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Simultaneous and Sequential Bilingual Memory Span for Arabic Numerals and Digit words - Japanese and English

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Research on bilingual speakers casts doubt on the prevailing view that speech rate is inversely related to memory span. Evidence suggests that, for example among Spanish-English bilinguals, memory span is longer for Arabic numerals than for digit words - although the latter are usually read faster than the former. This anomaly may be due to methodological factors such as inadequate definitions of bilingualism and the neglect of the effect of orthographic variables, such as sound-to-script matching. This study attempts to address these issues. 20 Japanese-English simultaneous bilinguals and 18 native English speaking, sequential bilingual speakers of Japanese participated in the study. Reading speeds and memory span were obtained for Arabic numerals and digit words in both English and Japanese. In English, both simultaneous and sequential bilinguals performed in accordance with the predictions of the standard Working Memory Model, i.e. reading rate was inversely related to memory span, with memory span for Arabic numerals being superior to that for digit words. However, in Japanese, the situation was not so straightforward. With sequential bilinguals, a longer memory span was observed for Arabic numerals than for digit words in Japanese, despite a similar reading time for both notations. With simultaneous bilinguals, Arabic numerals were read faster than digit words in Japanese, but memory span for Arabic numerals was comparable to that for Japanese kanji digit words. These findings suggest that the discrepancy in the literature may be due to inconsistent definitions of bilingualism and the effect of orthographic features. It would appear that kanji may be excused from the accepted inverse relationship between speech rate and memory span in bilinguals.

Key words: Bilingual, Numerals, Digits, Japanese, English

Introdction

Baddeley's (1990) theory of working memory holds the view that individual differences in speech rate and phonological loop capacity determine memory span. Several studies carried out within a specific language have observed an inverse relationship between speech rate and memory span tasks (Schweickert & Boruff, 1986; Standing, Bond, Smith & Isely, 1980). However, the examination of bilingual memory capacity has provided conflicting results.

For example, Chincotta and Underwood (1997) found that the relationship between speech rate, as measured by reading rate, and memory span was not as straightforward as predicted by a simple version of the Working Memory Theory. In particular, they reported that with Spanish dominant, Spanish-English bilinguals, reading time was shorter in Spanish than English for both numerals and digit words. Both number representations were read at equivalent rates in Spanish,

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whereas in English, digit words were read faster than numerals. A faster reading time for digit words relative to Arabic numerals in English would predict a larger memory span for the former. However, the results indicated a span advantage for Arabic numerals compared to digit words in *both* languages. The memory span advantage for Arabic numerals over digit words persisted for both languages under articulatory suppression. Similar trends were found with French second language, native English speaking subjects (Brown & Hulme, 1992).

What factors may explain this inconsistent relationship between speech rate and memory span? It is plausible that, when tested in the less dominant language, the greater level of lexical support available in digit words relative to Arabic numerals resulted in a decrease in cognitive demands during the recognition and articulation processes and may have occasioned faster speech rate. It is also possible that reading rate for the Arabic numerals in the less dominant language may require more complex processing due to a Stroop-like interference from the dominant language, resulting in delays in the retrieval of the appropriate words from the bilingual lexicon (Chincotta & Hoosain, 1995). For example, a Spanish dominant, Spanish-English bilingual may process *123* in Spanish even when asked to read the Arabic numerals in their less dominant language, English. Whilst this explanation of the reading time results seems plausible, the question remains as to why was there a memory span advantage for Arabic numerals over digit words, when the naming speed was faster for the latter.

Although these findings would appear to raise fundamental questions about the well established inverse relationship between memory span and the articulatory duration of stimuli, there were potential flaws in these studies. Specifically, variations occurred among researchers with regard to definition and measurement of degree of bilingualism. In addition, the differences in the nature of the script in which the stimulus material was presented was not considered. Let us consider these issues in more detail now.

Definitions of bilingualism run from "native-like control of two languages" (Bloomfield, 1933:56) , and "those who use two languages in their everyday life" (Grosjean, 1982:30) to "passive" or "receptive" bilingualism with an understanding of utterances in the less dominant language, but no productive control over the language (Diebold, 1964; Paradis, 1998). The degree of bilingualism in Chincotta and Underwood's (1997) study was unclear as participants were described as being students "attending a British university under the auspices of the ERASMUS exchange programme. They had studied English for an average of approximately nine years" (p.298-299). Indeed, in an attempt to explain the differences in experimental results between their bilingual study and that of da Costa Pinto (1991), Chincotta and Hoosain (1995) suggest that they may have been due to the fact that the participants' language abilities in the two studies differed - the latter being bilingual and the former being more in the category of second language speakers. In the present study, the definition of bilingual will rest on the criterion of the age of acquisition.

Orthographic features of written language influence memory. Tzeng and Singer (1981) suggest that "orthographic structure in a writing system must somehow mould the cognitive processes of its readers" (p.382). It has been claimed that the processes involved in extracting meaning from a printed array depend to some degree on how the information is represented graphically (Besner & Coltheart, 1979; Frost, 1994; Perfetti, Zhang & Berent, 1992). McCloskey, Caramazza and Basili (1985) have demonstrated dramatic differences in processing between Arabic numerals and digit words and developed a cognitive architecture of number processing and calculation based on evidence from studies of brain-damaged patients. This model proposes separate production and comprehension proceses for Arabic numerals and verbal numbers (digit words). Perhaps it is the visual representation of Arabic numerals, represented as logographs[1], that allows a longer memory span than digit words, represented in alphabet, regardless of the articulatory duration, or reading speed of the stimuli. It may be possible that the delay in reading Arabic numerals in the less dominant language relative to reading digit words is caused by a possible Stroop like interference from the dominant language. This shortcoming may be overcome if the Arabic numerals and digit words in the less dominant language were both represented in logographic script. The present study employs Japanese, with its logographic script, Kanji, for this reason.

This study attempts to address the debate in the literature concerning the inverse relationship between reading rate and memory span in bilinguals by employing Japanese-English speakers. The definition of bilingual will depend on the age of acquisition, i.e. simultaneous or sequential. Japanese kanji[2], like numerals, are logographs. The visual form of logographic script is crucial to the identity of a character[3].

It is hypothesized that the inverse relationship between speech rate and memory span is not universal, especially when dealing with a bilingual situation. It depends on who (level of bilingualism) is being tested and what (logographic/phonetic script) they are being tested on.

Method

Subjects

20 English-Japanese simultaneous bilingual subjects (11 males and 9 females; aged 17-40, mean age = 22.45) and 18 native English speaking, sequential bilingual speakers of Japanese[4] (9 males and 9 females; aged 21-40, mean age = 29.68) participated in the experiment.

The simultaneous bilingual subjects had learnt both Japanese and English as their native languages as children. 14 had one Japanese parent and one English speaking parent. Five were of Japanese parents, but spent their childhood in U.S.A. and returned to Japan as adults. One was of American missionary parents, born and brought up in Japan. The subjects were recruited through international schools in Japan, the Bicultural HAPA club and the Foreign Wives Club.

1. A "logograph" is a meaning-based, rather than sound-based script, without a systematic sound representation or a one-to-one relationship between sound and symbol. Therefore, pronunciation is essentially memorized for each character (e.g. 2 /two/, but 2 is pronounced /twen/ when seen in 20 /twenty/.
2. For example, 人 /hito/ (means "man"), but 人 is pronounced /jin/ when seen in 人口 /jinko/(means "population", literally "man mouths"). See Appendix.
3. The question of the importance of phonetic representation in processing logographic scripts is far from settled and will not be discussed here (see Perfetti, Zhang & Berent ,1992; Wydell, Patterson & Humphreys, 1993).
4. Originally, 23 sequential bilinguals were recruited and tested. However, five subjects were excluded from the analysis as their reading rate in Japanese was unacceptably long.

All sequential bilingual subjects had passed the 2nd Grade of the International Japanese Exam (Nihongo Nyoryoku Shiken, 1998) or equivalent. Subjects estimated their fluency in Japanese and English on a 10-point self rating scale. Sequential bilinguals rated between 5-7 on Japanese and 10 on English. High positive correlations have been recorded between subjective reports and objective measures of bilingualism (Rose, 1975). The subjects were recruited through the School of Oriental and African Studies, London.

All subjects had completed second level education. They were paid £ 10, or equivalent for participation in the experiment.

Design

The relationship between speech rate (reading speed) and memory span in both simultaneous and sequential bilinguals in English and Japanese was the focus of attention. Thus, the speed at which they read Arabic numerals and digit words in both English and Japanese was measured. Memory span for Arabic numerals and digit words in both languages was then measured.

Materials

A. Reading Time

For measurement of reading time four lists of 200 numbers varying from 1 to 9 were constructed. Two of the lists consisted of Arabic numerals, the remaining two lists contained digit words in either Japanese[5] or English. Consecutive repetition of numbers, as well as ascending and descending sequences of more than two digits was avoided. Sequences of numbers that contained mnemonic cues were eliminated, i.e. 1, 7 were not allowed because the words, *ichi-shichi* rhyme in Japanese. Each list was printed in 10 rows each containing 20 items. Instructions for the reading time and memory span measures were prepared in both Japanese and English.

B. Memory Span

For measurement of Arabic numeral and digit word span in Japanese and English, four sets of random number sequences were prepared. Each set commenced with three two-item sequences followed by three three-item sequences, and so on to a maximum of three 12-item sequences. Identical items appearing contiguously and ascending and descending sequences were avoided. A computer was programmed to present these sequences at the rate of one digit per second.

Procedure

Subjects were tested individually. Before measuring the reading time, subjects were given a practice trial on a list of 50 random digits for which language was varied. Measures of reading time were then obtained. The subjects were asked to read aloud the lists of 200 random Arabic numerals and digit words as fast as possible without sacrificing accuracy, pronouncing each digit

5. The number names in Japanese run as follows: *ichi* (1), *ni* (2), *san* (3), *shi* or *yon* (4), *go* (5), *roku* (6), *shichi* or *nana* (7), *hachi* (8), *kyu* (9).

individually and audibly. One list was read in English and the other in Japanese, the order being counterbalanced in both languages. Time taken was recorded.

Measures of memory span for both Arabic numerals and digit words were taken. The sequences of random Arabic numerals and digit words were presented via computer . Digit words in English and Japanese and Arabic numerals were presented in a random sequence for each subject to avoid the consistent interference of fatigue on any one stimulus material.

Each condition commenced with three two-item sequences, three three-item sequences, three four-item sequences, and so on to a maximum of three-12 item sequences. The sequences were presented at the rate of one item per second. Each item appeared in the same position on a monitor and the presentation sequence was as follows. First, the legend *READY (or SUGU NI..SHIYO TO SURU* -Japanese equivalent) was presented. This prompted the person to press a key on a computer keyboard after which the presentation sequence then commenced and consisted of a blank screen (1500 ms), a fixation point (1500 ms) and the item sequence. Once the item sequence terminated, the fixation point reappeared for 1500 ms followed by the legend *'RECALL (or OMOIDASU-* Japanese equivalent) prompting participants to commence recall. Participants immediately recalled the sequence serially and verbally, as quickly and accurately as possible.

They continued recalling the item sequences verbally until two incorrect responses on the same item length were made. Memory span was operationalised as the length of the last correctly recalled sequence (following Chincotta & Underwood's (1997) methodology). Before testing, subjects were allowed three practice trials for sequences of two notations in both languages.

The various tasks, reading and memory of digit words and Arabic numerals in two languages, were carried out in a random sequence for each subject to avoid the consistent interference of fatigue on any one part of the experiment.

Results

Reading measures for 200 Arabic numerals and digit words in English and Japanese in simultaneous and sequential bilinguals are represented in Table 1.

The data for the simultaneous bilinguals were analyzed with a two-way analysis of variance (ANOVA) in which language (English or Japanese) and notation (Arabic numerals or digit words) were within-subjects factors. This showed a significant effect of notation ($F(1,19)=28.54$, $p«.0001$) and a significant interaction between language and notation ($F(1,19)=3.97$, $p«.05$). A post hoc tukey analysis revealed that the Arabic numerals were always read faster than the digit words.

The memory span data are summarized in Table 2.

For the simultaneous bilinguals, there was no main effect of language, i.e. there was no difference in the simultaneous bilinguals' memory span in English and that in Japanese ($F(1,19)=1.99$, n.s.).There was no notation effect ($F(1, 19)=3.09$, n.s.). There was an item by language interaction ($F1,19)=3.91$, $p«.05$). A post hoc tukey analysis was carried out. When responding in English, the Arabic numerals were memorized better than the English digit words

Table 1: Mean reading times in sec. for Simultaneous and Sequential Bilinguals

Subject Group	Language	Notation	Mean	S.D.
Simultaneous Bilinguals (n = 20)	English	Words	74.26	19.33
		Arabic Numerals	69.77	18.69
	Japanese	Words	74.39	16.95
		Arabic Numerals	64.55	19.34
Sequential Bilinguals (n = 18)	English	Words	64.00	8.42
		Arabic Numerals	58.26	11.27
	Japanese	Words	92.85	10.40
		Arabic Numerals	92.00	17.12

Table 2: Mean memory spans for Simultaneous and Sequential Bilinguals

Subject Group	Language	Notation	Mean	S.D.
Simultaneous Bilinguals (n = 20)	English	Words	5.51	0.81
		Arabic Numerals	5.57	0.83
	Japanese	Words	5.80	1.20
		Arabic Numerals	5.77	1.14
Sequential Bilinguals (n = 18)	English	Words	6.00	1.65
		Arabic Numerals	6.72	1.04
	Japanese	Words	5.91	0.94
		Arabic Numerals	5.66	0.87

(t = -3.64, p«.01); when responding in Japanese, there was no difference in the memory span on Arabic numerals and kanji words.

There was a negative correlation between reading speed and memory span on all notations for the simultaneous bilinguals (see Table 3).

Table 3: Correlations between reading speed and memory span for the Simultaneous Bilinguals

Read English digit words	- Memory English digit words	-.4470*
Read Japanese digit words	- Memory Japanese digit words	-.4307
Read Arabic numerals (in Eng.)	- Memory Arabic numerals (in Eng.)	-.4237
Read Arabic numerals (in Japan.)	- Memory Arabic numerals (in Japan)	-.6355**

*p < .05 **p < .01

The data for the sequential bilinguals were analyzed with a two-way analysis of variance (ANOVA) in which language (English or Japanese) and notation (Arabic numerals or digit words) were within-subjects factors. This showed a significant effect of both language (F(1, 17) = 69.90, p«.0001) and notation (F(1,17) = 4.10, p«.05). A post hoc tukey analysis revealed that when responding in English, the Arabic numerals were read faster than the English digit words (t = 3.62, p«.01); when responding in Japanese, there was no difference in the reading speed on Arabic numerals and kanji words.

For the sequential bilinguals, there was no main effect of language (F(1,17) = 2.69, n.s.) nor notation (F(1, 17) = 1.73, n.s.) in memory span. There was an item by language interaction (F1,17) = 7.37, p«.01). A post hoc tukey analysis revealed that when responding in English, the Arabic numerals were memorized better than the English digit words(t = -4.14, p«.01); when responding in Japanese, there was no difference in the memory span on Arabic numerals and kanji words.

There was a negative correlation between reading speed and memory span on all notations for the sequential bilinguals, except for the Japanese digit words (see Table 4).

Table 4: Correlations between reading speed and memory span for the Sequential Bilinguals

Read English digit words	- Memory English digit words	-.625**
Read Japanese digit words	- Memory Japanese digit words	-.705**
Read Arabic numerals (in Eng.)	- Memory Arabic numerals (in Eng.)	-.542**
Read Arabic numerals (in Japan.)	- Memory Arabic numerals (in Japan)	-.0029

*p < .05 **p < .01

Discussion

In English, both simultaneous and sequential bilinguals conformed with the standard Working Memory Model, i.e. reading rate was inversely related to memory span, with Arabic numerals being superior to digit words. However, in Japanese, the findings were different. With sequential bilinguals, a longer memory span was observed for Arabic numerals than for digit words in Japanese, despite a similar reading time for both notations. With simultaneous bilinguals, Arabic numerals were read faster than digit words in Japanese, but memory span for Arabic numerals was comparable to that for Japanese kanji digit words. The Working Memory Model would forecast that a faster reading time for Arabic numerals relative to digit words in Japanese would predict a larger memory span for the former. However, the results indicated that there was no difference between them.

Before considering the implications of the current findings, it is important to highlight the meaning of "bilingual" in terms of previous studies. The reading rates of the simultaneous bilinguals in this study averaged 359 msec per digit (digit word and Arabic numeral) in English and 347 msec in Japanese; the sequential bilinguals averaged 305 msec per digit (digit word and Arabic numeral) in English and 462 msec in Japanese. The bilingual subjects in da Costa Pinto's (1991) study averaged 407msec per digit in the less dominant language, in Chincotta and Hoosain's (1995), 439msec. Memory span of the subjects in aforementioned studies hold a closer comparison to those of the sequential bilinguals than the simultaneous bilinguals in the current study. These discrepancies in definition support doubts about the criteria of bilingualism used in previous studies. Thus the results of sequential bilinguals in this study may be compared with "bilingual" results in previous literature.

A similar reading time was recorded for Arabic numerals and digit words in the less dominant language, Japanese, in the sequential bilinguals. This result runs contrary to that found by Chincotta and Underwood (1997) with Spanish bilinguals, where the bilingual subjects read the digit words in the less dominant language (English) faster than the Arabic numerals. However, the simultaneous bilinguals in the current experiment read the Arabic numerals in Japanese faster than the kanji words. This lends insight into the possible reason why the Spanish subjects in Chincotta and Underwood's (1997) work managed better with the digit words; they could sound them out. Digit words in English offer more direct lexical support, i.e., they can be sounded out, and are less likely to activate language output in the dominant language than Arabic numerals. Both Arabic numerals and kanji are logographs and are thus less mediated phonologically. Arabic numerals are commonly encoded in both languages resulting in consequent delays when output is specified in the less dominant language. Further delays were encountered with the kanji logographs. In Japanese, all digit words can have a number of pronunciations depending on context (see Appendix). Because kanji do not have separable phonemic components, and because their appropriate phonological representations are so word specific, it has typically been assumed that for kanji characters, meaning is directly accessed from print, and access to phonology follows access to meaning. This semantically mediated procedure is believed by some researchers to be the only way to retrieve the phonology of words written in kanji (Shimamura, 1987). Hatano, Kuhara and Akiyama (1981) found that Japanese store words where possible as a visual code.

The comparable memory spans in Arabic numerals and kanji found in both the sequential and simultaneous bilinguals may be due to their being logographs. The orthographic depth hypothesis (Frost, Katz & Bentin, 1987) would propose a direct route to lexical access. McCloskey, Caramazza and Basili, (1985) suggest that there may be separate production and comprehension processes for Arabic numerals (and indeed other logographic scripts such as kanji), and verbal numbers written in an alphabet such as in English.

Previous studies have reported a memory span advantage for Arabic numerals over a variety of stimuli. Cranell and Parrish (1957) found that memory span was greatest for Arabic numerals, then letters and then words. Similar findings were reported in patients with memory disorders (Valler & Papagno, 1995). However, recent findings by Flaherty and Moran, (2000) suggest that memory strategy in dealing with kanji appears to bear more resemblance to Arabic numerals than to words in English. The current findings with both simultaneous and sequential bilinguals support these findings and question the universal superiority of memory span of Arabic numerals over digit words in all languages. The analogy between kanji and Arabic numerals was suggested by Fenollaso (cited in Pound, 1934). Indeed, Japanese memorize words where possible as kanji rather than the supporting syllabic script kana[6] due to the inbuilt possibility of chunking with kanji (Flaherty, 1992; Suzuki, 1986).

The present findings support the importance of subjective frequency (i.e., how familiar one is with a particular object) on memory span (Gardner, Rothkopt, Lapan, & Lafferty, 1987). The Arabic numeral advantage in English in both the simultaneous and sequential bilinguals may be due to the fact that Arabic numerals are used more frequently in daily life than digit words. In a similar vein, as numbers are experienced as both Arabic numerals and kanji with comparable frequency in Japanese (Yokoyama, 1998), memory span for Arabic numerals and digit words in Japanese was comparable in both the simultaneous and sequential bilinguals. There are research findings to suggest an independent contribution of non-temporal factors such as long-term memory and familiarity of stimuli to Working Memory capacity (Hulme, Roodenrys, Brown & Mercer, 1995).

This study raises a number of issues relevant to Working Memory studies. Firstly, the relationship between reading rate and memory span seems not as straightforward as assumed by a simple version of the working memory theory. The view that holds speech rate as the most influential determinant of verbal memory span needs to be moderated. Secondly, when presented with a logograph such as kanji with its multiple pronunciations, the possibilities of levels of encoding (Craik, 1990; Collins, Gathercole, Conway & Morris, 1993) are highlighted. Phonetic rehearsal may give way to a visual or indeed a kinesthetic processing strategy (Logie, 1999). Thirdly, the potential relationship between bilingualism and working memory (Clifton, Sorce & Cruse, 1977; Clifton, Sorce, Schaya & Fiszman, 1978), and practice in preferred and nonpreferred languages as related to speed of information processing requires a standardization of terms such as "*bilingual*" in the literature. Finally, the memory span advantage for Arabic numerals over other stimuli in processes involving recognition and memory capacity has been questioned. Further research on these issues will no doubt shed further light on the question of lexical organization in simultaneous and sequential bilinguals.

6. Japanese use a syllabic script, *Kana*, principally for words endings (*higagana*) and for transcribing foreign words (*katakana*).

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Appendix A: Kanji has different phonetic translations depending on the particular compound, for example

上

Pronounced *ue* when meaning *above*,

a when meaning *to ascend (Japanese: agaru)*

nobo when meaning *to go up (Japanese: noboru)*

jo when meaning *high or upper*

kami when meaning *first half of the year (Japanese: kamihaki)*

Another example,

重

Pronounced *e* when meaning *folds*

omo when meaning *heavy* (Japanese: *omoi*)

jou when meaning *weight* (Japanese: *jouryou*)

kasa/gasa when meaning *pile up* (Japanese: *kasanaru*)

cho when meaning *overlap* (Japanese: *choufuku*)

tae when meaning *creased eyelid* (Japanese: *futaemabuta*)

Digit words in Japanese have different pronunciations, depending on the context, For example, *one*, 一 can be pronounced as *ichi*, *ich*, *hitotsu*, and more rarely *kazu*, *hajime* and *hi*; 九 meaning *nine*, as *kyu*, *ku*, *kokono.*

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