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Working memory in multilinguals: factors that assist and impede

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ABSTRACT

Investigations of working memory advantages in bilinguals yield inconsistent findings. Even less is known about how the addition of languages beyond two (multilingualism) may affect working memory. Due to their experience with managing multiple languages, it is possible that multilinguals may be more practised in the use of their working memories. This exploratory study investigated whether multilingualism in three or more languages contributes to working memory ability. Participants were South African multilinguals with good to excellent proficiency in English and two or more African languages. The study investigated the influence of balanced proficiency across the participants' languages, number of languages spoken, age of acquisition of additional languages, percentage exposure to each language, intelligence, gender and socioeconomic status on the components of working memory (verbal STM, verbal processing, visuospatial STM and visuospatial processing). Results suggest that the addition of a third language has a negative effect on visuospatial working memory, that modality (verbal or nonverbal) and type of working memory tests are influential and that nonverbal intelligence exerts the most consistent and largest influence. The results are interpreted within the context of the contention surrounding the existence of bilingual advantages in working memory, and debates concerning working memory structure in adults.

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Introduction

Whether bilingual language experience modulates brain structure and function (i.e. the bilingual advantage) is debated. There is evidence of bilingual advantages in the executive functions (EFs) of inhibitory control, cognitive flexibility, conflict management, switching, and working memory (WM; Bialystok, 2017; Costa et al., 2009). However, critics argue that these advantages are extremely small and are highlighted because of a publication bias towards positive outcomes (De Bruin et al., 2014; Lehtonen et al., 2018; Paap & Greenberg, 2013). They also contend that investigations into the phenomenon are flawed due to poor control of confounding variables (e.g. socioeconomic status

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-SES, language proficiency, intelligence), and/or inappropriate measurement of latent cognitive variables (Lehtonen et al., 2018; Paap et al., 2015). Supporters of the bilingual advantage maintain that critics ignore studies with good controls for confounding variables which demonstrate bilingual advantages, that non-significant findings do not imply on evidence, and that more data will enable a better understanding of the issue (Bialystok, 2017; Woumans & Duyck, 2015).

Some (DeLuca et al., 2019a; von Bastian et al., 2016; Woumans & Duyck, 2015) suggest different methodological approaches to the topic. Instead of categorical studies of monolinguals and bilinguals, continuous designs are recommended that consider the complexity and variability of bilingualism by focusing on participant factors and experiences that may moderate cognition. These include types of bilingualism (e.g. balanced or sequential, frequency of use, and proficiency in, each language), language orthographies, age, gender, SES and intelligence. Variations in these factors undoubtedly contribute to inconsistencies in findings (De Bruin et al., 2015; DeLuca et al., 2019b). Consequently, the current study used a continuous design to explore the language, cognitive and demographic factors that may influence the WM abilities of multilinguals. Few studies have considered whether proficiency in more than two languages (multilingualism) confers cognitive advantages. Multilingualism could confer greater advantages through strengthened executive control mechanisms, or there could be a deleterious effect from the additional cognitive resources required to manage interference between more than two languages (Berthele & Udry, 2019).

There has also been a call for wider representation of data from non-WEIRD (Western, educated, industrialised, rich and developed; Henrich et al., 2010) countries to add diversity to the data pool. Consequently, this paper presents an exploratory study of the factors that may influence WM functioning of multilingual young South Africans adults.

Bilingual advantages in working memory

Bilinguals are believed to develop a domain-general mechanism to monitor, inhibit and control their languages which actively compete when one language is in use (Green, 1998; Green & Abutalebi, 2013). Through this process, long-term bilingualism enhances EFs involved in monitoring, inhibiting, shifting, and controlling dual language use (Miyake & Friedman, 2012). While there is evidence of bilingual advantages in all of the EFs, this remains controversial as reviews and meta-analyses have reached varying conclusions (e.g. Adesope et al., 2010; Bialystok, 2017; De Bruin et al., 2015; Hilchey & Klein, 2011; Lehtonen et al., 2018; von Bastian et al., 2016). This paper focuses on the executive function of WM.

There are theoretical and applied benefits to understanding how proficiency in multiple languages may facilitate WM, the system that briefly holds and manipulates limited amounts of visuospatial and verbal material prior to long-term memory storage (Baddeley, 2007). Studies based on clear conceptualisations of WM can add to theoretical debates about how WM is structured (e.g. modality specific components or a unitary construct; Baddeley, 2012; Cowan, 2008; Engle & Kane, 2004). However, many bilingual advantage studies are not grounded in a theory of WM, resulting in methodological limitations in design and interpretation.

The current study was based on Baddeley's (2007) conceptualisation of WM as fractionable, but related, components. Three components are responsible for storage, namely a visuospatial sketchpad (for visuospatial information), a phonological loop (for auditory-verbal information), and an episodic buffer (for integrating information into meaningful episodes and communicating with long-term memory; Baddeley, 2012). The central executive, responsible for controlled attentional processing (e.g. coordinating tasks, activating long-term memory, maintaining task goals, and resolving interference) oversees the storage components; Baddeley, 2007). Most research has explored bilingual advantages in the central executive using visuospatial stimuli (Bonifacci et al., 2011; Morales et al., 2013). Few studies have considered whether bilingualism affects other WM components.

Evidence for a bilingual advantage in WM is controversial. A meta-analysis by Monnier et al. (2021) found a small bilingual advantage in WM (Hedges' g $= 0.12$, $p < 0.05$) compared to monolinguals. Similarly, Adesope et al.'s (2010) 63 study meta-analysis of bilingual versus monolingual differences in WM found a small/medium WM advantage (Hedges' g = 0.48, $p < .01$), with no publication bias. Following this, Grundy and Timmer (2017) meta-analysed 27 papers and reported a significant bilingual advantage in WM with a small/medium effect size (g = 0.20). Lastly, Lehtonen et al. (2018) meta-analysed 152 publications to investigate the relationship between bilingualism and EFs (including WM). After correcting for publication bias, the initial small bilingual WM advantage (g = 0.07) disappeared. Thus, three of four meta-analyses found evidence supporting a bilingual advantage in WM. The heterogeneity in effect sizes is likely due to inconsistent measurement of moderating factors (e.g. language of assessment, sample age, task type and modality of presentation, language proficiency, age of acquisition -AoA- of L2, exposure to each language, SES and intelligence; Lehtonen et al., 2018; Monnier et al., 2021).

Advantages in WM appear to be influenced by the language in which bilinguals' verbal WM is assessed (L1 or L2). Monnier et al. (2021) and Grundy and Timmer (2017) both found supportive, but opposite, evidence of this in their meta-analyses. Monnier et al. (2021) noticed a stronger bilingual advantage in those studies where the WM tasks were undertaken in the bilinguals' L2, compared to those performed in their L1, while Grundy and Timmer (2017) found the opposite pattern (better performance in the L1). A proposed reason for these opposing findings is that categorisation of participants' L1 and L2 may mean different things in different studies. For example, learning a L2 in a L1 daily context versus living in a L2 context and seldom speaking the L1 (Lehtonen et al., 2018: Monnier et al., 2021). Thus, what is recorded as the L1 may no longer be the bilingual's dominant language. This makes it important to evaluate participants' levels of proficiency in each language, and to identify which they perceive as dominant. Although these constructs (proficiency and dominance) are conceptually overlapping (and often correlated), they are also distinct, with dominance incorporating proficiency, as well as fluency, frequency of use and the relationship between the multilingual's languages (Gertken et al., 2014).

Benefits of bilingualism may also depend on age, and so samples with broad age ranges may dilute findings. Young adults (sampled in the current study) show the fewest bilingual advantages (Paap & Sawi, 2014; Ware et al., 2020), possibly because their WM skills are at their peak, and tasks may be insufficiently challenging and there

is insufficient inter-individual variability for differences to emerge (Bialystok, 2017; Valian, 2015). The current study included a comprehensive assessment of WM in young adults and extended this by sampling multilingual speakers of three to five languages (English and African languages).

Type of and modality of WM task may also influence results (von Bastian et al., 2016; Ware et al., 2020). Bilingual advantage studies report a variety of 'WM' tasks which draw on executive control to different degrees, with most employing visuospatial stimuli (Grundy & Timmer, 2017). There is evidence that bilingualism may exert varying effects on the different components of WM. The phonological loop (verbal STM) assists with first- and second-language learning (Baddeley et al., 2017) and so its inclusion was important. The current study used the Automated Working Memory Assessment (AWMA; Alloway, 2007), to tap both visuospatial and verbal WM and STM. The AWMA includes three tests of each WM component to ensure construct validity, whereas many studies rely on a single WM measurement (von Bastian et al., 2016; Monnier et al., 2021

Other potentially moderating language variables which were included in the current study, are balance in proficiency between bilinguals' languages (Lehtonen et al., 2018) and AoA of each language, which impact bilingual brain structure (DeLuca et al., 2019a). The amount of daily use is an indicator of proficiency and automatisation of each language, and was also included here (Adesope et al., 2010; von Bastian et al., 2016).

The current study

The components of WM appear to be differentially related to L2 proficiency (Blom et al., 2014), and so multilingualism may exert qualitatively different effects on these components. Consequently, the current study included four components of WM (phonological loop/verbal storage/STM, visuospatial sketchpad/visuospatial storage/STM, central executive and phonological loop/verbal processing/WM, and central executive and visuospatial sketchpad/visuospatial processing/WM). While the central executive is depicted in Baddeley's (2007) model as one component, it is typically operationalised by separate tests that tap processing via either verbal or visuospatial modalities. Although storage and processing in WM are described as being theoretically distinct, this is not strictly true (Baddeley, 2007, pp. 63–64; 124–129). In measuring WM processing, there is some task impurity, as these tasks typically involve some storage (Valian, 2015).

Understanding how the components of WM may be impacted by multilingualism is important because WM provides the foundation that allows us to manage progressively more complex information (Cowan, 2008), and proficient WM is critical for many domains, including interpersonal skill, self-regulation and resilience (Baddeley, 2007; Bemath et al., 2020). Further, WM dysfunction is related to many difficulties, including ADHD (Alloway & Cockcroft, 2014), Autism and HIV-infection (Cockcroft & Milligan, 2019). There is also evidence that WM is amendable to training (Melby-Lervåg & Hulme, 2013). Consequently, understanding the factors underlying sound WM would enable the identification of those which could potentially be developed for people with WM difficulties.

Most studies of cognitive advantages in WM focus on bilinguals (Grundy & Timmer, 2017). It is uncertain whether proficiency in three or more languages affects WM. Multilingualism may further boost WM advantages through strengthened central executive

mechanisms (Berthele & Udry, 2019). Conversely, multilingualism could be deleterious due to the additional cognitive resource requirements of managing interference across extra languages. Of the multilingual advantage studies, none found significant advantages for multilinguals over bilinguals, while evidence for an advantage of multilinguals over monolinguals is equivocal.

In the youngest group (18m), trilingual infants did not show any memory advantages relative to monolinguals or bilinguals (Brito et al., 2014). In an older sample, bilingual and trilingual 5–8-year olds did not differ on inhibitory or attentional control (Poarch & van Hell, 2012). In young adults, multilinguals outperformed their monolingual peers on WM tasks (Cockcroft et al., 2019). Bi- and trilinguals were not compared in that study. However, two other studies (Humphrey & Valian, 2012; Paap et al., 2015) found no differences in inhibitory control between mono-, bi- and trilingual young adults. It is possible that more experience is needed with processing three languages and that cognitive advantages may only manifest with more extensive multi-language exposure, which translates to an older age. In support of this, the number of languages mastered throughout the lifespan predicted cognitive task performance in older adults (Kavé et al., 2008). However, Guðmundsdóttir and Lesk (2019), in a rare comparison of monolingual, bilingual and trilingual adults (18–70 years) found no differences between language groups on inhibitory control. In terms of WM, bi- and trilinguals were at a significant disadvantage compared to monolinguals. Percentage daily language use predicted WM performance only in bilinguals, with worse performance with a more dominant use of one language.

Differences in study findings may be a result of the divergent conceptualisations of bi- and multilingualism. Many use artificial, categorical distinctions between these constructs (von Bastian et al., 2016). It is important to acknowledge that, given the continuum of bilingual/multilingual experience, multilingualism is not a clear cut category, but rather a diverse collection of ways in which language is used, and that the boundaries between these language processes are graded and fuzzy (Berthele, 2021). We attempted to use multiple 'indicators' of language in our study (AoA of L2 and L3, percentage exposure to L1, L2 and L3, perceived dominance of each language (while acknowledging that dominance is not an absolute category), self-reported proficiency in reading, writing and comprehending each language, and a measure of extent of balance between languages (to capture the relativist nature of multilingual proficiency) to provide a comprehensive picture of our multilingual samples' language backgrounds (See Methods section for detail).

It remains unclear how multilingualism may influence WM. Several of the reviewed studies lack detailed sample descriptions, while demographic, cognitive and contextual factors which could influence outcomes, such as extent of proficiency and vocabulary in each language, IQ and SES were not consistently reported. In addition, the studies adopted a categorical approach to participant grouping which is problematic given the dynamic and random nature of language experience (Berthele, 2021; Luk & Bialystok, 2013; von Bastian et al., 2016). This is particularly relevant to South Africa, where schoolchildren are exposed to a L2 for 11 years, multilingualism is the norm with 30 languages in use (11 official languages), 2.84 languages are spoken on average, and linguistic borrowing occurs in daily discourse (Wigdorowitz et al., 2020). Thus, binary language groups are unlikely to represent the nature of participants' multilingual exposure and so multilingual proficiency was treated as a continuous variable in this study.

This study investigated factors that may influence WM in young adult multilinguals. Many studies are limited by small samples (Paap et al., 2015; von Bastian et al., 2016) where results could be disproportionately influenced by confounding variables such as SES (Morton & Harper, 2007), level of education (Perani et al., 2017) and intelligence (De Bruin et al., 2015). Instead, we sampled a large group of multilingual students, and included as variables: gender, cognitive ability, SES, maternal and paternal levels of education, percentage exposure to each language, AoA of each, and balance in proficiency among languages. The focus was on the relative contributions of these variables to WM, and a directional hypothesis was not posed, given the controversy in the literature.

Methods

Participants

Undergraduate students ($n = 162$) were recruited from the University of [Removed for review]. Most of South Africa's official languages were represented. The majority (76%) spoke an African language as their L1, and English as their L2 (Table 1). Participants were asked to rank their languages in terms of dominance (extent of use and proficiency in each; Marian et al., 2007).

The sample spoke 3.9 languages (SD = 0.8) on average, and their average proficiency in reading, speaking and comprehension was good to excellent (above 5) for their first three languages (Table 2).

Measures

Demographic questionnaire

This collected information about participants' educational histories. A living standards measure captured SES (South African Audience Research Foundation -SAARF, 2014) on an ordinal score on a scale from 1 (lowest) to 10.5 (highest).

Language experience and proficiency

Since no standardized language proficiency measures exist in all of the languages spoken by participants, the self-report Language Experience and Proficiency Questionnaire (LEAP-Q; Marian et al., 2007) was used to collect language background and proficiency information about each of the participants' languages. The LEAP-Q has good internal and

Table 1. Self-reported language dominance of the sample ($N = 162$).

Dominance		*N*	%
L1	English	39	24.0
	Nguni	38	23.5
	Sotho	85	52.5
L2	English	107	66.0
	Nguni	35	21.6
	Sotho	20	12.4
L3	English	22	13.6
	Nguni	67	41.4
	Sotho	73	45.0

Table 2. Self-reported proficiency in each of the Sample's Languages ($N = 162$).

Proficiency[1]	Mean	SD	Range
Reading L1 ($n = 162$)	8.22	1.98	2-10
Speaking L1 ($n = 162$)	8.88	1.46	2-10
Comprehending L1 ($n = 162$)	9.04	1.23	3-10
Reading L2 ($n = 162$)	8.09	1.91	2-10
Speaking L2 ($n = 162$)	8.09	1.47	1-10
Comprehending L2 ($n = 162$)	8.40	1.43	3-10
Reading L3 ($n = 162$)	5.14	2.80	0-10
Speaking L3 ($n = 162$)	6.41	1.87	1-10
Comprehending L3 ($n = 162$)	7.32	1.61	2-10
Reading L4 ($n = 93$)	4.82	2.65	0-10
Speaking L4 ($n = 93$)	5.94	2.25	0-10
Comprehending L4 ($n = 93$)	6.80	2.02	2-10
Reading L5 ($n = 50$)	3.52	2.15	0-10
Speaking L5 ($n = 50$)	5.02	1.71	1-9
Comprehending L5 ($n = 50$)	6.46	1.88	1-10

Note: [1]0 (none) to 10 (perfect).

criterion-based validity (Marian et al., 2007), and internally consistent factors that represent language ability among multilingual South African students (Cockcroft & Laher, 2018).

Participants rated their proficiency in speaking, comprehension and reading each language on a scale from 0 (none) to 10 (perfect). Additional questions tapped language competence (including dominance, and preference), age of language acquisition, and percentage daily exposure.

Intelligence

Four subtests of the Wechsler Adult Intelligence Scale-III (WAIS-III; Wechsler, 1997) tapped verbal and nonverbal intelligence. *Verbal subtests:* The Vocabulary subtest evaluated English word knowledge, and the Similarities subtest assessed conceptual similarities between word pairs. *Nonverbal subtests*: The Block Design subtest measured visuospatial integration and construction and the Matrix Reasoning subtest measured fluid analogical reasoning.

Working memory

The Automated Working Memory Assessment (AWMA; Alloway, 2007), a computerized battery of 12 tests, measured verbal storage and processing, and visuospatial storage and processing. The storage tests (tapping the phonological loop or visuospatial sketchpad) involve recall of strings of data with no processing component, whereas the processing tasks require the recall of data as well as manipulation or processing (tapping the central executive together with the modality-specific stores; Alloway, 2007).

Verbal storage: The Digit Recall, Word Recall and Nonword Recall tasks are span tasks involving the recall of a sequence (digits, words and English-like non-words respectively). *Visuospatial storage*: The Dot Matrix, Mazes Memory and Block Recall tasks all involve replicating a pattern or shape in the order presented. Dot Matrix requires recall of the position of a sequence of red dots in a 4×4 grid. Mazes Memory involves the recall of a path out of a maze. In Block Recall, cubes are scattered on the screen and the participant must recall which cubes are pointed at in sequence.

Verbal processing: The Listening Recall, Counting Recall and Backwards Digit Recall tasks, all require recall of a string of figures or words after performing a calculation or manipulation. Listening Recall involves judging the veracity of spoken sentences while remembering the final word of each. Counting Recall involves counting circles in a series of images consisting of circles and triangles before recalling the number of circles in sequence. Backwards Digit Recall replicates the Digit Recall task, but the digits must be recalled in reverse order.

Visuospatial processing: The Odd One Out, Mister X and Spatial Recall tasks in which a series of locations must be recalled after answering questions that require visuospatial manipulation. In the Odd One Out task, the participant must identify which shape (of three) is the odd one out in a sequence of trials before recalling the position of odd shapes in the sequence. In the Mister X task, the participants must determine whether two figures (rotated at different angles) are holding a ball in the same (or a different) hand before recalling the location of the balls in the sequence. In the Spatial Recall task, two shapes are presented and the participant must indicate whether the shape on the right which has a red dot above it and has been rotated is the opposite or the same as the one on the left, before recalling the locations of the dots in sequence.

The AWMA has sound construct validity for UK individuals (Alloway et al., 2008), and has also been used with South Africans (Cockcroft et al., 2019; Cockcroft & Alloway, 2012).

Procedure

Assessments were conducted individually in English over two 90-minute sessions. Task presentations were fixed, with standardized instructions and practice examples. Informed, written consent was obtained from all participants, with appropriate opportunities for withdrawal.

Results

Table 3 shows the univariate statistics for the continuous variables, namely means (with SDs) for normally distributed data (in bold) and medians (with interquartile ranges) for non-normal data (in bold).

The mean sample age was 20.41 years ($SD = 1.82$ years), the majority were female (63%) and had attended preschool (75%). The SES score ($M = 7.4$, $SD = 2.3$) placed most participants in the middle of the SES range. On average, participants acquired their second language at 5 years 3 m and their third at 9 years 7m.

WM performance was highest for visuospatial processing ($M = 97.1$, $SD = 14.9$), lowest for verbal storage ($M = 87.3.54$, $SD = 13.3$), and intermediate for verbal processing ($M = 91.6$, $SD = 13.5$) and visuospatial storage ($M = 91.9$, $SD = 15.1$). Mean scores on each WM component differed significantly ($p = .001$), except for verbal processing and visuospatial storage. All WM components were significantly inter-correlated ($r = .35$ to $.71$; p-values at $<.0001$).

Language variables: In order to provide a comprehensive picture of participants' language backgrounds, multiple language variables were included in the analyses. A language balance variable was calculated from the reading, speaking and comprehension proficiency scores (for the first three languages), following the approach suggested in the

Table 3. Descriptive statistics for sample demographics and tasks.

Variable	Mean	SD	Median	25th p	75th p	Min	Max
SES	7.4	2.3	**7.5**	**3**	**5**	2	10.5
Maternal education[1]	4.0	1.4	**4**	**6**	**9.5**	0	7
Paternal education	4.7	1.6	**5**	**3**	**5**	1	7
% exposure L1	39.5	20.9	**40**	**4**	**6**	5	98
% exposure L2	39.5	21.0	**40**	**25**	**50**	2	93
% exposure L3	13.6	12.5	**10**	**25**	**50**	0	80
AOA[2] L2	63.6	33.5	**60**	**5**	**20**	0	180
AOA L3	**116.7**	**54.1**	120	48	84	0	240
Lang Balance	**4.4**	**1.6**	4.3	84	156	0.3	8.3
Digit Recall	90.1	11.7	**89**	**3.3**	**5.7**	69	136
Word Recall	85.5	13.1	**81**	**29**	**40**	64	129
Nonword Recall	**93.4**	**17.7**	95	27	43	55	136
Verbal STM	*87.3*	*13.3*	***87***	***86***	***102***	*50*	*127*
Listening Recall	95.1	13.8	**96**	**16**	**22**	73	139
Counting Recall	**96.0**	**15.1**	95	16	20	57	138
Backwards Digit Recall	89.1	14.0	**87**	**82**	**96**	65	132
Verbal WM	*91.6*	*13.5*	***90***	***74***	***96***	*51*	*126*
Dot Matrix	97.3	17.1	**96**	**77**	**93**	63	146
Mazes Memory	**95.7**	**16.0**	98	77	104	58	136
Block Recall	87.6	15.3	**89**	**80**	**102**	60	135
Visuospatial STM	***91.9***	***15.1***	*91*	*89*	*108*	*62*	*139*
Odd One Out	**99.6**	**15.1**	104	89	108	69	134
Mister X	**99.2**	**15.8**	99	80	98	61	132
Spatial Recall	95.9	15.1	**93**	**83**	**110**	72	137
Visuospatial WM	***97.1***	***14.9***	*96*	*85*	*113*	*55*	*133*
WAIS Vocabulary	**34.5**	**9.4**	34	29	40	11	64
WAIS Similarities	**19.3**	**5.4**	19	16	22	8	51
WAIS Block Designs	**35.2**	**11.3**	34.5	27	43	12	68
WAIS Matrix Reasoning	**17.6**	**3.7**	18	16	20	6	26

Note: [1]Scale 0 (none) – 7 (tertiary); [2] in months; STM: short-term memory; WM: working memory; WAIS: Wechsler Adult Intelligence Scale.

Bilingual Language Profile (BLP; Gertken et al., 2014). Languages four and five were not included in the analyses due to smaller numbers. For each proficiency type (across all languages), a difference score was calculated (maximum-minimum score), and the balance score was the average of the three difference scores. Thus, the more balanced proficiency is across languages, the closer the difference score is to zero. Other language variables were AoA for L2, percentage exposure to L1 and L3. The categorical variable of language dominance was significantly correlated with many IVs, as were percentage exposure for L2, and AoA in L3 ($p < .0001$; Table 4) and these variables were consequently omitted from analyses.

In order to understand the relative contributions of each independent variable (IV) to WM ability, demographic, intelligence (WAIS Similarities, Block Designs and Matrix Reasoning scores) and language variables were regressed on the WM components (DVs) using a General Linear Model. Sample size estimation required at least 10 (ideally 15–20) observations per estimated parameter. A limitation was that the sample size did not allow for the modelling of interactions between variables. The sample ($N = 162$) allowed the estimation of ~16 parameters, but only 13 were included due to multicollinearity issues. Pairwise associations between IVs were determined by Spearman's correlation coefficient for continuous variables (effect sizes measured by rho), Fisher's exact test for categorical variables (effect sizes measured by the ph coefficient), independent samples *t*-test (or one-way ANOVA for more than two categories) for combinations of

Table 4. Spearman correlation coefficients between independent variables ($N = 162$).

	No. langs	SES	Ed(M)	Ed(P)	%Exp1	%Exp2	%Exp3	AOA2	AOA3	Lang Bal	Vocab	BD	Sim	MR
No. langs	1.00													
SES	−.096	1.00												
	.22													
Ed(M)	−.127	.382	1.00											
	.11	**<.0001**												
Ed(P)	−.015	.080	0.281	1.00										
	.85	.31	**.0003**											
% Exp L1	−.132	.329	.211	.102	1.00									
	.10	**<.0001**	**.0071**	.20										
% Exp L2	−.139	−.204	−.167	−.136	−.713	1.00								
	.078	**.0091**	**0.034**	.085	**<.0001**									
% Exp L3	.049	−.212	−.102	.106	−.190	−.235	1.00							
	.54	**.0066**	.20	.18	**.015**	**.0026**								
AOA 2	−.090	−.225	−.091	.085	−.233	.199	.054	1.00						
	.25	**.0041**	.25	.28	**.0028**	**.011**	.50							
AOA 3	−.251	−.083	.003	.015	−.178	.226	−.029	.505	1.00					
	.0013	.29	.97	.85	**.024**	**.0038**	.72	**<.0001**						
Lang Bal	.342	−.122	−.033	−.191	.070	−.030	−.250	.098	.204	1.00				
	<.0001	.12	.68	**.015**	.37	.70	**.0013**	.21	**.0093**					
Vocab	−.104	.311	.184	−.036	.133	−.078	−.155	−.342	−.193	−.082	1.00			
	.19	**<.0001**	**.019**	.65	.092	.32	**.049**	**<.0001**	**.014**	.30				
BD	.024	.049	−.032	−.224	.064	−.061	−.080	−.093	.029	.004	.185	1.00		
	.76	.54	.69	**.0042**	.42	.44	.31	.24	.71	.96	**.019**			
Sim	−.120	.232	.148	−.053	.155	−.060	−.198	−.264	−.044	−.084	.574	.247	1.00	
	.13	**.0029**	.061	.50	**.049**	**.45**	**.012**	**.0013**	.58	.29	**<.0001**	**.0016**		
MR	−.003	.132	.042	−.113	.063	−.010	−.189	−.117	−.002	.056	.098	.369	.096	1.00
	.97	.094	.60	.15	.42	.90	**.016**	.14	.98	.48	.21	**<.0001**	.22	

SES: socioeconomic status; Ed (M/P): educational level (maternal/paternal); % Exp L1/2/3 = percentage exposure to language 1/2/3; AOA = age of acquisition; Lang Bal: language balance; Vocab: WAIS Vocabulary subtest; BD: WAIS Block Design subtest; Sim: WAIS Similarities subtest; MR: WAIS Matrix Reasoning subtest.

categorical and continuous variables (effect sizes measured by Cohen's d). The WAIS Vocabulary score was significantly inter-correlated (p<.0001) with several IVs and was omitted from analyses (Table 4). The IVs included in the models were: gender, attendance at preschool, number of languages spoken, SES, maternal and paternal highest educational level, percentage exposure to L1 and L3, AoA of L2, balance in proficiency between L1, L2 and L3, and the cognitive tests of WAIS Similarities, Block Designs and Matrix Reasoning. Model diagnostics did not require any outlier removal. The Benjamini-Hochberg procedure was applied to control for the false discovery rate ($p \leq .013$). Data analysis was carried out using SAS version 9.4 for Windows, with a 5% significance level.

In the regression analyses (Supplementary Tables 5–9), models were tested with each WM composite score and the individual WM subtests as the criterion. It was hypothesized that each IV would account for significant variance in the DVs. The overall models for verbal STM and WM composites were not significant (Table 5), although the individual *t*-test for each coefficient comprising verbal WM revealed a significant association with WAIS Block Design, Matrix Reasoning and percentage exposure to L3 (negative association). None of the individual subtests that comprise verbal STM (Table 6) were significant while WAIS Matrix Reasoning accounted for a significant portion of the variance in Listening Recall, one of the three subtests constituting verbal WM (Table 7).

In contrast, the regression models for visuospatial STM and WM were both significant (Table 5), although the only significant association emerged between visuospatial STM and WAIS Block Design. Of the three subtests comprising the visuospatial STM composite, Dot Matrix showed significant associations with several IVs, namely gender, percentage exposure to L3 (negative association), WAIS Matrix Reasoning and Block Design. Block Design also accounted for significant variance in the Block Recall visuospatial STM subtests (Table 8). While the overall model for the Mazes Memory visuospatial STM subtest was significant, none of the IVs reached significance independently. In the visuospatial WM subtest regressions (Table 9), all three subtest models were significant, but only WAIS Block Design and percentage exposure to L3 (negative association) accounted for significant variance in the Odd-One-Out subtest.

Discussion

This exploratory study contributes to the debate about the influence of multilingualism on cognition, particularly WM. Since language processing is dependent on WM, more proficient, balanced multilinguals, who have experience deploying their WM in shifting between languages, may strengthen and automatise this function (Green & Abutalebi, 2013). Alternatively, highly proficient multilinguals may experience more co-activation of their languages leading to more lexical competition, and more effort resisting interference, which may negatively impact WM (Blom et al., 2014). These views were explored in the current study, together with an investigation of demographic, language and intelligence variables that research suggests are potentially influential. The findings revealed that the effects of language variables on WM were relatively small and task specific; that nonverbal intelligence was the strongest and most consistent predictor of WM; and that of all the demographic variables included, only gender and exposure to a third language exerted small and targeted effects.

In terms of multilingual advantages in WM, the language variables (balanced proficiency between languages, AoA, number of languages spoken, percentage time exposed to a L3) yielded small to medium effects predominantly in nonverbal tasks. Percentage time exposed to a third language appeared to negatively affect WM for this sample. Specifically, such exposure was negatively associated with visuospatial WM and STM, verbal WM (to a very limited extent) but not with verbal STM. Furthermore, in the current study, the sample was significantly better at visuospatial than verbal WM processing ($p = .001$), language variables only showed positive effects on the visuospatial WM tasks, and the variables in the regressions accounted for greater variance in nonverbal STM (30%) and WM (23%), compared to their verbal counterparts (7% and 5% respectively).

Balanced proficiency between languages was not a significant contributor to any aspects of WM, substantiating the null findings of Monnier et al. (2021) and Lehtonen et al. (2018) with bilinguals. A negative relationship was also not evident, which would have supported the suggestion that proficiency imbalances between multilinguals' languages could lead to larger advantages. Number of languages and AoA of L2 were also not significant predictors, suggesting that the findings of Kavé et al. (2008), Lehtonen et al. (2018) and Monnier et al. (2021) of no significant associations between L2 AoA or number of languages and WM apply to multilinguals as well.

The limited effects of the language variables supports Berthele and Udry's (2019) findings with multilingual schoolchildren of no evidence for a multilingual boost (i.e. prior language abilities advantaging the learning of a third or fourth language). Instead, Berthele and Udry (2019) found that general cognitive abilities appear to be most impactful. Indeed, we found that nonverbal intelligence was the most consistent predictor across the verbal and nonverbal WM tests, and for nonverbal STM. Consequently, studies that match participants on, or control for, IQ may have limited chances of finding bilingual advantages since IQ effects seem to over-ride the effects of language variables (Lehtonen et al., 2018; Schmiedek et al., 2007). The role of nonverbal intelligence (especially Matrix Reasoning, a measure of fluid intelligence) was anticipated since there is evidence that WM and fluid intelligence are related (Engle & Kane, 2004; Oberauer et al., 2000). Theoretically, Matrix Reasoning may account for the central executive/controlled attention component of working memory, since it is one of the best WAIS subtests for predicting WM performance (Hill et al., 2010). The WAIS subtest, Block Design, does not appear to tap WM and was probably measuring STM (visuospatial sketchpad) in the current study (Hill et al., 2010). Questions remain regarding the extent to which the young adult WM system is subserved by domain-specific systems specialised for particular kinds of input e.g. verbal STM, or by domain-general systems that are broadly configured for a range of inputs. The findings from the current study provide tentative support for modality specificity in WM.

In terms of the demographic variables, gender (seldom explored in bilingual advantage research) played a minimal role in WM performance in this sample, with a small influence only in the visuospatial STM subtest, Dot Matrix. None of the tasks tapping WM or STM in the current study were affected by SES, suggesting that they are not reliant on educational opportunity or acquired knowledge (Alloway & Cockcroft, 2014; Alloway et al., 2014). Thus, these measures are potentially useful for non-WEIRD settings where there is considerable SES diversity.

The different predictive variables for different components of WM suggests that the type of task for assessing WM is important. The use of several WM subtests (12 in total) revealed that different combinations of language and cognitive variables accounted for performance in each. This may explain the heterogeneous findings in this field, since researchers use a range of WM tests. While all tap WM capacity, they require differing levels of executive control (Monnier et al., 2021). Simple span or STM tasks (often used in WM studies), are distinct, as they measure passive storage, without processing (Cowan, 2008). The results suggest that task choice is a limiting issue in bilingual advantage research (Valian, 2015; von Bastian et al., 2016).

Conclusion

From the multiplicity of factors that may benefit the WM of multilingual young adults, nonverbal intellectual ability exerts the largest and most consistent effects. In addition, WM task type and modality are instrumental in WM performance for samples who have home languages different to the language of assessment. This study suggests that there may be some costs to multilingualism, with the addition of a third language placing further demands on visuospatial WM and STM.

Since participants were multilingual speakers of between three and five languages (English and African languages), and passive experience in linguistically diverse, multilingual communities may influence cognition, these findings may have limited generalisability (Wigdorowitz et al., 2020).Nonetheless, the sample is interesting as African languages are orthographically different from European languages (which are commonly studied in bilingual advantage research). It is hoped that, by including a range of variables and a non-WEIRD sample, this research has contributed to a broader perspective on the topic.

Our findings suggest that subjecting multilingualism and its cognitive impacts to empirical investigation of this nature may be limited. Richer and more nuanced information may be yielded by employing Berthele's (2021) cognitive cultural model that prioritizes participants' contextualised, language interactions and practices, as well as the degree of relatedness between languages, the relative importance of literacy practices in each language, similarities and differences across writing systems and the status of each language in society.

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