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Digit Span and Articulatory Suppression: A Cross-linguistic Comparison

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Native speakers of six languages (Chinese, English, Finnish, Greek, Spanish and Swedish) were tested for digit span with and without articulatory suppression. The results showed that under control conditions Chinese speakers obtained a larger digit span than speakers of the remaining languages, who did not differ among themselves. However, under articulatory suppression, these differences were eliminated and suppressed digit span was equivalent across the languages. These findings provide empirical support for the view that attributes cross-linguistic differences in digit span to variation in the articulatory duration of digit names and the rate of subvocal rehearsal between languages.

INTRODUCTION

Miller (1956) proposed that the capacity limit of immediate memory span lies within the range 7 ± 2 items. The Chinese, however, have been known to exceed this boundary and have recorded digit spans of 9.9 (Hoosain, 1984). It has been known for some time that the Chinese outperform English speakers in tasks such as rote memory for text (Pyle, 1918) and memory span for digits (Hao, 1924). This was confirmed more recently by Stigler, Lee and Stevenson (1986).

Hoosain (1982) reported a correlation between pronunciation speed and digit span. The high level of performance by Chinese speakers in digit span tasks may, therefore, be a feature of the language, in that digit names are monosyllabic and shorter in terms of articulation duration

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than, say, English, even though the latter contains only one bisyllabic digit name (Hoosain, 1984). Actual articulation duration rather than the number of syllables, however, is the crucial variable in determining differences in speech rate between languages, as Hoosain (1984) has shown that *six* takes longer to articulate than *seven* (see also Baddeley, Thomson, & Buchanan, 1975).

A cross-linguistic study by Naveh-Benjamin and Ayres (1986) found that digit span was larger for languages in which speech rate (as estimated by reading speed) was faster. Digit span for English, for example, was greater than Arabic (7.21 and 5.77 respectively) and the relationship between the languages was predicted by reading time (256 and 370 msec per digit respectively). Studies of bilinguals have shown that larger digit spans are obtained in the language in which speech rate is fastest (Chincotta & Hoosain, 1995; Chincotta & Underwood, 1996; da Costa Pinto, 1991; Ellis & Hennelly, 1980).

The range of findings from monolingual, bilingual and cross-lingual studies is neatly accommodated by working memory theory (e.g. Baddeley, 1990). This model offers a detailed explanation of the relationship between speech rate and memory span and proposes that immediate memory capacity is principally determined by two factors: phonological loop capacity and the articulatory duration of items. The phonological loop component of working memory consists of two subsystems operating in tandem: a passive phonological store and a dynamic articulatory control process. The phonological store maintains information for approximately 2 sec, after which it becomes irretrievable due to trace decay. However, material may be maintained more or less indefinitely in the phonological store by the refreshing action of the articulatory control process through subvocal rehearsal. When the renewal of traces is prevented by the concurrent articulation of an irrelevant phrase (Murray, 1965), word length ceases to be a determinant of memory span (Baddeley, Lewis, & Vallar, 1984) and bilingual digit span differences are eliminated (Chincotta & Hoosain, 1995). The time-limited basis of the phonological loop, then, provides a natural explanation for the word-length effect and the inverse relationship between memory span and the articulatory duration of items.

Although the evidence we have described suggests that it is reasonable to attribute cross-linguistic variation in digit span and the superior performance of Chinese speakers to differences in the articulatory duration of digit names between languages, this view has not been tested empirically. Over the past few years, we have been engaged in testing a range of languages that vary in terms of articulation duration for digit names in an attempt to assess various aspects of bilingual information processing. The digit span data of native speakers of six languages (Chinese, English, Finnish, Greek, Spanish and Swedish) allowed us to address a relatively simple question: Is the superior memory span ability of the Chinese due exclusively to shorter articulatory durations for digit names and phonological loop functioning, or are there other factors that contribute towards their ability to outperform speakers of other languages in digit span tasks?

Working memory theory proposes that articulatory suppression engages the articulatory control process, thereby diminishing the involvement of the phonological loop. Under such circumstances, differences in articulation duration between items cease to be an influential determinant of memory capacity, as recall involves non-phonological factors. If the larger digit span of Chinese speakers is mediated by a relative efficiency in the articulation duration of digits, working memory theory predicts that cross-linguistic differences in digit span will be abolished by concurrent articulation. If, on the other hand, the larger digit span for Chinese speakers relative to other languages persists under articulatory suppression, an alternative explanation of the superiority of Chinese speakers in digit span tasks would be required.

METHODS

Subjects

The subjects consisted of 112 native speakers of Chinese (Cantonese), English, Finnish, Greek, Spanish and Swedish. All the subjects were undergraduate or postgraduate students and registered with the same British university, with the exception of the Finnish and Swedish students, who were studying at Finnish and Swedish universities respectively in Finland. There were 16 subjects in each language group, with the exception of the Greek and Finnish groups, which contained 24 subjects each. The ages of the students in each language group were comparable and ranged from 18 to 30 years.

Materials and Procedure

For the measurement of digit span with and without articulatory suppression, sets of random digit sequences were constructed. Each set commenced with two 2-digit sequences, followed by two 3-digit sequences and so on to a maximum of two 13-digit sequences. Identical items appearing contiguously and ascending or descending sequences were avoided. The sequences of digits were presented via a computer and each successive Arabic numeral appeared in the same position on the screen.

In the articulatory suppression condition, the legend *la-la* appeared on the screen 2 sec prior to the sequences of digits and prompted the subjects to commence articulating the suppression phrase at the rate of two phrases per second. Two seconds after the sequence terminated, the legend RECALL (or the equivalent in the other languages) prompted the subjects to commence verbal recall.

The rate of presentation for the Greek, Spanish and Swedish groups was one digit per second and for the Chinese, English and Finnish groups one digit per 1.5 sec. This variation in rate of presentation resulted from a minor difference in experimental design between the groups. In addition, the Chinese, English and Finnish language groups also performed a digit span task under visual suppression which required modification of the rate of presentation across the control and articulatory suppression conditions.

Testing continued until two errors at the same sequence length were made. Digit span was operationalised as the length of the last correctly recalled sequence. If both sequences at the last sequence length were correct, a score of 0.5 was added. Each language group was tested by a native speaker of the target language and the recall tasks were counterbalanced. Phonological transcriptions of digit names for each language are provided in the Appendix.

RESULTS

The homogeneity of variance between the language groups for each level of recall condition was examined with a Bartlett-Box Test. This analysis revealed that the variances for both the control ($F = 2.19$, $P > 0.05$) and suppressed ($F = 0.82$, $P > 0.05$) recall conditions were homogeneous (see Fig. 1). The data were subjected to a mixed-design, multivariate analysis of variance (MANOVA) in which language was a between-subjects factor and recall condition (control or articulatory suppression) was a within-subjects factor. MANOVA was chosen to obtain significance levels as well as *a posteriori* estimates of both power and effect size (partial η^2 for each analysis).

The results of the MANOVA revealed reliable main effects of language and recall condition and an interaction between these factors (see Table 1). The main effect of language was analysed further using a *t*-test and indicated that digit span in Chinese was greater than that in the remaining five languages (all $P < 0.001$); it did not differ among the other five language groups. The main effect of recall condition revealed that control digit span was greater than suppressed span (7.31 and 5.78 respectively).

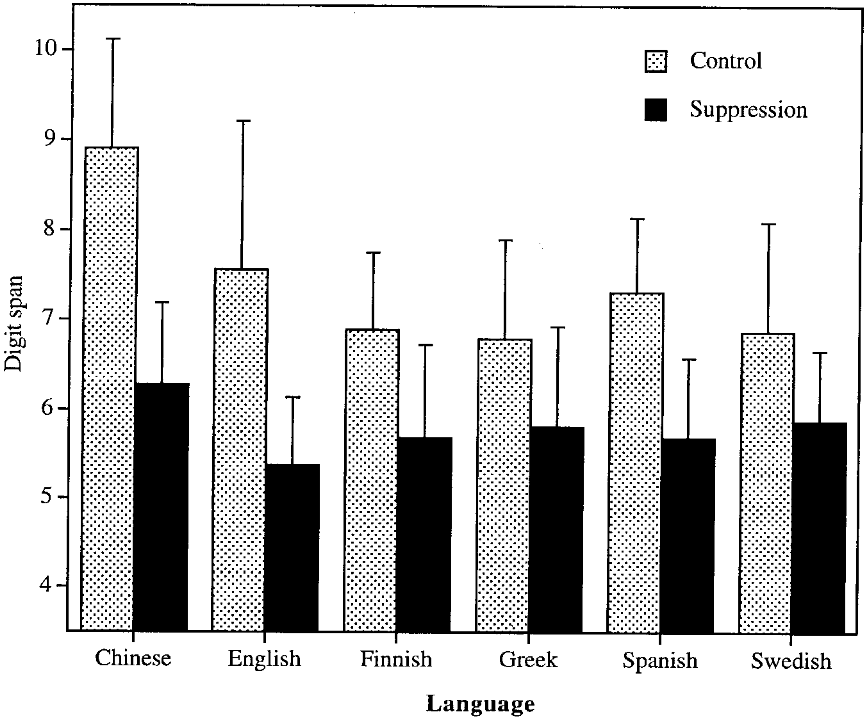

FIG. 1. Mean digit span under control and articulatory suppression conditions for six languages.

Analysis of the two-way interaction by simple main effects indicated differences between recall conditions for each language, with control span consistently greater than suppressed span (all $P < 0.01$). Between-language differences were present at the control [$F(5,212) = 9.83$, $P < 0.0001$] but not the suppressed level of recall, hence the interaction

TABLE 1
Summary of MANOVA Results

Source	*SS*	*df*	*MS*	*Power*	η^2	*F*	*P*
Language	42.28	5	8.46	0.99	0.211	5.68	< 0.01
Recall	138.96	1	138.96	1.00	0.632	181.70	< 0.01
Language × recall	20.25	5	4.05	0.99	0.20	5.30	< 0.01
Error	157.85	106	1.49				

term. Further analysis by *t*-test indicated that at the control level, Chinese digit span was greater than in the remaining languages (all $P < 0.01$); it did not differ among the other five languages. The *a posteriori* power of the effects was excellent (0.99–1.00) and the percentage variance accounted for was acceptable (20–63%).

In short, the results indicate that articulatory suppression eliminated the differences between the languages in the control recall condition and provide empirical evidence in support of the view that superior recall by Chinese speakers is mediated by phonological loop functioning.

DISCUSSION

The aim of this study was to test the nature of cross-linguistic variation in digit span. We re-examined the data from a number of studies of bilingual information processing and compared digit spans under control and articulatory suppression conditions for six language groups. Working memory theory attributes cross-linguistic variation in digit span to differences in the articulatory duration for digit names. Under articulatory suppression, the translation of visual stimuli into phonological codes is prevented by the disablement of the articulatory control process, thus reducing the contribution of the phonological loop. The present results indicate that superior digit span in Chinese is determined by phonological loop functioning, as articulatory suppression eliminated the advantage of this language over the remaining five.

Although there were slight procedural differences between the groups, the crucial variables (namely the pace and duration of articulatory suppression) were held constant. In addition, the finding that the comparisons involving Chinese, English and Finnish (where the rate of presentation was identical) did not differ from those of the remaining languages shows that the variation in presentation rate was not a major consequence in the present study.

We found no differences in digit span between the five European languages, whereas Naveh-Benjamin and Ayres (1986) found that native speakers of English obtained larger digit spans than their Spanish counterparts. One explanation for this lack of convergence between the studies is that Naveh-Benjamin and Ayres (1986) excluded the number *7* (the only bisyllabic digit in English) from the set of stimuli used to measure digit span "in order to maximise the differences between the languages" (p. 743). We believe that this curious manipulation by Naveh-Benjamin and Ayres (1986) may have exaggerated the difference between

English and Spanish digit span and that this may explain the equivalence between these two languages in the present study.

In summary, the findings of the present study suggest that the superior digit span of the Chinese speakers was mediated by phonological loop functioning and a faster rate of subvocal rehearsal as predicted by working memory theory. This finding provides empirical support for the hypothesis that attributes cross-linguistic differences in digit span to variation in the articulation duration of digit names between languages.

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APPENDIX

Phonological transcriptions of digit names (1–9) in the six languages tested (International Phonetic Alphabet)

	Language					
Digit	*Chinese*	*English*	*Finnish*	*Greek*	*Spanish*	*Swedish*
1	jat	wʌn	′yksi	′ena	′uno	ɛt:
2	ji	tu:	′kaksi	′δeeo	dos	tvo:
3	saam	θri:	′kɔlmɛ	′treea	tres	tre:
4	sei	fɔ:	′nɛljæ	′tessara	′kwatro	′fy:ra
5	ng	faɪv	′vi:si	′pente	′θinko	fɛm:
6	luk	sɪks	′ku:si	′eksee	seis	sɛks
7	tsat	′sɛvən	′sɛitsɛmæn	ef′ta	′sjete	ʃʉ:
8	baat	eɪt	′kahdɛksan	oh′to	′otʃo	ɔt:a
9	gau	naɪn	′yhdɛksæn	en′nea	′nweβe	′ni:u