingualism enhances both verbal and nonverbal STM/WM capacity, as moderator analyses revealed no significant effect of STM/WM task type (verbal, nonverbal). Lastly, when bilinguals completed the STM/WM task in their first language (L1), the effect size was much larger than when they completed the STM/WM task in their second language (L2). It should be noted that, in their meta-analysis, Grundy and Timmer (2017) did not distinguish between STM and WM, but used the term WM to refer to both WM and STM. Thus, studies focusing on STM and/or WM were included in the same analysis, without distinguishing between "STM studies" and "WM studies". Hence, based on this meta-analysis one cannot confidently conclude that bilingualism confers a cognitive advantage in BOTH STM and WM.

In a recent well-controlled study, Antón, Carreiras, and Duñabeitia (2019) investigated the impact of bilingualism on verbal and nonverbal EFs, and on verbal and nonverbal STM and WM capacity. They tested a large monolingual (Spanish) group of young adults (n = 90) and a large bilingual (Basque-Spanish) group of young adults (n = 90). The study provided evidence for a bilingual advantage in verbal and nonverbal WM capacity only. They argued that, since WM is closely related to EFs (e.g., Engle, 2002), the bilingual advantage in EFs reported in previous studies may be driven by a primary bilingual advantage in WM. This view, which was also supported by bootstrapping analyses carried out by Antón et al. (2019), is in line with previous studies (e.g., Namazi & Thordardottir, 2010). As Antón et al. (2019) pointed out, since WM is involved in the management of languages that constantly compete for selection (e.g., Thorn & Gathercole, 1999), it is safe to assume that this training enhances bilinguals' WM capacity (e.g., Morales, Calvo & Bialystok, 2013). Moreover, the authors argued that the WM resources that are critically involved in the resolution of the competition between two or more languages are domain-general, as they detected a bilingual advantage in both verbal and nonverbal WM tasks. Further, Antón et al. (2019) adopted the view that, in WM, MAINTENANCE, PROCESSING and RETRIEVAL are domain-general processes, whereas ENCODING involves both domain-specific and domain-general processes (see Li, Christ & Cowan, 2014). Lastly, following Li et al. (2014) and based on findings reported in Morales et al. (2013) and Blom, Küntay, Messer, Verhagen and Leseman (2014), Antón et al. (2019) claimed that only demanding complex span tasks (such as the digit backward span task) tap into domain-general WM resources. They argued that simple span tasks such as the digit forward span task only tap into domain-specific resources.

Nevertheless, at least according to the widely accepted and influential model of WM developed by Baddeley and Hitch (1974; see also Baddeley, 1992), STM is part of WM in that the latter consists of storage and processing components, and the former constitutes the storage component of WM. Even if Antón et al. (2019) are correct in assuming that only encoding involves domain-specific processes (in addition to domain-general processes), it is clear that STM involves not only encoding processes, but also maintenance and retrieval processes. On the other hand, WM subserves all three processes (i.e., encoding, maintenance and retrieval processes) plus computational processes. Thus, it appears logical to assume that both WM and STM involve both domain-specific and domain-general processes/resources. In other words, not only complex span tasks (measuring WM), but also simple span tasks (measuring STM) tap into both domain-specific and domain-general resources (for a similar view, see Kane, Conway, Hambrick & Engle, 2008). Consistent with this, it has been found that STM is critically involved in word retrieval and between- and within-language competition resolution (e.g., Kaushanskaya, Blumenfeld & Marian, 2011).

It should be noted that not all studies on the effect of bilingualism on WM capacity reported evidence for a bilingual advantage in WM. For example, Lehtonen et al.'s (2018) meta-analytic review found no evidence for a bilingual advantage in STM/WM after correcting estimates for publication bias. Moreover, in an online sample of 485 participants, Lukasik, Lehtonen, Soveri, Waris, Jylkkä, and Laine (2018) investigated the impact of different types of bilingualism (early vs. late bilingualism) on verbal and visuospatial WM performance, and did not find evidence for a bilingual advantage in either verbal WM or visuospatial WM. They only found some evidence for an advantage of late bilinguals over early bilinguals and monolinguals on n-back tasks, which however tap more into updating and attentional switching than into WM (e.g., Gajewski, Hanisch, Falkenstein, Thönes & Wascher, 2018). It has also been suggested that the n-back tasks "may be a more appropriate indicator of the construct measured by STMC, rather than by WMC tasks" (Conway, Kane, Bunting, Hambrick, Wilhelm & Engle, 2005, p. 780).

1.1. The present study

The present study investigates whether sequential bilingualism/multilingualism has a positive effect on the verbal STM and verbal WM capacity of neurotypical middle-aged and older individuals who are of the same immigration status and of similar socio-economic status and educational level. In this study bilingualism/multilingualism is treated as a continuous variable. We hypothesize that since both verbal STM and verbal WM involve domain-general resources (as they both involve maintenance and retrieval processes), the higher the degree of bilingualism/multilingualism, the greater the verbal STM capacity and the verbal WM capacity should be. Moreover, since word retrieval and between- and within-language competition resolution relies on STM (e.g., Kaushanskaya et al., 2011), and since STM is part of WM (e.g., Baddeley, 1992), we predict that there will be associations of similar magnitude between degree of bilingualism/multilingualism and verbal STM capacity and between degree of bilingualism/multilingualism and verbal WM capacity.

We also explore which aspects of the bilingual/multilingual experience drive the putative bilingual advantage in STM/WM. In particular, we address whether use-related or proficiency-related aspects of bilingualism/multilingualism contribute to the bilingual advantage the most, and investigate whether it is only the speaking modality that matters or other modalities (i.e., listening, writing, reading) also play a role. To anticipate a relevant aspect of the design, the following bilingualism/multilingualism-related measures were used in the current study:

1. Number of Foreign Languages Known
2. Cumulative Amount of Use of Foreign Languages in Speaking
3. Cumulative Amount of Use of Foreign Languages in Listening
4. Cumulative Amount of Use of Foreign Languages in Writing
5. Cumulative Amount of Use of Foreign Languages in Reading
6. Cumulative Foreign Language Proficiency in Speaking
7. Cumulative Foreign Language Proficiency in Listening
8. Cumulative Foreign Language Proficiency in Writing
9. Cumulative Foreign Language Proficiency in Reading
10. Age of Acquisition (AoA) of first foreign language/L2
11. Cumulative Language Switching/Mixing

We predict that a bilingual advantage in STM/WM is predominantly driven by bilingual/multilingual experiences in speaking and listening rather than in writing and reading comprehension. This prediction is based on the assumption that, although all four modalities require cognitive control to some extent (as both languages of bilinguals are activated not only in speaking and writing, but also in reading and listening – see, for example, Van Heuven, Schriefers, Dijkstra & Hagoort, 2008), speaking and listening are more demanding than writing and reading comprehension in terms of STM/WM resources as stricter time constraints

https://doi.org/10.1017/S1366728922000621

apply to the former modalities than to the latter ones. For instance, when reading a conversation in a novel, the reader has the option to make regressive eye movements to earlier portions of the current sentence or paragraph. These regressive eye movements indicate processing strategies that may compensate for limited STM/WM resources. In contrast, when listening to a real-time conversation, one cannot go back in speech and check what exactly was said three seconds ago. Listening to real-time speech, therefore, appears to load on STM/WM more than reading comprehension does. Similarly, although self-corrections and rewordings take place in both speaking and writing, they are more common and extensive in writing. Presumably this is partly due to the fact that the written modality counteracts writers' STM/WM limitations, thus allowing them to better monitor and evaluate what they have written and to realize what they could have written in a better way.[3] Finally, since written (and oral) production involve(s) a cross-language conflict between responses at the output level, which is not the case with reading, and since conflict monitoring and interference suppression (among other cognitive control processes) are subserved by WM (Green & Abutalebi, 2013), one would expect writing in two or more languages to enhance STM/WM capacity more than reading in two or more languages.

It should be noted that the predictions above are only partly based on the existing evidence on the role of STM/WM in language processing. STM/WM capacity has been found to affect off-line sentence comprehension in both the listening/auditory and written modalities (see Varkanitsa & Caplan, 2018, and references therein). Most of the evidence about the relationship between STM/WM and off-line language comprehension comes from sentence-picture matching tasks (for a recent systematic review on this topic, see Varkanitsa & Caplan, 2018), in which experimental sentences are presented either visually (e.g., Caspari, Parkinson, LaPointe & Katz, 1998) or auditorily (e.g., Martin, 1987; Wright, Downey, Gravier, Love & Shapiro, 2007). Evidence for a role of verbal STM/WM in off-line sentence comprehension has also been provided by self-paced listening experiments and self-paced reading experiments (e.g., Caplan, DeDe, Waters, Michaud & Tripodis, 2011; Caplan, Michaud & Hufford, 2013; Sung, McNeil, Pratt, Dickey, Hula & Szuminsky, 2009), involving end-of-sentence tasks such as answering questions testing off-line sentence comprehension or plausibility judgment, or choosing between two pictures the one that best matches the sentence. This end-of-sentence task involves "post-interpretive processing" in Caplan and Waters' (1999) terms. There is evidence that STM/WM capacity also affects off-line paragraph comprehension (e.g., Waters & Caplan, 2005). To the best of our knowledge, however, to date no study has addressed whether stimulus presentation modality (e.g., auditory vs. visual presentation) modulates the relationship between STM/WM and off-line language comprehension; that is, no study has addressed this question by directly contrasting the listening and reading modalities. To investigate in an ecologically valid manner whether the relationship between verbal STM/WM and off-line sentence comprehension is modulated by the modality of stimulus presentation, the critical feature of the design should be the differential accessibility of visually presented vs. auditorily presented experimental sentences. For example, in designs involving experimental sentences and questions probing off-line sentence comprehension, the written experimental sentences should remain on the screen during the presentation of the probe questions; in contrast, the auditorily presented experimental sentences should precede the probe questions. Since only the written modality would allow the participant uninterrupted access to the experimental sentence, the listening modality should pose more demands on the participant's verbal STM/WM system compared to the written modality. In such a design, therefore, we would expect a stronger association to emerge between verbal STM/WM capacity and off-line sentence comprehension in the auditory stimulus presentation condition than in the written stimulus presentation condition.

2. Methods

2.1. Participants

One hundred participants were recruited via invitations sent (via email) to professors and researchers working at universities and research centers in the Oslo metropolitan area. However, only 82 met the inclusion criteria, which were the following: (1) native speakers of Norwegian, with Norwegian being their only L1; (2) active academics or researchers working at universities and/or research centers in the metropolitan area of Oslo; (3) aged between 54–70; (4) sequential bilinguals/multilinguals who started learning their first foreign language after the age of 5; (5) free of medical conditions which could affect cognitive performance (e.g., depression, neurological diseases); and (6) no immigration background. The total consisted of 29 (35.4%) women, and 53 (64.6%) men. Seventy-seven (93.9%) of the participants were PhD holders, while 5 (6.1%) held a high level of education below PhD (MA or similar). There were 58 (70.7%) full professors, 8 (9.8%) associate professors, 14 (17.1%) researchers and 2 (2.4%) dentist instructors. The total number of years of formal education (from 1st grade to completed highest university degree) for each participant ranged from 17 to 29 (mean = 21.6, SD = 2.5), meaning that all had had at least five years of higher education. Moreover, they started learning their first foreign language between the ages of 5 and 15 (mean = 10.1; SD = 1.9). Hence, all participants were sequential bilinguals or multilinguals.

This group of participants was chosen in order to control for several of the confounding factors associated with the bilingual advantage: firstly, choosing to test participants of a higher age was due to the many studies showing a more pronounced effect in children and older adults (e.g., Bialystok, Poarch, Luo & Craik, 2014). Secondly, the participants were similar in terms of socioeconomic status, education length, and cognitive complexity of occupation. All these factors have been shown to influence performance on cognitive tasks (see, for example, Kavé, Eyal, Shorek & Cohen-Mansfield, 2008; Valian, 2015). Similarly, it was ensured that all participants were actively working (i.e., not retired), as retirement for many, particularly in cognitively demanding jobs, would mean losing an important contributor to cognitive maintenance, possibly leading to a more rapid cognitive decline (although it is possible to minimize the effect of retirement by taking up leisure activities and staying socially active, cf. Valian, 2015). Finally, all participants were born and raised in Norway; therefore, none of them had an immigration background. As shown in Table 1, participants varied in terms of how many languages they knew and the rate of use and degree of proficiency in the respective languages. The study was approved by the Norwegian Centre for Research Data, and all participants gave informed consent in accordance with the Declaration of Helsinki.

https://doi.org/10.1017/S1366728922000621

Table 1. Descriptive statistics

	Mean (SD)	Min	Max
Multilingualism-related variables			
Number of Foreign Languages Known	3.5 (1.2)	1	6
Speaking – Cumulative Amount of Use of Foreign Languages	21.6% (13.4%)	0%	60%
Writing – Cumulative Amount of Use of Foreign Languages	42.9% (24.2%)	0%	90%
Listening – Cumulative Amount of Use of Foreign Languages	28.4% (15.5%)	0%	70%
Reading – Cumulative Amount of Use of Foreign Languages	45% (20.7%)	0%	90%
Speaking – Cumulative Foreign Language Proficiency	15.2 (7.4)	6	35
Writing – Cumulative Foreign Language Proficiency	13.6 (5.9)	5	33
Listening – Cumulative Foreign Language Proficiency	18.9 (9.2)	7	46
Reading – Cumulative Foreign Language Proficiency	20.3 (10.0)	7	46
AoA of first foreign language/L2	10.1 (1.9)	5	15
Composite Language Switching/Mixing Score	8.7 (7.8)	0	40
Other relevant variables			
Age	61.4 (4.3)	54	70
Years of formal education	21.6 (2.5)	17	29
Nonverbal Fluid Intelligence (Raven Progressive Matrices)	50.3 (6.0)	36	60
Physical Activity (weekly hours)	5.6 (4.0)	0	25
Playing Instruments (weekly hours)	0.6 (1.3)	0	6
Playing Video Games (weekly hours)	0.4 (1.4)	0	7
WM/STM measures			
% Verbal STM capacity	69 (14.5)	42.9	100
% Verbal WM capacity	69.9 (9.7)	44.1	96.4

2.2. Tasks and Procedure

Participants were tested in the facilities of the Center for Multilingualism in Society across the Lifespan (MultiLing) at the University of Oslo or in their offices. They were all administered the tasks and questionnaire described below in the same order, which mirrors the order of presentation below.

Addenbrooke's Cognitive Examination-Revised *(ACE-R; Mioshi, Dawson, Mitchell, Arnold & Hodges, 2006)*

Participants were screened for symptoms of dementia/mild cognitive impairment using a Norwegian version of ACE-R. The ACE-R measures performance in orientation, attention, memory, category and letter fluency, language and visuospatial abilities. No participants scored below the cut-off point (89 out of 100 points), meaning that none of them presented signs of dementia or mild cognitive impairment.

Comprehensive Questionnaire

Subsequently, participants filled out a Norwegian comprehensive questionnaire that was largely based on the Language and Social Background Questionnaire developed by Anderson, Mak, Keyvani Chahi, and Bialystok (2018). Participants self-reported their age, gender, education level, information regarding their linguistic repertoire, and information about their involvement in cognitively enriching activities and aspects of lifestyle such as playing computer games or musical instruments, and amount of physical exercise. Gaming, playing instruments and exercise/physical activity were reported in hours per week.

Participants were asked a series of questions about their language background, reporting the languages they knew, their AoA for all languages they knew, level of activity in each foreign language ranging from "daily (five days a week or more)" to "less than once a month", as well as proficiency and usage patterns in each foreign language.

Proficiency was (self-)rated for each language on a scale from 1-10 in the SPEAKING, WRITING, LISTENING and READING modalities. For each participant, a composite score for each language modality was computed based on the proficiency scores in all foreign languages. In particular, we determined the sum of self-rated proficiency by adding up the proficiency scores of all known foreign languages. For instance, a hypothetical participant might know Norwegian (L1), English (L2), and German (L3). Suppose that her self-rated proficiency in the speaking modality consisted of the following scores: Norwegian/L1 = 10; English/L2 = 9; and German/L3 = 7. This would result in a sum proficiency score for the speaking modality of L2 + L3 = 16. These composite scores were taken as estimates of the cumulative foreign language proficiency for each language modality for each participant, reflecting proficiency-based degrees of bilingualism/multilingualism (in each modality for each participant).

Participants were also asked to rate the proportional use of each of their languages in each modality, adding up to a score of 100% in each of the four modalities (e.g., Norwegian writing:

https://doi.org/10.1017/S1366728922000621

70%, English writing: 20%, French writing: 10%). For each participant, the percentage scores on all languages but Norwegian (L1) were then used to calculate composite (sum) scores for each modality. These scores were taken as estimates of cumulative amount of use of foreign languages in each language modality for each participant, reflecting amount of use-based degrees of bilingualism/multilingualism (in each modality for each participant).

Lastly, participants were asked to rate on a 10-point Likert scale how often they exhibited language switching ("code switching") or mixing in four interactional contexts (i.e., conversing with family, with friends, with colleagues or with people on social media). For each participant, a composite language switching/mixing score was computed based on their separate scores in the four interactional contexts.

Raven's Standard Progressive Matrices (RSPM; Raven, 1948)

Participants were also administered a computerized version of RSPM (Raven, 1948) to control for differences in nonverbal fluid intelligence and nonverbal abstract reasoning ability. RSPM consists of 60 items that are arranged in five sets. Each set includes 12 items, and each item consists of a picture with a missing piece, and of either six or eight possible pieces to complete the picture, which appear below the picture. The items within the sets and the sets are arranged in order of difficulty. Participants are given a score (1 or 0) for each correct answer, and the maximum number of correct answers is 60. Raven raw scores usually are converted into standardized scores based an age-based norming tables (e.g., Bialystok, Craik, Klein & Viswanathan, 2004; Chung-Fat-Yim et al., 2020; but see Mishra, Padmanabhuni, Bhandari, Viswambharan & Prasad, 2019). However, raw values were used in the present study, as normative data and conversion tables for RSPM do not exist in Norwegian (Helland-Riise & Martinussen, 2017).

STM/WM tasks

Participants were also administered Norwegian versions of the digit backward span task and the digit ordering span task, which both measure verbal WM capacity, and a Norwegian version of the digit forward span task, which measures verbal STM capacity (e.g., MacDonald, Almor, Henderson, Kempler & Andersen, 2001; Salis, Kelly & Code, 2015). In the digit backward span task, the participant hears a series of digits (e.g., 2, 8, 5, 4) and immediately reports them back in reverse order of presentation (4, 5, 8, 2). The version we used included seven levels of difficulty, which ranged from two to eight digits. Each level consisted of two (equal length) series of digits. In the digit ordering span task, the participant hears a series of digits (e.g., 2, 8, 5, 4) and immediately reports them back in ascending numerical order (2, 4, 5, 8). The version we used included five levels of difficulty, which ranged from two to six digits to order. Each level consisted of three (equal length) series of digits. In the digit forward span task, the participant hears a series of digits (e.g., 2, 8, 5, 4) and immediately reports them back in the same order of presentation (i.e., 2, 8, 5, 4). The version of this task we used included seven levels of difficulty, which ranged from two to eight digits. Each level consisted of two (equal length) series of digits. In each memory task, the score obtained was the number of correctly remembered sequences, not the number of digits one could handle (i.e., DIGIT SPAN). Each correct answer was given one point. If the participant correctly remembered only one series of one of the difficulty levels, we would give one point to this series and zero points to the other series of that level. The maximum score for the digit forward span task and the digit backward span task was 14 and the minimum score was 0. The maximum score for the digit ordering span task was 15 and the minimum score was 0. Moreover, following Waters and Caplan (2003), for each participant we computed a composite WM score taking into account their scores on the digit backward span task and digit ordering span task. Specifically, we converted the performance of each participant on the digit ordering span task (e.g., 13/15 correct) and the digit backwards span task (e.g., 7/14 correct) into percent correct performances (i.e., 86.7% and 50% correct, respectively), and subsequently we took the mean of the two percentages (i.e., 68.4% correct) as the composite score for the participant's verbal WM capacity. All participants completed the STM/WM tasks in their native (and dominant) language (i.e., Norwegian).

2.3. Data analysis

Statistical analyses were performed with R version 4.0.2 (R Core team, 2020) in RStudio version 1.3 (RStudio team, 2020), using the package ggplot2 (Wickham, 2016) for preparation of figures. We used both correlational and regression analyses. We first correlated STM and WM individual scores with bilingualism/multilingualism-related and other non-linguistic relevant variables (i.e., age, years of formal education, physical activity, nonverbal fluid intelligence, playing instruments, and playing video games). We employed Kendall correlation as it is considered to be more robust and efficient than Spearman correlation (Croux & Dehon, 2010). Since multiple correlations were performed (17 for STM and 17 for WM), we used Bonferroni correction and adjusted the alpha level to 0.002941.

Subsequently, we fitted maximal linear regression models predicting verbal STM capacity and verbal WM capacity from multilingualism-related and general background variables. The initial maximal regression models included all 17 predictor variables listed in Table 2. Subsequently, we calculated the variance inflation factor (VIF), which detects harmful multicollinearity in regression analyses. In both models, we first removed the variables with a VIF higher than 10 – that is, *Cumulative Foreign Language Proficiency in Listening* and *Cumulative Foreign Language Proficiency in Reading*. We then checked the VIFs of the variables included in the resulting models and excluded the variable whose VIF was higher than 5, that is, *Cumulative Foreign Language Proficiency in Speaking*. The resulting maximal regression models, therefore, included 14 variables each. In both models, the VIFs of the predictor variables were lower than 5, which is considered acceptable (e.g., Akinwande, Dikko & Samson, 2015).

Given our sample size (n=82), however, maximal models including 14 predictor variables are suboptimal. It has been suggested that one would need approximately 30 participants per predictor variable to ensure better power to detect small effect sizes (Van Voorhis & Morgan, 2007). Therefore, we also fitted minimal regression models – one for STM and one for WM – consisting of three factors each. The factors that entered the minimal models were those factors which yielded the three smallest p-values in the corresponding maximal models (see Table 3 and Table 5) – that is, *Number of Foreign Languages Known*, *Playing Instruments* and *Age* in the "STM model", *and Number of Foreign Languages Known*, *Cumulative Amount of Use of Foreign Languages in Writing* and (amount of) *Language Switching/Mixing* in the "WM model". Again, to reduce the risk of false positives due to

https://doi.org/10.1017/S1366728922000621

Table 2. Kendall correlations (tau values) between STM/WM and multilingualism-related and other variables.

	verbal STM	verbal WM
Multilingualism-related variables		
Number of Foreign Languages Known	0.308*	0.252*
Speaking – Cumulative Amount of Use of Foreign Languages	−0.092	−0.046
Writing – Cumulative Amount of Use of Foreign Languages	−0.114	−0.135
Listening – Cumulative Amount of Use of Foreign Languages	−0.096	−0.007
Reading – Cumulative Amount of Use of Foreign Languages	−0.045	−0.046
Speaking – Cumulative Foreign Language Proficiency	0.161	0.182
Writing – Cumulative Foreign Language Proficiency	0.089	0.077
Listening – Cumulative Foreign Language Proficiency	0.159	0.159
Reading – Cumulative Foreign Language Proficiency	0.143	0.151
AoA of First Foreign Language/L2	0.070	−0.031
Composite Language Switching/Mixing Score	−0.042	−0.059
Other relevant variables		
Nonverbal Fluid Intelligence (Raven Progressive Matrices)	0.157	0.132
Age	−0.157	−0.012
Physical Activity (weekly hours)	0.012	0.033
Education (years)	−0.001	−0.007
Playing Instruments (weekly hours)	0.220	0.072
Playing Video Games (weekly hours)	−0.184	−0.019

AoA = Age of Acquisition. The symbol * indicates significant correlations. The Bonferroni corrected *p*-value is 0.002941.

Table 3. Maximal linear regression model predicting verbal STM capacity from multilingualism-related and general background variables.

	Estimate	SE	t	*p*
(Intercept)	92.343	41.397	2.231	0.030*
Number of foreign languages	5.330	1.735	3.071	<0.01*
Writing – Cum. Foreign Lang. Prof.	−0.411	0.374	−1.098	0.277
Speaking – Cum. Use of Foreign Lang.	1.711	2.028	0.844	0.402
Writing – Cum. Use of Foreign Lang.	−0.986	0.925	−1.066	0.291
Listening – Cum. Use of Foreign Lang.	−0.534	1.767	−0.302	0.763
Reading – Cum. Use of Foreign Lang.	−0.451	1.191	−0.379	0.706
AoA of First Foreign Language/L2	−0.005	0.875	−0.006	0.995
Composite Lang. Switching/Mixing Score	−0.178	0.239	−0.744	0.460
Physical Activity (weekly hours)	−0.288	0.540	−0.533	0.596
Age	−0.611	0.438	−1.395	0.168
Education	0.009	0.687	0.014	0.989
Playing Instruments (weekly hours)	2.222	1.290	1.722	0.090
Playing Video Games (weekly hours)	−0.960	1.192	−0.806	0.424
Nonverbal Fluid Intelligence (RPM)	0.136	0.311	0.436	0.665

R^2 = 0.2996; Adjusted R^2 = 0.1334; F (14, 59) = 1.802; p-value = 0.060
Cum. Foreign Lang. Prof. = Cumulative Foreign Language Proficiency; Cum. Use of Foreign Lang. = Cumulative Amount of Use of Foreign Languages; AoA = Age of Acquisition; Lang. = Language; RPM = Raven Progressive Matrices
The symbol * indicates significant effects.

https://doi.org/10.1017/S1366728922000621

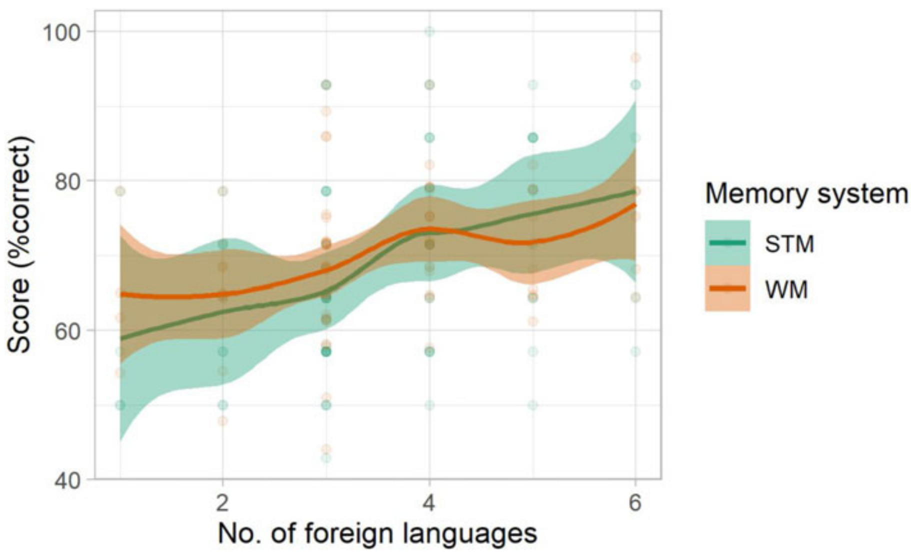

Figure 1. Relationship between number of foreign languages known and verbal STM/WM capacity.

coincidence, we applied Bonferroni correction to the minimal models, and adjusted the alpha level to 0.0166.

3. Results

Descriptive statistics for all measures are given in Table 1. The main findings from the correlational analysis are given in Table 2. The only significant correlations that emerged were those between number of foreign languages known and verbal STM capacity and verbal WM capacity. Specifically, number of foreign languages known was POSITIVELY correlated with verbal STM/WM capacity.

Results of the maximal regression model predicting verbal STM capacity from multilingualism-related and general background variables are presented in Table 3. This model was marginally significant, $F(14, 59) = 1.802$, $p = 0.060$, with $R^2 = 29.96\%$. *Number of Foreign Languages Known* was the only significant predictor of verbal STM capacity. The more languages the participants knew, the greater their STM capacity (see also Figure 1).

Results of the minimal regression model predicting verbal STM capacity from multilingualism-related and general background variables are presented in Table 4. This model was significant, $F(3, 72) = 7.152$, $p < 0.001$, with $R^2 = 22.96\%$. Consistent with the maximal model, and the correlational analysis of the three predictor variables included in this minimal model – namely, *Number of Foreign Languages Known*, *Playing Instruments* and *Age* – only the former had a significant effect on verbal STM capacity.

Table 4. Minimal linear regression model predicting verbal STM capacity from multilingualism-related and general background variables.

	Estimate	SE	t	*p*
(Intercept)	89.141	22.124	4.029	< 0.001*
Number of Foreign Languages	4.202	1.223	3.437	< 0.001*
Playing Instruments (weekly hours)	2.515	1.121	2.245	0.028
Age	−0.597	0.350	−1.708	0.092

*$R^2 = 0.2296$; Adjusted $R^2 = 0.1975$; $F(3, 72) = 7.152$; p-value < 0.001**
The Bonferroni corrected *p*-value is 0.0166. The symbol * indicates significant effects.

Results of the maximal regression model predicting verbal WM capacity from multilingualism-related and general background variables are presented in Table 5. Although this model did not reach significance ($F(14, 63) = 1.508$, $p = 0.134$, $R^2 = 25.1\%$), again *Number of Foreign Languages Known* was the only significant predictor of verbal WM capacity. Results of the minimal regression model predicting verbal WM capacity from multilingualism-related and general background variables are presented in Table 6. This model was significant, $F(3, 76) = 5.354$, $p < 0.01$, with $R^2 = 17.45\%$. Again, of the three predictor variables included in this minimal model, that is, *Number of Foreign Languages Known*, *Cumulative Amount of Use of Foreign Languages in Writing* and (amount of) *Language Switching/Mixing*, only the former had a significant effect on verbal WM capacity, which is in line with the results of the maximal regression model and the correlational analysis.

Plot matrices for the "verbal STM minimal linear regression model" and the "verbal WM minimal linear regression model" are presented in Figure 2 and Figure 3, respectively. These matrices consist of a histogram of residuals, a 'quantile-quantile' plot (Q-Q plot), and a 'residual plot'. The normality assumption is assessed based on the first two plots. The Q-Q plot is considered a better way to visually inspect the normality assumption (Winter, 2020). As stated by Winter (2020, p. 109), "(w)hen the sample quantiles in this plot assemble into a straight line, the residuals conform with the normal distribution". The constant variance assumption is assessed based on the 'residual plot', which plots the residuals against the fitted values (y-axis and x-axis, respectively). Visual inspection of quality diagnostics for the two minimal regression models described above yielded satisfactory results (see Figures 2–3), as both models showed normality of residuals and constant variance (a.k.a. homoscedasticity) of residuals. Hence, both fundamental assumptions of linear regression – namely, the normality assumption and the constant variance assumption – were met (e.g., Winter, 2020).

In sum, the correlational and regression analyses consistently showed that *Number of Foreign Languages Known* was the only significant predictor of both verbal STM capacity and verbal WM capacity. As indicated in Figure 1, the strongest effect is observed in the transition from those who know three foreign languages to those who know four foreign languages.

https://doi.org/10.1017/S1366728922000621

Table 5. Maximal linear regression model predicting verbal WM capacity from multilingualism-related and general background variables.

	Estimate	SE	t	*p*
(Intercept)	59.126	25.646	2.305	0.024*
Number of Foreign Languages	3.545	1.192	2.973	<0.01*
Writing – Cum. Foreign Lang. Prof.	−0.336	0.274	−1.227	0.224
Speaking – Cum. Use of Foreign Lang.	0.756	1.302	0.581	0.564
Writing – Cum. Use of Foreign Lang.	−1.086	0.633	−1.717	0.091
Listening – Cum. Use of Foreign Lang.	0.819	1.126	0.727	0.470
Reading – Cum. Use of Foreign Lang.	−0.251	0.829	−0.303	0.763
AoA of first foreign language/L2	−0.559	0.608	−0.919	0.361
Composite Lang. Switching/Mixing Score	−0.199	0.159	−1.253	0.215
Physical Activity (weekly hours)	−0.167	0.360	−0.463	0.645
Age	0.114	0.282	0.404	0.687
Education	−0.229	0.460	−0.497	0.621
Playing Instruments (weekly hours)	0.075	0.886	0.085	0.933
Playing Video Games (weekly hours)	−0.320	0.830	−0.386	0.701
Nonverbal Fluid Intelligence (RPM)	0.219	0.194	1.128	0.264

R^2 = 0.251; Adjusted R^2 = 0.0846; F (14, 63) = 1.508; p-value = 0.134
Cum. Foreign Lang. Prof. = Cumulative Foreign Language Proficiency; Cum. Use of Foreign Lang. = Cumulative Amount of Use of Foreign Languages; AoA = Age of Acquisition; Lang. = Language; RPM = Raven Progressive Matrices
The symbol * indicates significant effects.

4. Discussion

This study investigated the impact of bilingualism/multilingualism on verbal STM capacity and verbal WM capacity, focusing on a sample of 82 neurologically healthy middle-aged and older bilinguals/multilinguals who were of the same socioeconomic and immigration status (i.e., non-immigrants), of the same bilingualism/multilingualism status (i.e., sequential bilinguals/multilinguals), and of similar educational level. We treated bilingualism/ multilingualism as a continuous variable and considered both proficiency-based and amount-of-use-based dimensions of bilingualism/multilingualism in all four modalities (i.e., speaking, listening, writing, and reading). Moreover, we controlled for potentially relevant "external" factors such as age, years of formal education, physical activity, nonverbal fluid intelligence, playing instruments, and playing video games. Since both verbal STM and verbal WM involve domain-general resources (as they both involve maintenance and retrieval processes), we expected to find a significant beneficial effect of bilingualism/multilingualism on both verbal STM and verbal WM capacity. That is, we hypothesized that the higher the degree of bilingualism/multilingualism, the greater the verbal STM capacity and the verbal WM capacity should be.

Although this study focused on high-achieving individuals (i.e., academics), which could have made it hard to detect a beneficial effect of bilingualism/multilingualism on STM/WM capacity (for a discussion of similar concerns, see Bialystok et al., 2014), we did find that multilingualism confers a cognitive advantage in STM/WM. Specifically, number of known foreign languages was found to be the strongest predictor of verbal STM capacity and verbal WM capacity. The more languages a participant knew, the greater their verbal STM capacity and verbal WM capacity was. This finding is not surprising. The larger the number of languages, the larger their combined vocabulary size and, thus, the greater the reliance on STM for word retrieval and between- and within-language competition resolution (Kaushanskaya et al., 2011). Therefore, since STM is part of WM (constituting its storage component), not only STM but also WM is critically involved in lexical retrieval and in between- and within-language competition resolution. However, if this explanation alone were to account for the main effects of number of foreign languages known on STM and WM capacity, one should also explain why there were no significant effects of cumulative foreign language proficiency on STM and WM capacity. First of all, it should be noted that there were strong, positive and significant correlations between number of foreign languages known and cumulative foreign language proficiency in speaking, listening and reading (tau = 0.59, p < 0.001; tau = 0.63, p < 0.001; tau = 0.62, p < 0.001, respectively), which was reflected in unacceptable VIFs for these three proficiency-related measures of multilingualism. As mentioned in sections 2.3 and 3, to address this multicollinearity issue, we excluded these variables from the maximal regression

Table 6. Minimal linear regression model predicting verbal WM capacity from multilingualism related and general background variables.

	Estimate	SE	t	*p*
(Intercept)	65.283	3.676	17.760	<0.001*
Number of Foreign Languages	2.777	0.839	3.312	0.001*
Writing – Cum. Use of Foreign Lang.	−0.855	0.425	−2.012	0.048
Composite Lang. Switching/Mixing Score	−0.157	0.132	−1.190	0.238

*R^2 = 0.1745; Adjusted R^2 = 0.1419; F (3, 76) = 5.354; p = 0.002**
Cum. Use of Foreign Lang. = Cumulative Amount of Use of Foreign Languages.
The Bonferroni corrected *p*-value is 0.0166. The symbol * indicates significant effects.

https://doi.org/10.1017/S1366728922000621

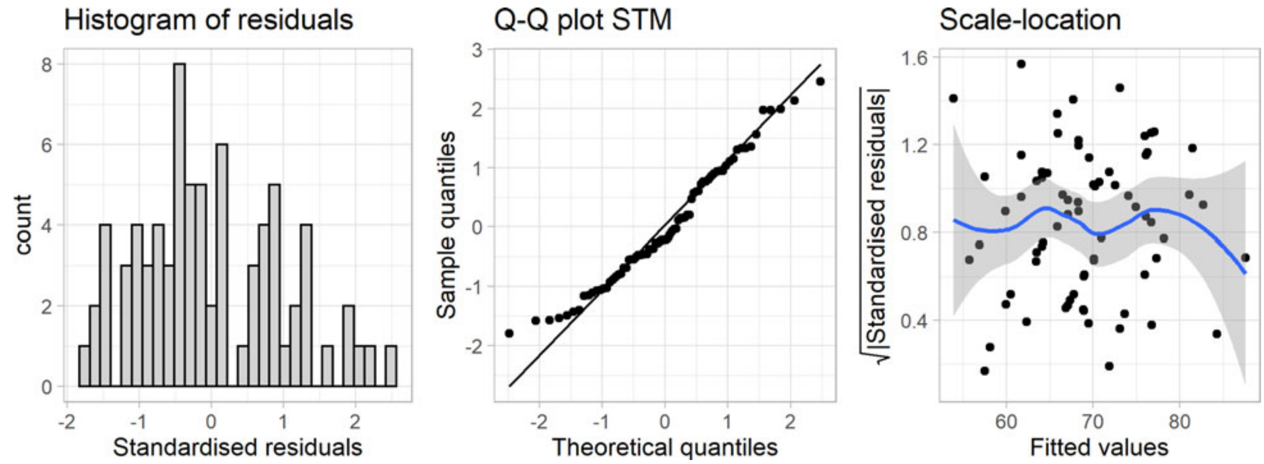

Figure 2. Plot matrix for the "verbal STM minimal linear regression model", consisting of (from left to right) a histogram of residuals, a Q-Q plot, and a residual plot.

models predicting verbal STM/WM capacity from bilingualism/multilingualism-related and general background variables. Thus, the variable *number of foreign languages known* may largely "incorporate" the variables *cumulative foreign language proficiency in speaking, cumulative foreign language proficiency in listening*, and *cumulative foreign language proficiency in reading*. However, these variables do not overlap fully, and thus a better (and more complete) account of the present results is warranted. In our view, the positive impact of number of foreign languages known on verbal STM capacity and verbal WM capacity could be attributed to the synergistic effect of two facts: (1) as described above, the larger the number of languages, the larger their combined vocabulary size and, thus, the greater the reliance on STM/WM for word retrieval and between- and within-language competition resolution (e.g., Kaushanskaya et al., 2011); and (2) language learning per se is a cognitively stimulating activity that leads to cognitive improvement, enhancing verbal WM (Wong, Ou, Pang, Zhang, Tse, Lam & Antoniou, 2019) and EFs (e.g., Bak, Long, Vega-Mendoza & Sorace, 2016).

The present results are also consistent with Kavé et al. (2008), who tested 814 older Israeli Jewish individuals (M age = 83.0 years) and found that the larger the number of languages spoken, the better the cognitive state of the participants. Furthermore, in line with our results, Kavé et al. found that this multilingualism-related variable was a stronger predictor of cognitive performance than demographic factors such as age and education.

Moreover, while the present results are at odds with the findings reported in Lehtonen et al. (2018) and Lukasik et al. (2018), they are consistent with Grundy and Timmer's (2017) finding that bilingualism confers an advantage in (both nonverbal and) verbal STM/WM capacity. The present study extends this finding to multilingualism. In their meta-analysis, Grundy and Timmer (2017) focused on studies comparing monolinguals with bilinguals. In our study, there were no monolinguals, and we treated multilingualism as a continuous variable to address whether higher degrees of multilingualism are associated with greater verbal STM and WM capacities. The answer to this question is positive.

Furthermore, results are partly consistent with Antón et al.'s (2019) findings. We found evidence for a beneficial impact of multilingualism on participants' performance on demanding complex span tasks tapping into WM, which is consistent with Antón et al.'s findings, but we also found that multilingualism positively impacts STM as well (tapped by "simple" span tasks such as the digit forward span task), which is contra Antón et al. (2019). This finding is consistent with the idea that both verbal STM and verbal WM share domain-general resources, that is, resources for maintenance and retrieval.

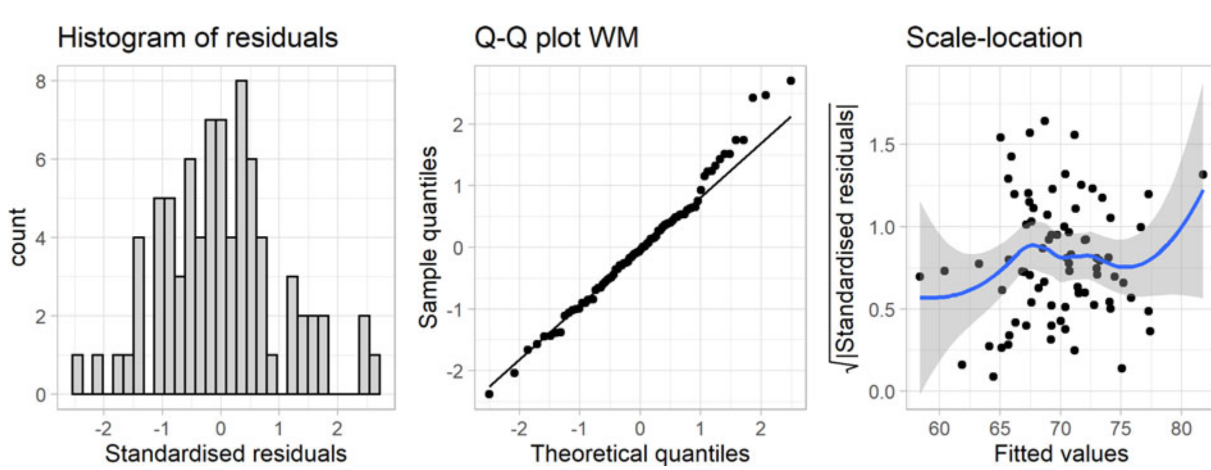

Figure 3. Plot matrix for the "verbal WM minimal linear regression model", consisting of (from left to right) a histogram of residuals, a Q-Q plot, and a residual plot.

https://doi.org/10.1017/S1366728922000621

One could call into question our interpretation of the present results by assuming that it was the greater STM and WM capacity of some participants that made them learn several languages. There is evidence that phonological STM is involved in foreign language vocabulary learning (e.g., Masoura & Gathercole, 1999; Papagno, Valentine & Baddeley, 1991). Thus, verbal STM contributes to the aptitude for learning foreign languages, and it is logical to assume that the higher someone's aptitude for learning foreign languages, the more languages they learn. This possibility is related to the reverse causality problem. Individuals who learn foreign languages later in life might have different baseline characteristics from those who do not. In other words, it might not be multilingualism that leads to a greater verbal STM and WM capacity in later life; instead, it could be that original cognitive differences lead to multilingualism (see Bak, 2016, pp. 212-213). However, the relationship between multilingualism and STM/WM may be bi-directional (Grundy & Timmer, 2017). Moreover, in a study that investigated the relationship between bilingualism and cognitive performance while addressing the reversed causality issue (Bak, Nissan, Allerhand & Deary, 2014), bilinguals outperformed monolinguals even when correcting for baseline differences in cognitive abilities, meaning that it is bilingualism that leads to a cognitive advantage and not the opposite. Also, consistent with this is some recent evidence that foreign language learning enhances cognitive abilities (e.g., Bak et al., 2016) including WM (Wong et al., 2019). These findings enable establishing a causal relationship between learning foreign languages and cognitive functions.

One could argue that the present findings are also consistent with Bialystok's (2017) and Comishen and Bialystok's (2021) view that executive attention or attentional control is the mechanism that underlies the bilingual advantage. Following Cowan (1995), Kane et al. (2008, p. 44) "view WM as an integrated memory and attention system". Furthermore, they argue that "WM span tasks measure, in part, executive attention processes that […] are domain-general and contribute to WM span performance irrespective of the skills or the stimuli involved. […] WM span tasks reflect primarily general executive processes and secondarily domain-specific rehearsal and storage processes. […] WMC variation is driven largely by individual differences in executive attention processes" (Kane et al., 2008, p. 24). Lastly, Kane et al. (2008) maintain that span tasks "cannot be dichotomized as reflecting either STM or WMC, or either storage or executive control, because all immediate memory tasks are complex and determined by a host of factors, including both storage and executive attention" (p. 38). In other words, adopting Kane et al.'s (2008) view of WM, the present results may be interpreted as suggesting that multilingualism confers an advantage in either executive attention or memory, or in both of them.

As far as the relationship between bilingualism, WM, and cognitive control is concerned, while it has been suggested that different interactional contexts (e.g., single-language context, dual-language context, dense code-switching context) which bilinguals/multilinguals engage in differentially recruit and train cognitive control processes (Adaptive Control hypothesis; Green & Abutalebi, 2013), little is known about the impact of such contexts on bilinguals'/multilinguals' STM/WM capacity. Although Green and Abutalebi (2013) postulated that "cognitive control processes select competing representations in working memory as individuals seek to achieve their intended goals" (p. 517), they did not expect – at least, not state explicitly – any interactional context to confer a bilingual advantage in WM. Since dual-language contexts recruit more cognitive control processes compared to single-language and dense code-switching contexts (Green & Abutalebi, 2013), and given the link between cognitive control processes and WM suggested by Green and Abutalebi, one would expect dual-language contexts to enhance WM capacity more than single-language and dense code-switching contexts. However, in Hartanto and Yang's (2020) study, which explored the impact of different interactional contexts (as described in Green & Abutalebi, 2013) on inhibitory control, task switching and WM, no effect of any interactional context on bilingual participants' WM capacity emerged.[4] The relationship between interactional contexts and STM/WM should be further investigated in future research. Finally, it should be noted that, since in real life dual-language contexts are presumably more common for the speaking and listening modalities than for the writing and reading modalities, it may be challenging to tease apart the contributions of interactional context and modality.

On a final note, as shown in Table 4 and Table 6, the variance in participants' verbal STM/WM capacity explained by the three factors included in the two minimal regression models ranges from 17.5% to 23%. Therefore, only a small percentage of the variance in STM/WM capacity is explained by these models. Unsurprisingly, when more variables enter the regression models (see Table 3 and Table 5) more variance is explained (25.1% – 30%), but still most of the variance in participants' verbal STM/WM remains unexplained. This is not surprising as there are several different sources of variation in STM/WM capacity in neurologically healthy participants, and only some of them were taken into account in the present study. It is well established, for example, that inter-individual variation in STM/WM capacity is partly due to individual differences in genetic factors (e.g., Wang & Saudino, 2013). Furthermore, some aspects of lifestyle and personality traits known to affect cognitive performance, such as sleep quality and quantity (e.g., Astill, Van der Heijden, Van Ijzendoorn & Van Someren, 2012), diet (Anastasiou, Yannakoulia, Kosmidis, Dardiotis, Hadjigeorgiou, Sakka, Arampatzi, Bougea, Labropoulos & Scarmeas, 2017) and introversion vs. extroversion (Campbell, Davalos, McCabe & Troup, 2011) were not considered in the current study. It has also been argued that variation in STM/WM capacity in neurotypical adults may reflect individual differences in executive attention (Kane et al., 2008), attentional inhibition (Hasher, Lustig & Zacks, 2008), speed of processing (e.g., Hale, Myerson, Emery, Lawrence & DuFault, 2008), capacity to simultaneously bind independent chunks (e.g., Oberauer, Süß, Wilhelm & Sander, 2008), and ability to engage proactive control or efficiently move from proactive to reactive control, and vice versa (Braver, Gray & Burgess, 2008).

To conclude, the present well-controlled study reports evidence that multilingualism enhances verbal STM/WM capacity. Treating bilingualism/multilingualism as a continuous variable, and not including monolingual participants at all, the study showed that higher degrees of multilingualism (as reflected in the number of foreign languages one knows) are associated with greater verbal STM and WM capacities. Hence, this study extended earlier findings that bilingualism enhances verbal STM/WM capacity (e.g., Grundy & Timmer, 2017) to multilingualism. Finally, following Kane et al.'s (2008) approach to WM as a combined system of memory and attention, the present results are potentially consistent with Bialystok's (2017) and Comishen and Bialystok's (2021) suggestion that executive attention or attentional control is the mechanism underlying the bilingual advantage.

https://doi.org/10.1017/S1366728922000621

Acknowledgements. Many thanks go to the participants, as well as to Ane Theimann, Nina Hagen Kaldhol and Christina Davril for contributing to participant recruitment, data collection and data transcription. Moreover, we thank David Caplan, Thomas Bak, Marianne Lind, Minna Lehtonen and Jussi Jylkkä for discussing with us aspects of the design or issues related to the motivation for the predictions of the study, Charalambos Themistocleous for performing preliminary analyses of previous versions of the dataset connected to this work, and Ellen Bialystok for kindly providing us with the Language and Social Background Questionnaire before Anderson et al.'s (2018) article was published. Additionally, many thanks go to the audiences of the *10th Annual Meeting of the Society for the Neurobiology of Language* (16-18 August 2018, Québec City, Canada) and several other events or meetings in which previous versions of this work were presented (i.e., *LingLab Webinars* organized by the Department of Linguistics, School of Philology, Aristotle University of Thessaloniki (23 April 2021, Thessaloniki, Greece), and events/meetings at the CNRS Laboratory *Structures Formelles du Langage* / University Paris 8 (4 June 2018, Paris, France), at the Department of Linguistics, University of Lille 3 (4 May 2018, Lille, France), and at Oslo Metropolitan University (23 April 2018, Oslo, Norway)). Finally, we are grateful to John A. E. Anderson and an anonymous reviewer for their critical comments and suggestions on how to improve earlier drafts of this paper. This research has been supported by the Research Council of Norway through its Centers of Excellence funding scheme (project number 223265).

Data availability statement. The data that support the findings of this study are openly available as supplementary material published together with this paper.

Competing interests declaration. The authors declare none.

Supplementary material. For supplementary material accompanying this paper, visit http://doi.org/10.1017/S1366728922000621

Notes

1 Here *bilingualism* is defined as a person's knowledge of two languages, whereas *multilingualism* refers to a person's knowledge of more than two languages.
2 The evidence for a bilingual advantage in adults' and children's cognitive abilities heavily relies on the speaking modality, which is due to the assumption that speaking is executively more demanding than listening. However, theories of bilingual language control such as the Adaptive Control hypothesis (Green & Abutalebi, 2013) do not rule out the possibility that also listening to two languages may confer advantages in EFs. Green and Abutalebi (2013, pp. 516) recognized that "comprehension processes in bilingual speakers are relevant to the adaptive response. They may tune the system to detect critical features that discriminate one language from another (Krizman, Marian, Shook, Shoe & Kraus, 2012; Kuipers & Thierry, 2010) and adapt processes that control interference between competing word meanings (e.g., Macizo, Bajo & Martin, 2010)". This is consistent with the evidence from bilingual infants and toddlers (Kovács & Mehler, 2009; Pons et al., 2015; Poulin-Dubois et al., 2011; Singh et al., 2015). More research is needed, however, on the impact of listening to two or more languages on adults' and children's cognitive abilities. If the new findings from bilingual adults and children align with the findings from bilingual infants and toddlers, the current models of bilingual language control should be expanded to cover the listening modality as well.
3 Different predictions could be made about the language modality that matters the most when it comes to possible bilingual advantages in self-monitoring. Specifically, one would expect writing in two or more languages to enhance self-monitoring more than speaking in two or more languages, as the former provides opportunities for more self-monitoring than the latter. Testing this hypothesis is beyond the scope of the present study. It is important to note, however, that language modalities may interact with cognitive abilities as different modalities seem to differentially recruit and engage cognitive capacities such as verbal STM/WM and self-monitoring.
4 Note that, although Hartanto and Yang (2020) claimed that the WM tasks they used – rotation span task, operation span task, and symmetry span task – tapped into updating, these tasks primarily measure WM capacity, not updating (see Foster Shipstead, Harrison, Hicks, Redick & Engle, 2015).

References

Akinwande MO, Dikko HG and Samson A (2015) Variance inflation factor: As a condition for the inclusion of suppressor variable(s) in regression analysis. *Open Journal of Statistics* **5**, 754–767. https://doi.org/10.4236/ojs.2015.57075
Alladi S, Bak TH, Duggirala V, Surampudi B, Shailaja M, Shukla AK, Chaudhuri JR and Kaul S (2013) Bilingualism delays age at onset of dementia, independent of education and immigration status. *Neurology* **81**(22), 1938–1944. https://doi.org/10.1212/01.wnl.0000436620.33155.a4
Anastasiou CA, Yannakoulia M, Kosmidis MH, Dardiotis E, Hadjigeorgiou GM, Sakka P, Arampatzi X, Bougea A, Labropoulos I and Scarmeas N (2017) Mediterranean diet and cognitive health: Initial results from the Hellenic Longitudinal Investigation of Ageing and Diet. *PLoS One* **12**(8): e0182048. https://doi.org/10.1371/journal.pone.0182048
Anderson JAE, Mak L, Keyvani Chahi A and Bialystok E (2018) The language and social background questionnaire: Assessing degree of bilingualism in a diverse population. *Behavior Research Methods* **50**, 250–263. https://doi.org/10.3758/s13428-017-0867-9
Antón E, Carreiras M and Duñabeitia J. A (2019) The impact of bilingualism on executive functions and working memory in young adults. *PLoS ONE* **14** (2): e0206770. https://doi.org/10.1371/journal.pone.0206770
Astill RG, Van der Heijden KB, Van Ijzendoorn MH and Van Someren EJW (2012) Sleep, cognition, and behavioral problems in school-age children: A century of research meta-analyzed. *Psychological Bulletin* **138**(6), 1109–1138. https://doi.org/10.1037/a0028204
Baddeley A. D (1992) Working memory. *Science* **255**(5044), 556–559. https://doi.org/10.1126/science.1736359
Baddeley AD and Hitch G (1974) Working Memory. *Psychology of Learning and Motivation* **8**, 47–89. http://dx.doi.org/10.1016/S0079-7421(08)60452-1
Bak T. H (2016) The impact of bilingualism on cognitive ageing and dementia: Finding a path through a forest of confounding variables. *Linguistic Approaches to Bilingualism* **6**(1–2), 205–226. https://doi.org/10.1075/lab.15002.bak
Bak TH, Long MR, Vega-Mendoza M and Sorace A (2016) Novelty, challenge, and practice: The impact of intensive language learning on attentional functions. *PLoS One* **11**(4), e0153485. https://doi.org/10.1371/journal.pone.0153485
Bak TH, Nissan JJ, Allerhand MM and Deary I. J (2014) Does bilingualism influence cognitive aging? *Annals of Neurology* **75**(6), 959–963. https://doi.org/10.1002/ana.24158
Bak TH, Vega-Mendoza M and Sorace A (2014) Never too late? Advantage on tests of auditory attention extends to late bilinguals. *Frontiers in Psychology* **5**, Article 485. https://doi.org/10.3389/fpsyg.2014.00485
Bialystok E (2009) Bilingualism: The good, the bad, and the indifferent. *Bilingualism: Language and Cognition* **12**(1), 3–11. https://doi.org/10.1017/S1366728908003477
Bialystok E (2017) The bilingual adaptation: How minds accommodate experience. *Psychological Bulletin* **143**(3), 233–262. https://doi.org/10.1037/bul0000099
Bialystok E and Barac R (2012) Emerging bilingualism: Dissociating advantages for metalinguistic awareness and executive control. *Cognition* **122** (1), 67–73. https://doi.org/10.1016/j.cognition.2011.08.003
Bialystok E, Craik FIM and Freedman M (2007) Bilingualism as a protection against the onset of symptoms of dementia. *Neuropsychologia* **45**(2), 459–464. https://doi.org/10.1016/j.neuropsychologia.2006.10.009
Bialystok E, Craik FIM, Klein R and Viswanathan M (2004) Bilingualism, aging, and cognitive control: Evidence from the Simon task. *Psychology and Aging* **19**(2), 290–303. https://doi.org/10.1037/0882-7974.19.2.290
Bialystok E, Poarch G, Luo L and Craik F. I (2014) Effects of bilingualism and aging on executive function and working memory. *Psychology and Aging* **29**(3), 696–705. https://doi.org/10.1037/a0037254
Blom E, Küntay AC, Messer M, Verhagen J and Leseman P (2014) The benefits of being bilingual: Working memory in bilingual Turkish–Dutch children. *Journal of Experimental Child Psychology* **128**, 105-119. https://doi.org/10.1016/j.jecp.2014.06.007

Boumeester M, Michel MC and Fyndanis V (2019) Sequential multilingualism and cognitive abilities: Preliminary data on the contribution of language proficiency and use in different modalities. *Behavioral Sciences* **9**(9), 92. https://doi.org/10.3390/bs9090092

Braver TS, Gray JR and Burgess G. C (2008). Explaining the many varieties of working memory variation: Dual mechanisms of cognitive control. In ARA Conway, C Jarrold, MJ Kane, A Miyake and JN Towse (eds), *Variation in working memory* (pp. 76–106). Oxford University Press.

Campbell AM, Davalos DB, McCabe DP and Troup L. J (2011) Executive functions and extraversion. *Personality and Individual Differences* **51**(6), 720–725. https://doi.org/10.1016/j.paid.2011.06.018

Caplan D, DeDe G, Waters G, Michaud J and Tripodis Y (2011) Effects of age, speed of processing, and working memory on comprehension of sentences with relative clauses. *Psychology and Aging* **26**(2), 439–450. https://doi.org/10.1037/a0021837

Caplan D, Michaud J and Hufford R (2013) Short-term memory, working memory, and syntactic comprehension in aphasia. *Cognitive Neuropsychology* **30**(2), 77–109. https://doi.org/10.1080/02643294.2013.803958

Caplan D and Waters G. S (1999) Verbal working memory and sentence comprehension. *Behavioral and Brain Sciences* **22**(1), 77–94 (Discussion: 95–126). https://doi.org/10.1017/S0140525X99001788

Caspari I, Parkinson SR, LaPointe LL and Katz RC (1998) Working memory and aphasia. *Brain and Cognition* **37**(2), 205–223. https://doi.org/10.1006/brcg.1997.0970

Chung-Fat-Yim A, Sorge GB and Bialystok E (2020) Continuous effects of bilingualism and attention on Flanker task performance. *Bilingualism: Language and Cognition* **23**(5), 1106–1111. https://doi.org/10.1017/S1366728920000036

Colomé À (2001) Lexical activation in bilinguals' speech production: Language-specific or language-independent? *Journal of Memory and Language* **45**(4), 721–736. https://doi.org/10.1006/jmla.2001.2793

Comishen KJ and Bialystok E (2021) Increases in attentional demands are associated with language group differences in working memory performance. *Brain and Cognition* **147**, 105658. https://doi.org/10.1016/j.bandc.2020.105658

Conway ARA, Kane MJ, Bunting MF, Hambrick DZ, Wilhelm O and Engle RW (2005) Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review* **12**(5), 769–786. https://doi.org/10.3758/BF03196772

Costa A, Caramazza A and Sebastián-Gallés N (2000) The cognate facilitation effect: Implications for models of lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition* **26**, 1283–1296. https://doi.org/10.1037/0278-7393.26.5.1283

Cowan N (1995) *Attention and memory: An integrated framework*. Oxford, *UK: Oxford University Press.* https://doi.org/10.1093/acprof:oso/9780195119107.001.0001

Croux C and Dehon C (2010) Influence functions of the Spearman and Kendall correlation measures. *Statistical Methods and Applications* **19**, 497–515. https://doi.org/10.1007/s10260-010-0142-z

de Bruin A, Treccani B and Della Sala S (2015) Cognitive advantage in bilingualism: An example of publication bias? *Psychological Science* **26**(1), 99–107. https://doi.org/10.1177/0956797614557866

Duñabeitia JA, Hernández JA, Antón E, Macizo P, Estévez A, Fuentes LJ and Carreiras M (2014) The inhibitory advantage in bilingual children revisited: Myth or reality? *Experimental Psychology* **61**, 234-251. https://doi.org/10.1027/1618-3169/a000243

Engle RW (2002) Working memory capacity as executive attention. *Current Directions in Psychological Science* **11**(1), 19–23. https://doi.org/10.1111/1467-8721.00160

Foster JL, Shipstead Z, Harrison TL, Hicks KL, Redick TS and Engle RW (2015) Shortened complex span tasks can reliably measure working memory capacity. *Memory & Cognition* **43**(2), 226 –236. http://dx.doi.org/10.3758/s13421-014-0461-7

Fuller-Thomson E and Kuh D (2014) The healthy migrant effect may confound the link between bilingualism and delayed onset of Alzheimer's disease. *Cortex* **52**, 128–130. https://doi.org/10.1016/j.cortex.2013.08.009

Gajewski PD, Hanisch E, Falkenstein M, Thönes S and Wascher E (2018) What does the n-back task measure as we get older? Relations between working-memory measures and other cognitive functions across the lifespan. *Frontiers in Psychology* **9**, Article 2208. https://www.frontiersin.org/article/10.3389/fpsyg.2018.02208

Green D. W (1998) Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and Cognition* **1**(2), 67–81. https://doi.org/10.1017/S1366728998000133

Green DW and Abutalebi J (2013) Language control in bilinguals: The adaptive control hypothesis. *Journal of cognitive psychology* **25**(5), 515-530.

Grundy JG and Timmer K (2017) Bilingualism and working memory capacity: A comprehensive meta-analysis. *Second Language Research* **33**(3), 325–340. https://doi.org/10.1177/0267658316678286

Hale S, Myerson J, Emery LJ, Lawrence BM and DuFault C (2008). Variation in working memory across the life span. In ARA Conway, C Jarrold, MJ Kane, A Miyake and JN Towse (eds), *Variation in working memory* (pp. 194–224). Oxford University Press.

Hartanto A and Yang H (2020) The role of bilingual interactional contexts in predicting interindividual variability in executive functions: A latent variable analysis. *Journal of Experimental Psychology: General* **149**(4), 609–633. https://doi.org/10.1037/xge0000672

Hasher L, Lustig C and Zacks R (2008) Inhibitory mechanisms and the control of attention. In ARA Conway, C Jarrold, MJ Kane, A Miyake and JN Towse (eds), *Variation in working memory* (pp. 227–249). Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195168648.003.0009

Helland-Riise F and Martinussen M (2017). *Måleegenskaper ved de norske versjonene av Ravens matriser* [*Standard Progressive Matrices (SPM)/ Coloured Progressive Matrices (CPM)*]. PsykTestBarn, 2:2

Hill TD, Angel JL and Balistreri K. S (2012). Does the "healthy immigrant effect" extend to cognitive aging? In JL Angel, F Torres-Gil and K Markides (eds), *Aging, health, and longevity in the Mexican-origin population* (pp. 19-33). Springer US. https://doi.org/10.1007/978-1-4614-1867-2_3

Kane MJ, Conway ARA, Hambrick DZ and Engle R. W (2008) Variation in working memory capacity as variation in executive attention and control. In ARA Conway, C Jarrold, MJ Kane, A Miyake and JN Towse (eds), *Variation in working memory* (pp. 21–46). Oxford University Press.

Kaushanskaya M, Blumenfeld HK and Marian V (2011) The relationship between vocabulary and short-term memory measures in monolingual and bilingual speakers. *International Journal of Bilingualism* **15**(4), 408–425. https://doi.org/10.1177/1367006911403201

Kavé G, Eyal N, Shorek A and Cohen-Mansfield J (2008) Multilingualism and cognitive state in the oldest old. *Psychology and Aging* **23**(1), 70–78. https://doi.org/10.1037/0882-7974.23.1.70

Kovács Á. M. and Mehler J (2009) Cognitive gains in 7-month-old bilingual infants. *Proceedings of the National Academy of Sciences of the U.S.A.*, **106** (16), 6556–6560. https://doi.org/10.1073/pnas.0811323106

Krizman J, Marian V, Shook A, Shoe E and Kraus N (2012) Subcortical encoding of sound is enhanced in bilinguals and relates to executive function advantages. *Proceedings of the National Academy of Sciences of the USA* **109**(20), 7877–7881. https://doi.org/10.1073/pnas.1201575109

Kroll JF, Dussias PE, Bice K and Perrotti L (2015) Bilingualism, mind, and brain. *Annual Review of Linguistics* **1**(1), 377–394. https://doi.org/10.1146/annurev-linguist-030514-124937

Kuipers JR and Thierry G (2010) Event-related brain potentials reveal the time-course of language change detection in early bilinguals. *NeuroImage* **50**(4), 1633–1638. https://doi.org/10.1016/j.neuroimage.2010.01.076

Lehtonen M, Soveri A, Laine A, Järvenpää J, de Bruin A and Antfolk J (2018) Is bilingualism associated with enhanced executive functioning in adults? A meta-analytic review. *Psychological Bulletin* **144**(4), 394–425. https://doi.org/10.1037/bul0000142

Li D, Christ SE and Cowan N (2014) Domain-general and domain-specific functional networks in working memory. *Neuroimage* **102**, 646–656. https://doi.org/10.1016/j.neuroimage.2014.08.028

Luk G and Bialystok E (2013) Bilingualism is not a categorical variable: Interaction between language proficiency and usage. *Journal of Cognitive Psychology* **25**(5), 605–621. https://doi.org/10.1080/20445911.2013.795574

Lukasik KM, Lehtonen M, Soveri A, Waris O, Jylkkä J and Laine M (2018) Bilingualism and working memory performance: Evidence from a large-scale online study. *PLoS ONE* **13**(11): e0205916 https://doi.org/10.1371/journal.pone.0205916

MacDonald MC, Almor A, Henderson VW, Kempler D and Andersen E. S (2001) Assessing working memory and language comprehension in Alzheimer's disease. *Brain and Language* **78**, 17–42. https://doi.org/10.1006/brln.2000.2436

Macizo P, Bajo T and Martin M. C (2010) Inhibitory processes in bilingual language comprehension: Evidence from Spanish-English interlexical homographs. *Journal of Memory and Language* **63**(2), 232–244. https://doi.org/10.1016/j.jml.2010.04.002

Martin R. C (1987) Articulatory and phonological deficits in short-term memory and their relation to syntactic processing. *Brain and Language* **32**(1), 159–192. https://doi.org/10.1016/0093-934X(87)90122-2

Masoura EV and Gathercole S. E (1999) Phonological short-term memory and foreign language learning. *International Journal of Psychology* **34** (5-6), 383–388. https://doi.org/10.1080/002075999399738

McCabe DP, Roediger HL, McDaniel MA, Balota DA and Hambrick D. Z (2010) The relationship between working memory capacity and executive functioning: Evidence for a common executive attention construct. *Neuropsychology* **24**(2), 222–243. https://doi.org/10.1037/a0017619

Mioshi E, Dawson K, Mitchell J, Arnold R and Hodges J. R (2006) The Addenbrooke's Cognitive Examination Revised (ACE-R): A brief cognitive test battery for dementia screening. *International Journal of Geriatric Psychiatry* **21**(11), 1078–1085. https://doi.org/10.1002/gps.1610

Mishra RK, Padmanabhuni M, Bhandari P, Viswambharan S and Prasad S. G (2019) Language proficiency does not modulate executive control in older bilinguals. *Aging, Neuropsychology, and Cognition* **26**(6), 920–951. https://doi.org/10.1080/13825585.2018.1562029

Miyake A and Friedman N. P (2012) The nature and organization of individual differences in executive functions: Four general conclusions. *Current Directions in Psychological Science* **21**(1), 8–14. https://doi.org/10.1177/0963721411429458

Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A and Wager TD (2000) The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: A latent variable analysis. *Cognitive Psychology* **41**(1), 49–100. https://doi.org/10.1006/cogp.1999.0734

Mondini S, Guarino R, Jarema G, Kehayia E, Nair V, Nucci M and Mapelli D (2014) Cognitive reserve in a cross-cultural population: The case of Italian emigrants in Montreal. *Aging Clinical and Experimental Research* **26**, 655–659. https://doi.org/10.1007/s40520-014-0224-0

Morales J, Calvo A and Bialystok E (2013) Working memory development in monolingual and bilingual children. *Journal of Experimental Child Psychology* **114**(2), 187–202. https://doi.org/10.1016/j.jecp.2012.09.002

Namazi M and Thordardottir E (2010) A working memory, not bilingual advantage, in controlled attention. *International Journal of Bilingual Education and Bilingualism* **13**(5), 597–616. https://doi.org/10.1080/13670050.2010.488288

Oberauer K, Süß H.-M., Wilhelm O and Sander N (2008). Individual differences in working memory capacity and reasoning ability. In ARA Conway, C Jarrold, MJ Kane, A Miyake and JN Towse (eds), *Variation in working memory* (pp. 49–75). Oxford University Press.

Paap KR and Greenberg Z. I (2013) There is no coherent evidence for a bilingual advantage in executive processing. *Cognitive Psychology* **66**(2), 232–258. https://doi.org/10.1016/j.cogpsych.2012.12.002

Paap KR, Johnson HA and Sawi O (2015) Bilingual advantages in executive functioning either do not exist or are restricted to very specific and undetermined circumstances. *Cortex* **69**, 265–278. https://doi.org/10.1016/j.cortex.2015.04.014

Paap KR, Myuz HA, Anders RT, Bockelman MF, Mikulinsky R and Sawi O. M (2017) No compelling evidence for a bilingual advantage in switching or that frequent language switching reduces switch cost. *Journal of Cognitive Psychology* **29**(2), 89–112. https://doi.org/10.1080/20445911.2016.1248436

Papagno C, Valentine T and Baddeley A (1991) Phonological short-term memory and foreign-language vocabulary learning. *Journal of Memory and Language* **30**(3), 331–347. https://doi.org/10.1016/0749-596X(91)90040-Q

Pons F, Bosch L and Lewkowicz D. J (2015) Bilingualism modulates infants' selective attention to the mouth of a talking face. *Psychological Science* **26** (4), 490–498. https://doi.org/10.1177/0956797614568320

Poulin-Dubois D, Blaye A, Coutya J and Bialystok E (2011) The effects of bilingualism on toddlers' executive functioning. *Journal of Experimental Child Psychology* **108**(3), 567–579. https://doi.org/10.1016/j.jecp.2010.10.009

Raven J. C (1948). *Standard Progressive Matrices*. London: Lewis.

R Core team. (2020). *R: A Language and Environment for Statistical Computing* [Computer Software]. Vienna: R Foundation for Statistical Computing.

RStudio team. (2020). *RStudio: Integrated Development Environment for R* [Computer Software]. Boston, MA: RStudio PBC.

Salis C, Kelly H and Code C (2015) Assessment and treatment of short-term and working memory impairments in stroke aphasia: A practical tutorial. *International Journal of Language and Communication Disorders* **50**, 721–736. https://doi.org/10.1111/1460-6984.12172

Singh L, Fu CSL, Rahman AA, Hameed WB, Sanmugam S, Agarwal P, Jiang B, Chong YS, Meaney MJ and Rifkin-Graboi A, On behalf of the GUSTO Research Team (2015) Back to basics: A bilingual advantage in infant visual habituation. *Child Development* **86**, 294–302. https://doi.org/10.1111/cdev.12271

Sorge GB, Toplak ME and Bialystok E (2017) Interactions between levels of attention ability and levels of bilingualism in children's executive functioning. *Developmental Science* **20**(1), 10.1111/desc.12408. https://doi.org/10.1111/desc.12408

Sung JE, McNeil MR, Pratt SR, Dickey MW, Hula WD and Szuminsky N. J (2009) Verbal working memory and its relationship to sentence level reading and listening comprehension in persons with aphasia. *Aphasiology* **23** (7–8), 1040–1052. https://doi.org/10.1080/02687030802592884

Thorn ASC and Gathercole S. E (1999) Language-specific knowledge and short-term memory in bilingual and non-bilingual children. *Quarterly Journal of Experimental Psychology, Section A* **52**(2), 303–324. https://doi.org/10.1080/713755823

Valian V (2015) Bilingualism and cognition. *Bilingualism: Language and Cognition* **18**(1), 3–24. https://doi.org/10.1017/S1366728914000522

van den Noort, M., Struys, E., Bosch, P., Jaswetz, L., Perriard, B., Yeo, S., Barisch, P., Vermeire, K., Lee, S.-H., & Lim, S. (2019) Does the bilingual advantage in cognitive control exist and if so, what are its modulating factors? A systematic review. *Behavioral Sciences* **9**(3), 27. https://doi.org/10.3390/bs9030027

Van Heuven WJB, Schriefers H, Dijkstra T and Hagoort P (2008) Language conflict in the bilingual brain. *Cerebral Cortex* **18**, 2706–2716. https://doi.org/10.1093/cercor/bhn030

Van Voorhis CRW and Morgan BL (2007) Understanding power and rules of thumb for determining sample sizes. *Tutorials in Quantitative Methods for Psychology* **3**(2), 43-50. https://doi.org/10.20982/tqmp.03.2.p043

Varkanitsa M and Caplan D (2018) On the association between memory capacity and sentence comprehension: Insights from a systematic review and meta-analysis of the aphasia literature. *Journal of Neurolinguistics* **48**, 4–25. https://doi.org/10.1016/j.jneuroling.2018.03.003

Vega-Mendoza M, West H, Sorace A and Bak T. H (2015) The impact of late, non balanced bilingualism on cognitive performance. *Cognition* **137**, 40–46. https://doi.org/10.1016/j.cognition.2014.12.008

Wang M and Saudino K. J (2013) Genetic and environmental influences on individual differences in emotion regulation and its relation to working memory in toddlerhood. *Emotion* **13**(6),1055-1067. https://doi.org/10.1037/a0033784

Waters G and Caplan D (2003) The reliability and stability of verbal working memory measures. *Behavior Research Methods, Instruments, & Computers* **35**, 550–564. https://doi.org/10.3758/BF03195534

Waters G and Caplan D (2005) The relationship between age, processing speed, working memory capacity, and language comprehension. *Memory*,**13**(3–4), 403–413. https://doi.org/10.1080/09658210344000459

Wickham H (2016). *ggplot2: Elegant Graphics for Data Analysis*. New York, NY: Springer-Verlag.

Winter B (2020). *Statistics for Linguists: An Introduction Using R*. New York/Abington: Routledge.

Wong PCM, Ou J, Pang CWY, Zhang L, Tse CS, Lam LCW and Antoniou M (2019) Language training leads to global cognitive improvement in older adults: A preliminary study. *Journal of Speech, Language and Hearing Research* **62**(7), 2411–2424. https://doi.org/10.1044/2019_JSLHR-L-18-0321

Wright HH, Downey RA, Gravier M, Love T and Shapiro L. P (2007) Processing distinct linguistic information types in working memory in aphasia. *Aphasiology* **21**(6–8), 802–813. https://doi.org/10.1080/02687030701192414