Are working memory measures free of socio-economic influence?

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Abstract

Purpose: This study evaluated the impact of socio-economic factors on children's performance on tests of working memory and vocabulary.

Method: 20 Brazilian children, aged 6 and 7 years from low-income families, completed tests of working memory (verbal short-term memory and verbal complex span) and vocabulary (expressive and receptive). A further group of Brazilian children from families of higher socio-economic status matched for age, sex, and nonverbal ability also participated in the study.

Results: Children from the low socio-economic group obtained significantly lower scores on measures of expressive and receptive vocabulary than their higher income peers but no significant group differences were found on the working memory measures.

Conclusion: Measures of working memory provide assessments of cognitive abilities that appear to be impervious to substantial differences in socio-economic background. As these measures are highly sensitive to language ability and learning in general, they appear to provide useful methods for diagnosing specific learning difficulties that are independent of environmental opportunity.

Keywords: working memory, verbal short-term memory, verbal complex span, vocabulary, socio-economic status

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Scores on assessments of working memory are strongly associated with language learning (Archibald & Gathercole, 2006a; Bishop, North, & Donlan, 1996; Dollaghan & Campbell, 1998) and provide excellent predictors of children's scholastic abilities up to 3 years later (Gathercole, Brown, & Pickering, 2003). One priority in developing tests that can be used in the diagnosis of language impairment and learning difficulties is to ensure that the assessments genuinely measure the child's basic learning abilities rather than reflecting knowledge or prior experience that may vary across individuals. Accordingly, the purpose of the present study is to explore whether measures of working memory are influenced by the child's socio-economic status (SES).

Working memory consists of a number of distinct but inter-related components. According to the influential Baddeley and Hitch (1974) model developed subsequently by Baddeley (1986, 2000), it consists of two specialized temporary stores and two domain-general components, the central executive and the episodic buffer. Verbal material is held in a rapidly-decaying phonological form in the phonological loop, and limited amounts of spatial and visual information are stored in the visuo-spatial sketchpad. The central executive is responsible for the allocation of limited capacity resources that support activities both within and beyond the working memory system. The final component, the episodic buffer, integrates inputs from within working memory and long term memory to form unitary multi-modal representations.

The phonological loop appears to play a significant role in supporting vocabulary acquisition with close associations between verbal short-term memory skills and both existing vocabulary knowledge and new word learning (Avons, Wragg, Cupples, &

Lovegrove, 1998; Baddeley, Gathercole, & Papagno, 1998; Gathercole, Hitch, Service, &

Martin, 1997; Majerus, Poncelet, Greffe, & Van der Linden, 2006; Service & Kohonen,

1995). One particular measure of the phonological loop, nonword repetition, has been

found to be highly predictive of language learning difficulties (Archibald & Gathercole,

2006a; Bishop et al., 1996; Gathercole & Baddeley, 1990; Montgomery, 2004). It has

been proposed that the phonological loop provides initial temporary storage of the novel

phonological forms of nonwords, and that representations in the phonological loop form

the basis for the gradual abstraction of the phonological structures and more permanent

storage in the mental lexicon (Baddeley et al., 1998; Gathercole, 2006).

It has also been suggested that the central executive supports the acquisition of

many important skills during childhood including reading (Gathercole, Alloway, Willis,

& Adams, 2006; Swanson, 1999, 2003), language comprehension (Cain, Oakhill, &

Bryant, 2004; Seigneuric, Ehrlich, Oakhill, & Yuill, 2000), and mathematics (Bull &

Scerif, 2001; Geary, Hoard, Byrd-Craven, & DeSoto, 2004). One severe developmental

disorder of language learning, Specific Language Impairment, is characterized by deficits

in both the phonological loop and the central executive components of working memory

(Archibald & Gathercole, 2006b, 2007).

The purpose of the present study is to investigate the extent to which measures of

working memory and of language ability are influenced by the child's environmental

experience. There is already some evidence that measures of verbal short-term memory

that tap the phonological loop, appear to be relatively culture-fair. Typically developing

children from ethnic majority and minority backgrounds have been found to differ on

standardized measures of vocabulary but not on nonword repetition (Campbell,

Dollaghan, Needleman, & Janosky, 1997; Ellis Weismer et al., 2000). Similarly, Santos and Bueno (2003) found no differences in nonword repetition performance of Brazilian children from different socio-economic and cultural backgrounds. Evidence relating to digit span, one of the most common used measures of short-term memory present in many standardized ability tests, is less consistent across studies (Beauchamp, Samuels, & Griffore, 1979; Jensen, 1970; Ostrosky-Solís & Lozano, 2006; Reynolds, Willson, & Ramsey, 1999).

In contrast, it is well-established that the social environment exerts a strong influence on vocabulary development (Hart & Risley, 1995; Hoff & Tian, 2005; Walker, Greenwood, Hart, & Carta, 1994). Mothers' talk to children, caregivers' attitudes towards education, beliefs about the value of talking to children, and the availability of material resources have all been identified as possible explanations for the observed low performances of children from lower SES groups on standardized language tests (Brody & Flor, 1998; Fuligni, 1997; Hoff, 2003; Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991; Tomblin et al., 1997; Walker et al., 1994).

One major distinction between tests of vocabulary knowledge and working memory is that the former taps crystallized knowledge that depends on acquired skills and knowledge, whereas the latter is a fluid ability that is not explicitly taught (Cattell, 1963; Horn & Cattell, 1967). Because the procedures and stimuli employed in working memory tests are designed to be equally unfamiliar to all participants, they may confer no obvious advantages or disadvantages to individuals with differing prior knowledge and experiences.

The present study was, to our knowledge, the first to compare the influences of substantial differences in socio-economic background on the central executive component of working memory (Daneman & Carpenter, 1980; Turner & Engle, 1989). The participants were school children from high and low socio-economic backgrounds from Brazil, a country with one of the most uneven income distributions in the world (UNDP, 2006) and in which the identification of individuals with language impairments in the poorer communities using standardized language tests is highly problematic (Silveira, 2006).

Measures of both the phonological loop and the central executive were included in the study. The phonological loop measures were digit recall and nonword repetition, both of which are widely used and reliable measures of verbal short-term memory (see Baddeley et al., 1998 for a review). The central executive was assessed by two complex span tasks that impose demands both on storage and on processing. Backwards digit span is present in many standardized ability tests (Alloway, 2007; Pickering & Gathercole, 2001; Wechsler, 2003). The second complex memory measure, counting recall, has been widely used in research with adults and children (Alloway, Gathercole, Willis, & Adams, 2004; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle, Kane, & Tuholski, 1999), and also correlates highly with backwards digit recall (Alloway et al., 2004). The vocabulary tests were Portuguese versions of the *Expressive One Word Picture Vocabulary Test* (EOWPVT: Brownell, 2000) and the *British Picture Vocabulary Scale-II* (Dunn, Dunn, Whetton, & Burley, 1997), both used extensively in the literature to assess children's expressive and receptive vocabulary knowledge (Archibald &

Gathercole, 2006a; Munson, Kurtz, & Windsor, 2005; Stothard, Snowling, Bishop, Chipchase, & Kaplan, 1998; Webster, Majnemer, Platt, & Shevell, 2004)

On the basis of previous studies it was predicted that the high and low SES groups would be markedly distinguished in vocabulary knowledge as a consequence of the disparate environmental experiences of the groups. No group differences on digit recall and nonword repetition were expected (Campbell et al., 1997; Jensen, 1970). Finally, we hypothesized that complex memory measures of central executive function are also independent of environmental influences and so the two groups should not differ in performance on the central executive measures. In addition to establishing the independence from environmental influence of the cognitive mechanisms underpinning these tasks, this finding would have considerable practical utility by extending the range of culture-fair assessments of basic cognitive abilities known to contribute both to language learning and scholastic achievement.

Method

Participants

A total of 40 children were included in the study: 20 children from high SES backgrounds and 20 children from low SES matched on age, sex, and nonverbal ability. Four additional children and their respective controls took part in the study but their data was excluded from the analyses: one child was ill at the time of the assessment, and 3 children from the high SES group manifested scores above the 90th centile on the *Raven's Progressive Matrices* (Raven, Court, & Raven, 1986) test of nonverbal reasoning. The remaining children scored at or below the 90th centile and above the 25th centile. Each group consisted of 9 boys and 11 girls. The mean age of the children in both groups was

6 years; 11 month (SD = 3.75, range = 6;5-7;6 for the low SES group; SD = 4.92, range =

6;3-7;6 for the high SES group). Mean raw scores of the groups on the *Raven's*

Progressive Matrices (Raven et al., 1986) did not differ significantly: low SES, 18.05

(SD = 2.03, range = 15-23) and high SES, 19.40 (SD = 2.39, range = 15-23). None of the

children were identified as having learning difficulties, emotional disturbances, motor

difficulties, speech or hearing impairments, or frank neurological deficits based on parent

and teacher report. All of the children were Brazilian nationals and native Portuguese

speakers, recruited from four public and two private schools in the region of Assis city in

São Paulo state. All participants had received an equal number of years of prior schooling

and had all been introduced into literacy one year prior to testing. Children from the

private schools received tuition in a foreign languages (English and for some, Spanish)

for a maximum of 1 hour per week. The amount of instruction of the Portuguese language

was equivalent across the schools. Only monolingual children with both parents speaking

to them in Portuguese participated in the study.

The socio-economic background of the children was indexed by three measures -

family monthly income, occupational status, and education of main carer - obtained from

a questionnaire completed by the caregiver either during individual interviews or group

meetings at the child's school. Family income was the total income received by the

household over one month. Caregivers were asked to select from seven categories of

monthly household income ranging from: less then 300.00 BRL (~ 154 USD; below

minimum wage set by the Federal Government of Brazil), to above 6,000.00 BRL (~

3,082 USD). The occupational status of the main caregiver was classified according to

nine occupational categories, based on the Hollingshead (1975) classification in which

codes range from 9 (professions of high status, involving a high level of control, and complex tasks), to 1 (less prestigious occupations involving low autonomy and routine tasks, with little opportunity for complex work); 0 corresponds to unemployment, unstable jobs, or housewives. Once the 10 divisions had been created, 20 Brazilian adults classified the occupations. The final scale was based on the frequency counts of this ranking, with occupations being placed in the category that was indicated by the majority of people. Education of the main caregiver consisted of 5 categories, ranging from 1 (illiterate- uncompleted primary school) to 5 (completed higher education). The questionnaire also elicited information concerning the number of parents living at home, their marital status, the main caregiver of the child (defined as the person that spends most of his/her time with the child), and the area of residence of the family.

The two groups differed significantly on all three socio-economic indicators, with caregivers of children from the private schools presenting higher levels of education [$W_s = 227.5$, $p < .001$, $r = .81$], and professional status of the main carer [$W_s = 210$, $p < .001$, $r = .88$], as well as higher monthly household incomes [$W_s = 210$, $p < .001$, $r = .87$]. The vast majority of the carers of the high SES children had completed higher education and had professional occupations such as teachers, physiotherapists, and lawyers. In contrast, none of the carers of the low SES group held a higher education degree, and most of them were housewives or cleaners. On average, the high SES families earned 10 times more than the low SES group.

Procedure

Each child was evaluated individually in a quiet area of the school in a single 30-minute session. With the exception of the *Brazilian Children's Test of Pseudoword*

Repetition (Santos & Bueno, 2003), all tests were adapted Portuguese versions of the English originals with test design following the same principles underlying the establishment of the English material. Tests were translated and adapted by the first author and checked for accuracy and comprehension by 6 independent native speakers. In a first phase the written versions of the English and Portuguese test material were consecutively evaluated for accuracy by 2 neutral judges, fluent in both Portuguese and English. Second, only the written Portuguese versions of the tests were assessed for comprehension by 3 native speakers of Brazilian Portuguese. The final oral versions of the tests were further evaluated for accuracy and comprehension by one native speaker. The test material was initially piloted on a group of Brazilian children aged 5 to 6 years. All audio recordings were made in a professional sound studio by a female native speaker in a neutral Brazilian Portuguese accent, and digitally edited as necessary using GoldWave (2004). The stimuli were presented to the children using a laptop computer with external speakers. The following tests were administered to each child in a fixed sequence designed to vary the task demands across successive tests.

Nonverbal ability was evaluated by the *Raven Colored Progressive Matrices Test* (Raven et al., 1986). In this test, the child is required to complete a geometrical figure by choosing the missing segment from 6 choices. The test consists of 36 items. Answers are scored as 1 for a correct answer and 0 for an error, with a possible maximum of 36.

Expressive vocabulary. A Portuguese version of the *Expressive One Word Picture Vocabulary Test* (EOWPVT: Brownell, 2000) was adapted for the purposes of this study. In each case, the child is required to name a picture consisting of a line drawing of an object or an action. Every child started at item 1, and finished at item 99 or after 8

consecutive errors. Answers were scored as 0 for errors and 1 for a correct answer. Minor mis-articulations in a word, such as substitution or omission of one phoneme, were scored as correct responses, providing that they were sufficiently close to the target for it to be unambiguously identified as such. One item (*wagon*) was removed because it was culturally inadequate for Brazilian children. The measure used for the analysis was the total number of correct responses, with a possible maximum score of 98.

Receptive vocabulary. An adapted Portuguese version of the *British Picture Vocabulary Scale* (BPVS-II: Dunn et al., 1997) was administered. In this test, the child is required to identify a target picture, out of a choice of four, to match a spoken word. For all the children the test started at item 1, and ended at item 84 or after 8 consecutive errors. Two items were removed from the original version (*ladder* and *antlers*) due to structural differences between English and Portuguese languages. All the children were presented with a recorded version of the BPVS in order to avoid any perceptual difficulties caused by the accent of the test administrator. Apart from the digitized auditory presentation, the rest of the test followed the original paper pencil based test administration. The total number of correct responses on the test was calculated, with a possible maximum score of 82.

Verbal complex span. Computerized Portuguese versions of two verbal complex span tasks from the Brazilian adapted version of the *Automated Working Memory Assessment* (AWMA: Alloway, 2007) were administered. In the *counting recall* test, the child is required to count and memorize the number of circles in a picture containing triangles and circles. At the end of each trial, the child has to recall the number of circles of each picture in the correct order. The test consists of 7 blocks, with trials of one picture

in the first block increasing to trials of 7 pictures in the last block. The criterion for moving on to the next block is correct recall of 4 consecutive trials. If the child fails 3 trials in one block, testing stops. The number of correct recall attempts is scored for each child, with a possible maximum score of 42. In the *backward digit recall* test, the child is required to immediately repeat a sequence of spoken digits in the reverse order. The test consists of 6 blocks each of 6 items, starting with two digits in block one, and increases to sequences of 7 digits in the last block. The criterion for moving on to the next block is correct repetition of 4 consecutive trials. If the child fails 3 trials in one block testing stops. Each correct response was scored, with a possible maximum of 36.

Verbal short-term memory. The following two measures were administered: In the computerized Portuguese version of the *digit recall* test (Alloway, 2007), the child is required to immediately repeat a sequence of spoken digits in the order that they were presented. The test consists of 9 blocks of 6 trials each, starting with one digit and increases to sequences of 9 digits. The criterion for moving on to the next block is correct repetition of 4 consecutive trials. After the failure of 3 trials in one block testing stops. A correct answer received a score of 1, and the possible maximum score on the test was 54.

The nonword repetition task used in this study was the *Brazilian Children's Test of Pseudoword Repetition* (BCPR: Santos & Bueno, 2003), a validated Brazilian version of the *Children's Test of Nonword Repetition* (CNRep: Gathercole & Baddeley, 1996). The test consists of 40 nonwords, ranging from 2 to 5 syllable lengths items (10 words per syllable lengths). The syllables occurred naturally in spoken Portuguese and contained no illegal sound combinations. The stress pattern of each nonword followed the dominant syllabic stress contour of Portuguese. A detailed description of the criteria guiding the

development of these nonwords is provided by Santos and Bueno (2003). The nonwords were presented auditorily via a computer and each repetition attempt was digitally recorded for later analysis. Two practice items were presented with feedback before the actual test started. Recall accuracy for each item was recorded on a response sheet by the experimenter at the time of testing. The recorded responses were later transcribed into phonetic transcription by the first author with the original score sheet, recorded at the time of testing, being used to aid phonetic transcription. Responses were scored as incorrect if the experimenter judged that the child produced a sound that differed from the target nonword by one or more phonemes. For cases in which it was apparent from the child's spontaneous speech that a specific phoneme was consistently misarticulated as another phoneme (e.g. [ʃ] for [s]), credit was given for the consistent substitution. The total number of correctly repeated nonwords at each of the syllable lengths was calculated, with a maximum score of 40. In order to ensure interrater reliability, 25% of the recorded data was scored by a second, qualified rater. The percentage of agreement on the total score was 98.5%.

Results

The data were screened for univariate and multivariate outliers. Univariate outliers on each of the 7 variables were defined as values more then 3 *SD* above or below the group mean (Kline, 1998). One case out of the 280 in the data set, met this criterion and was replaced with a score corresponding to minus 3 *SD*. No multivariate outliers were identified using Mahalanobis' distance d^2 scores, with $p < .005$. Skew and kurtosis for all the variables met criteria for univariate normality (Kline, 1998). The distributions of the variables were also examined for their fit with the assumptions of multivariate analysis.

With equal sample size of 20 cases in each group, multivariate normality of the sampling

distribution of means should be assured (Mardia, 1971). Analysis of within-group

scatterplots between pairs of variables indicated that all the variables were reasonably

linear. The data did not manifest any problems of multicollinearlity (tolerance and VIF

values above .1 and below 10 respectively) or violation of homogeneity (F_{max} below 10).

<div align="center">Table 1 about here</div>

Descriptive statistics for all principal measures according to group are provided in

Table 1. None of the measures manifested floor or ceiling effects: all means were at least

one standard deviation from the maximum and minimum scores and from chance.

Separate multivariate analyses of variances (MANOVAs) were performed on the

language and the memory measures. Univariate F-tests were then carried out, comparing

the performance of the low and high SES children on the individual measures. To correct

for the effect of multiple tests on the likelihood of a type I error, a significance cut-off of

$p < .02$ was adopted for the language measures, and of $p < .01$ for the working memory

measures, representing Bonferroni corrections for 2 tests and 4 tests respectively. The

MANOVA performed on the language measures revealed a significant group effect:

Hoteling's T (2, 37) = 13.51, $p = .00$. By univariate F-tests, the high SES group scored

significantly higher than the low SES group on both the EOWPVT [F (1, 38) = 19.37, $p =$

.00] and the BPVS [F (1, 38) = 23.11, $p = .00$]. Effect sizes, as indicated by Cohen's d,

were very large, with d's of 1.39 for the expressive vocabulary and of 1.52 for the

receptive measure (Cohen, 1992). A further MANOVA explored group differences on the

four memory measures and manifested no significant effect, with Hoteling's T (4, 35) =

1.88, $p = .13$. Univariate F-tests revealed no group differences on any of the working

memory measures: nonword repetition [F (1, 38) = .20, p = .66], digit recall [F (1, 38) = .18, p = .67], backward digit recall [F (1, 38) = .50, p = .48], and counting recall [F (1, 38) = 5.32, p = .03]. Effect sizes were small for nonword repetition, digit recall, and backwards digit recall (d's ranging from .13 to .22) and medium for counting recall (d of .73). Multivariate analyses of covariance were also performed on the data with nonverbal ability (Raven's raw score) entered as covariates. The patterns of significance did not differ across the two sets of analyses.

Discussion

The purpose of this study was to investigate whether working memory measures are less sensitive to children's socio-economic backgrounds than standard language assessments of vocabulary knowledge. Children from impoverished and wealthy families in Brazil were compared, providing an extreme contrast on a range of SES indicators including family income, caregiver's educational level, and caregiver's occupation. The findings were very clear: large differences between the groups were found on both expressive and receptive vocabulary measures, with the high SES group obtaining consistently higher scores. This finding reinforces many previous reports that environmental differences in background and opportunity have substantial impact on a child's performance on norm-referenced tests of language ability (Campbell et al., 1997; Jensen, 1970; Tomblin et al., 1997).

In contrast, working memory scores did not differ between the children in the high and low SES groups, extending previous findings of the independence of nonword repetition and digit recall from factors relating to the child's background (Campbell et al., 1997; Dollaghan & Campbell, 1998; Jensen, 1970; Santos & Bueno, 2003). Importantly,

the independence of working memory performance from SES was not restricted to measures of the phonological loop but extended also to complex span tasks that tap the central executive. These findings indicate that working memory measures reflect fluid cognitive abilities that are independent of acquired knowledge and skills (Conway et al., 2002; Engle, Kane et al., 1999; Engle, Tuholski, Laughlin, & Conway, 1999) whereas vocabulary assessments seem to rely on crystallized knowledge associated with the opportunity for learning.

Measures of working memory are unlikely to be entirely independent of experience and acquire knowledge. The working memory system is closely linked with more permanent knowledge systems (Baddeley, 2000) and in many situation participants rely, in part at least, on long-term memory to support performance on tests of verbal short-term memory and complex span (Conlin & Gathercole, 2006; Hulme, Maughan, & Brown, 1991). Tasks that allow greater opportunity to use long-term memory support may therefore show some influence of environmental experience. Indeed there is some indication of this in the present study in which the difference between the SES groups on counting recall approached statistical significance. Children from lower SES backgrounds may have received less practice in counting prior to school than those in the high SES group; as a consequence, this processing activity may have been more cognitively demanding for them and this may have led to reduced availability of central executive resources to support storage (Case, Kurland, & Goldberg, 1982).

One limitation of the present study was that group sizes were relatively small, and so statistical power may not been sufficiently high to provide sensitivity to small but consistent differences. For example, although the SES effect size of .73 on counting

recall was moderate in magnitude (Cohen, 1992), it failed to reach the criterion for statistical significance. With larger sample sizes, group differences on this measure are likely to have emerged. It should also be acknowledged that although the choice of comparing two SES extremes was justified in order to strengthen our argument of the culture fairness of working memory measures, the very large effect sizes on the vocabulary measures should be treated with some degree of caution as the study did not involve a full range of SES variation.

Despite these limitations, the main finding of robust and sizeable effects of SES on vocabulary knowledge but not on working memory has some practical implications for the detection of language and other learning problems in children from impoverished backgrounds. Whereas language assessments based on measurements of vocabulary may over-estimate language learning difficulties, working memory measures will not. As working memory measures are highly associated with children's language learning and more general academic progress, these tests can provide methods of identifying children with potential learning difficulties that are unlikely to be distorted by differences in wealth or other significant environmental factors that impact on language learning opportunities.

Acknowledgments

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Table 1

Descriptive Statistics for Age, Nonverbal Ability, Language and Working Memory Measures

Measures		Low SES (N=20)			High SES (N=20)			Significance tests		
		Mean	*SD*	Range	Mean	*SD*	Range	*F*	*p*	*d*
Age		83.75	3.75	77-90	83.05	4.92	75-90	.50	.62	.16
Nonverbal ability	Raven	18.05	2.03	15-23	19.40	2.39	15-23	-1.28	.21	.61
Language	EOWPVT	57.75	7.40	41-70	70.00	10.00	47-87	19.37	.00	1.39
	BPVS	58.30	7.00	45-68	67.35	4.68	55-74	23.11	.00	1.52
Verbal short-term memory	Nonword repetition	34.65	2.74	29-39	34.27	2.57	26-38	.20	.66	.14
	Digit recall	20.65	4.08	13-29	21.15	3.31	17-29	.18	.67	.13
Verbal complex span	Counting recall	10.30	2.56	6-17	12.4	3.17	6-18	5.32	.03	.73
	Backwards digit recall	8.40	2.6	4-12	7.9	1.8	6-12	.50	.48	.22

Note: Raven, possible maximum score 36*;* EOWPVT (Expressive One Word Picture Vocabulary Test), possible maximum score 98;

BPVS (British Picture Vocabulary Scale), possible maximum score 82; nonword repetition, possible maximum score 40; digit recall,

possible maximum score 54; counting recall, possible maximum score 42; backwards digit recall, possible maximum score 36