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Digit Span, Reading Rate, and Linguistic Relativity

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The relations between reading time and memory span were studied in four languages: English, Spanish, Hebrew, and Arabic. Reading rate was measured either in speeded reading of digits or in normal-pace reading of stories. Faster speeded reading and normal-pace reading rates for a given language were associated with larger memory span for speakers of that language. These relations, which were shown to be monotonically related to the number of syllables or phonemes per item, extend the within-language word-length effect reported by Baddeley, Thomson and Buchanan (1975), across languages. In addition, these findings demonstrate a form of linguistic relativity: a relation between simple surface-structural features of language (number of syllables) and cognitive processing (memory span and reading rate). It is argued that this linguistic relativity may be limited by trade-offs between surface features and common linguistic practice.

Introduction

The theory of linguistic relativity asserts that language shapes or determines thought (Whorf, 1956). Initial tests and applications, which emphasized the influence of semantic categories in perception and

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cognition, ran into serious problems; despite recent persuasive restatements, the theory has fallen from the limelight (Bloom, 1981). It is reasonable, however, to give some consideration to a new type of linguistic relativity: the relationship between surface-structure features of language and cognitive processing. For example, orthographic features of written language influence reading, and certain differences in reading performance between speakers of different languages can be traced to orthographic differences (Daftuar, 1977; Tzeng and Hung, 1981; Wang, 1981). Phonetic or articulatory features of languages are also good candidates for linguistic relativity in cognitive tasks.

The present investigation focused on a procedurally simple measure of cognitive processing: the memory span, defined as the greatest number of items that can be recalled in correct order immediately after presentation. Miller (1956) suggested that memory span was constant (7 ± 2) when measured in terms of chunks or subjectively meaningful units. It now appears, however, that the bottleneck for immediate recall is more closely related to the time needed to scan mentally, identify, or rehearse the items (Baddeley et al., 1975; Puckett and Kausler, 1984).

Baddeley contends that memory span for words in non-deaf people is mediated by a rehearsal process involving an articulatory loop of approximately two seconds' duration (Baddeley, 1983; Baddeley and Hitch, 1974; Baddeley, Lewis and Vallar, 1984). Memory span is shorter for items that take longer to rehearse covertly; accordingly, memory span is inversely related to word length across a wide range of materials within a given language, except when articulatory rehearsal is suppressed. Case, Kurland and Goldberg (1982) suggest instead a limited workspace capacity but arrive at an equivalent conclusion: memory span decreases with the amount of time or capacity needed to process the individual items.

Covert rehearsal rate for verbal material can be predicted from phonological features such as the number of syllables involved, or it can be estimated more directly from measures of the time needed to read items. It has been shown that individual differences in memory span can be predicted from the rate at which the material can be whispered or subvocalized (Standing, Bond, Smith and Isely, 1980). Similarly, developmental differences in memory span are closely related to measures of rehearsal time or processing speed (Case et al., 1982; Hulme, Thomson, Muir and Lawrence, 1984). Thus the limited-duration articulatory-loop hypothesis accounts for memory performance across individuals and ages, as well as across stimuli.

Given the importance of articulation rate for memory span, it follows that memory span should vary across languages that differ in the time to read a given set of items. This prediction has been confirmed in comparisons of English and Welsh (Ellis and Hennelly, 1980) and English and Cantonese (Hoosain, 1982, 1983). Unfortunately, results cannot readily be compared across these studies since they produced conflicting estimates of both reading speed (375 vs. 321 msec per monosyllabic word) and memory span for English (6.55 vs. 7.3 items)—differences that may be related to procedural and sampling variables. In addition, the use of just two languages does not permit us to be confident in extrapolating to other conditions. The range of word lengths in these earlier studies was restricted. Hoosain (1982) does not provide quantitative information about differences in word length in English and Cantonese, while the Ellis and Hennelly study compared languages that show only about 10% difference in word length, both in terms of number of syllables and in number of phonemes. These restricted ranges could limit the generality of these results across a wider range of word lengths (in other languages).

The present study was designed to extend the work on cross-linguistic aspects of memory span and to address theoretical concerns. First, selecting and testing memory span and reading rate in four languages provided a much wider range of word lengths for the material tested. The range selected is much greater than that in the English–Welsh comparison: digits in Arabic have more than twice as many syllables per item as those in English. This allows us to be more accurate in estimating quantitative aspects of the variables, and it enables us to examine the relationships between word length, word production rate, and memory span. By choosing languages in which the average word length varies, it should be possible to decide whether the word-length effect (Baddeley et al., 1975) holds across languages. If Baddeley's explanation of the word-length effect has some merit, then we would expect speakers of languages with greater word length to take more time in rehearsing the information, thus resulting in more decay of items and smaller memory span.

Second, the results should reveal whether or not the capacity for immediate-recall storage is a universal constant, and, if so, whether the duration of the articulatory loop approximates two seconds (Baddeley, 1983; Baddeley and Hitch, 1974; Baddeley et al., 1984). This universality is an important prediction of any theory of human information processing interested in identifying important factors determining performance.

In addition, the study of memory span across languages may be important for practical reasons. Purported measures of intelligence which rely in part on short-term memory performance, such as the Wechsler test, may need to have norms adjusted according to the language of the testee (Ellis and Hennelly, 1980); the same is true for testing prelinguistically deaf individuals, whose first language is a sign language (Belmont and Karchmer, 1978). Differences in short-term memory performance, in turn, could influence demonstration of arithmetic skills, since digit memory may be an important factor in the speed with which mental arithmetic calculations can be completed (Ellis and Hennelly, 1980; Hoosain, 1983; Suppes, Hyman and Jerman, 1967).

Finally, one might wonder whether the articulatory surface features of languages could affect other kinds of behaviour aside from those relying directly on memory. The cross-linguistic studies cited (Ellis and Hennelly, 1980; Hoosain, 1983) have looked only at speeded reading rate. Differences in normal reading rate, on the other hand, might affect the time it takes to complete a wide variety of tasks.

In order to address these issues, native speakers of each of four languages participated in tests of digit memory span, speeded reading rate for digits, and normal reading rate for a story. All time measures were made with items produced in context, rather than with syllables in isolation; this ensured that results would be relevant to normal linguistic practice. The languages chosen (English, Spanish, Hebrew and Arabic) differ in the mean number of syllables per word for the digits used (0–6, 8–9): 1.00; 1.625; 1.875 and 2.25, respectively. (Regarding the use of a syllable as a basic unit in rate of articulation, see Lenneberg, 1967.)

While it might be difficult to equate groups on all possible variables in such a between-subject design, a within-subject design using bilinguals (as employed by Ellis and Hennelly and Hoosain) faces a different but equally grave danger: experience may not be equivalent in the two languages. Even if people appear on various criteria to be balanced (equal fluency) bilinguals, it is likely that their schooling will have favoured one language over the other. As one instance of this problem, we have found that foreign students attending college in the United States have often received much of their mathematical and science training in English in their home country. Thus, the finding (from a pilot study) that some of these students have larger memory spans in English than in their first language cannot safely be interpreted as reflecting characteristics of the languages used.

In order to attribute the results as far as possible to linguistic rather than to situational or group differences, the groups used were equated on relevant subject variables and were run under identical conditions.[1]

[1] Initially, one of the authors tested speakers of English and Spanish in the United States, and the other author tested speakers of English, Hebrew and Arabic in Israel. Upon comparing results for English, it was found that memory span differed by more than one item and whisper rate by over 100 msec per item. Therefore it seemed preferable to eliminate possible effects of procedure, experimenter and location.

Table I

Subjects' Characteristics in the Different Languages Used

Language	Age	Gender distribution (Percent males)	Years of formal schooling	Field of study (Percent in humanities and social sciences)
English	23.3	52	13.8	52
Spanish	24.1	56	14.3	44
Hebrew	22.7	50	13.7	57
Arabic	22.9	55	13.6	47

Method

Subjects

One hundred and twelve students (age 20–30) from Ben-Gurion University took part. All had some knowledge of Hebrew, and all were run in their native language: Arabic (36), English (23), Hebrew (28) or Spanish (25). Groups were very similar in terms of years of formal schooling, field of study, gender distribution and mean age (see Table I). Most subjects were paid for participation, although a few in each group received course credit.

Materials

A. *Digit Span.* For each language there were 24 lists of digits. Stimuli were selected randomly with replacement from the set of digits 1–6, 8–9; the number 7, which has two syllables in English, was excluded in order to maximize the differences between languages for this study, and the number 0 was excluded because its length is ambiguous in English (being pronounced as "zero", "oh", "ought" or "nought"). List length increased from 5 to 10 items, decreased to 5, and then increased and decreased again. Lists were read by a native speaker of each language at a rate of one digit per second. Each recorded list was preceded by a warning tone.

B. *Speeded Digit Reading.* Two sheets of four lines were prepared. Each line contained 25 digits (1–6, 8–9, in random order) in five 5-digit groups.

C. *Normal Story Reading.* A 227-word excerpt was taken from the English version of "The War of the Ghosts" (an Inuit story used for studies of memorial reconstruction by Bartlett, 1932). Bilingual translators rendered this excerpt in Arabic (185 words), Hebrew (180 words), and Spanish (221 words).

Procedure

In the digit memory-span task, subjects were instructed to recall the items in each list in correct order immediately after list presentation. The response sheet indicated the appropriate number of digits for each trial. Fifteen seconds were allowed for response following each pre-recorded list. Next, in the speeded digit-reading task, subjects were asked to whisper the lists of digits (quietly but audibly, so the experimenter could monitor performance) as fast as possible; they were timed for reading each of the two pages. Finally, in the story-reading task, subjects were timed after being asked to read the story aloud at a normal rate, as though reading to a group of friends. Subjects were run in groups of two to six for the digit-span task, and individually in the reading tasks.

Results

Memory span for each subject was computed as the longest list length for which the subject answered all trials completely correct (and for which all shorter lists were also answered correctly), plus 0.25 for each single longer correctly-recalled list (Woodworth and Schlosberg, 1954). Speeded digit whispering rate was averaged for the two trials of each subject and was then divided by 100 to obtain the average duration per digit. Split-half reliabilities for the memory span and speeded digit-reading measures were 0.86 and 0.95, respectively.

Table II presents the results for each of the tasks, averaged for each language. In the digit-span task, span was highest in English and lowest in Arabic. This trend was confirmed by an analysis of variance, which showed the effect of language to be significant [$F(3, 108) = 9.81$, $p < 0.01$]. A Newman–Keuls test showed all pairwise comparisons, except Hebrew vs. Spanish, to be significant ($p < 0.05$).

For the speeded digit-reading task, Column 4 of Table II shows that the fastest rate was in English and the slowest in Arabic. This trend was confirmed by an analysis of variance which showed the effect of language to be significant [$F(3, 108) = 29.47$, $p < 0.01$]. Here too all pairwise comparisons except Hebrew vs. Spanish were significant ($p < 0.05$; Newman–Keuls test).

For the normal-pace story-reading task, the results, shown in Column 8 of Table II, were in the same direction as those obtained for speeded digit reading, with English fastest and Arabic slowest. The effect of language was significant [$F(3, 108) = 58.14$, $p < 0.01$], and all pairwise comparisons were significant, except for Hebrew vs. Spanish ($p < 0.05$; Newman–Keuls test).

Digit memory span and speeded reading of digits were significantly negatively correlated across subjects within each language (r varied from -0.28 to -0.50, $p < 0.05$), as well as when pooled across languages ($r = -0.49$, $p < 0.01$). The same trend was observed in the relation between digit memory span and normal story reading across languages ($r = -0.48$, $p < 0.01$). The two reading-rate measures were significantly positively correlated ($r = 0.75$, $p < 0.01$).

Table II

Memory Span and Reading Rate

Language	1 Number of subjects	2 Mean number of syllables per digit	3 Actual memory span[a]	4 Speeded digit reading[b]	5 Immediate recall capacity[c]	6 Speeded digit reading[d]	7 Predicted memory span[a]	8 Story reading[c]
English	23	1.00	7.21 (1.17)	0.256 (0.038)	1.85 (0.39)	0.256 (0.038)	7.81	57.1 (5.91)
Spanish	25	1.625	6.37 (0.93)	0.287 (0.048)	1.83 (0.27)	0.177 (0.03)	6.97	72.2 (9.15)
Hebrew	28	1.875	6.51 (0.64)	0.309 (0.054)	2.01 (0.43)	0.165 (0.029)	6.47	70.5 (8.62)
Arabic	36	2.25	5.77 (0.83)	0.370 (0.044)	2.13 (0.45)	0.164 (0.02)	5.41	87.4 (7.23)

[a] Items. [b] Sec. per digit. [c] In sec. [d] Sec. per syllable.

Note: Column 1 shows the number of subjects run in each language. Column 2 shows mean number of syllables per digit for each language. Column 3 shows the actual memory span, followed by mean seconds per digit for speeded digit reading in Column 4. Column 5 provides an estimate of actual immediate-recall capacity, followed by mean seconds per syllable for fast digit reading in Column 6. Predicted memory span based on a storage of 2 sec is given in Column 7, followed by the total time to read the story in Column 8. Standard deviations for performance are provided in parentheses.

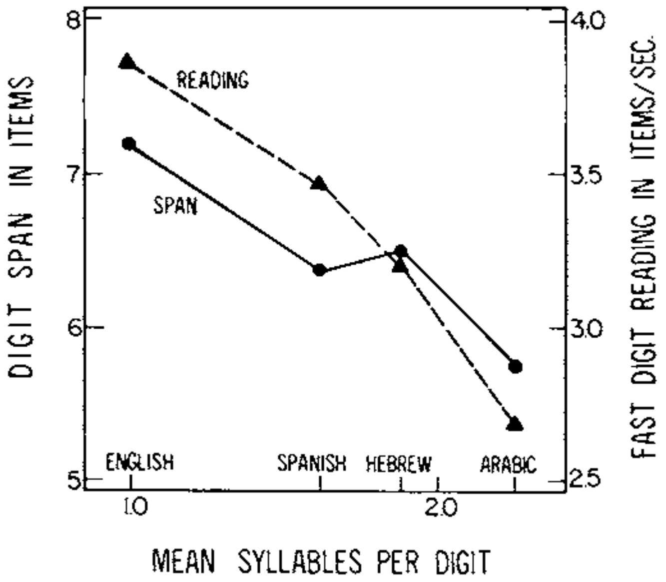

Figure 1. Digit memory span in items and speeded digit-reading rate in items per second as functions of the mean number of syllables per digit for English, Spanish, Hebrew and Arabic.

In order to assess the relations between reading rate and memory span in terms of the word length in each language, the digit memory span and the speeded digit-reading rate for each language are plotted in Figure 1 as a function of mean syllables per digit. In general, a larger number of syllables per item in a language is found with slower reading rates and a smaller memory span. The same holds true if the data are analysed in terms of the number of phonemes per item. (Although we have used the counts of syllables or phonemes of the digits 1–6 and 8–9, this count is closely proportional to the average number of syllables or phonemes for other types of material that we examined for these four languages, including the story excerpts.)

The relations between unit length in a language and both reading speed and memory span seem to be approximately linear for the languages tested: each additional syllable contributed to an increase of 120 msec in speeded reading of a digit, 145 msec in normal-pace reading of a word in the story, and to a decrease of 1.3 units in the memory span.

The mediating role of the number of syllables in the correlation between memory span and reading rate across languages is demonstrated when differences in number of syllables are partialled out. The partial correlations between memory span and reading-rate measures decrease significantly ($p<0.05$) from -0.49 to -0.24 for speeded digit reading and from -0.48 to -0.20 for normal story reading.

Finally, the capacity in time units of immediate-recall store (the articulatory loop) was computed for each language group as the product of memory span in digits and speeded reading time per digit (see Table II, Column 5). Values range from 1.83 sec in Spanish, to 2.13 sec in Arabic. Differences between English or Spanish, on the one hand, and Hebrew or Arabic, on the other, were significant ($p<0.05$; Newman–Keuls), but the differences within each of those pairs were not significant.

Discussion

These findings confirm the important relationship between articulation (or rehearsal) rate and immediate memory span. First, individual scores for speeded whispering of a given set of items can predict memory span (Baddeley et al., 1975; Standing et al., 1980). Second, using a between-subject design, differences in reading rate across four languages were shown to be associated with memory span variation, as previously found in a within-subject design for pairs of languages (Ellis and Hennelly, 1980; Hoosain, 1979, 1982, 1983).

The results also show that, for languages varying widely in mean word length, the average size in syllables (or phonemes) of a meaningful unit, such as a word or a digit, is inversely related to reading speed (either fast or normal pace) and to memory span. This provides a clear indication that the word-length effect reported for differences within a language (Baddeley et al., 1975) applies to differences between languages as well. Furthermore, the current results, while showing that memory span expressed in terms of items stored varies both between individuals and across languages, further confirm previous reports that immediate store capacity can be described as reasonably constant in terms of the duration of speech that can be stored (Baddeley, 1983; Baddeley et al., 1984) or the amount of time that can be devoted to processing (Case et al., 1982).

Although as a first approximation word length can be operationalized as the number of syllables (Lenneberg, 1967), in some cases it might be better to use phonemes per item instead. In the present case, the syllabic and phonemic counts were closely proportional across languages (number of phonemes in the digits used in the four languages was 22, 33, 35 and 47 for English, Spanish, Hebrew and Arabic, respectively). Some languages, however, may differ in the average number of phonemes used per syllable, which, in turn, could affect articulation rate independently of the number of syllables involved. Hoosain (1983) found faster digit reading and longer digit memory span in Cantonese than in English, despite both languages having one syllable/digit; this can probably be attributed to the lower average phoneme/syllable count in Cantonese digits.

Note that although the present results on memory span were obtained only for digits, the conclusions are likely to apply to other materials as well. Unlike Cantonese, in which the digits are unusually brief as compared with other words (Hoosain, 1983), the languages studied here yielded a close association between syllables/word in digits and in the stories. Furthermore, interlinguistic differences in speeded reading rate for digits were strongly correlated with differences in the time it took to read a story at a normal pace. This latter result suggests that the findings may ultimately prove relevant to a variety of verbal tasks, not just those that depend primarily on memory. In other words, differences in the articulatory/phonemic demands of languages may affect performance in areas such as reading and conversation, regardless of whether or not overt vocalization is involved (Ayres, 1984; Haber and Haber, 1982). In sum, we have observed simple relations between articulatory structure (number of syllables or phonemes), normal or fast reading rates, and memory span across four languages. These findings provide support for the new linguistic relativity: the relationship between simple structural features of language and cognitive processing.

A closer examination of the present data, however, could lead us to some qualifications on this linguistic relativity. Although the estimates of the capacity of immediate recall store are close to the two seconds reported by Baddeley et al. (1975), it is also true that these estimates increase with reading time across languages. So it is evident that speeded reading time per item is not a perfect predictor of memory span across languages.

Conversely, suppose that the articulatory loop had a fixed average capacity of two seconds of material; then memory span could be predicted as two divided by the time taken to read one digit. Actual differences in memory span across languages were smaller than predicted (see Table II, Columns 3 and 7); the observed range was 5.77 to 7.21 items, rather than 5.41 to 7.81.[2] It is also noteworthy that the average time taken to whisper a syllable was inversely related to the

[2] Note, also, that not all the effect of language on memory span is mediated by reading rate. An analysis of covariance using speeded digit-reading rate as a covariate revealed that a significant portion of the differences in memory span between languages remains, even when differences in speeded digit-reading rate between languages are factored out [$F(3, 108) = 3.08$, $p < 0.05$]. So, there could be ways in which languages affect memory span other than through reading rate—for example, by affecting search rate or order encoding (Dempster, 1981).

mean number of syllables per item (Table II, Column 6): that is, the slowest time per syllable and the smallest number of syllables per digit occurred together (in English). Thus, structural features (the number of syllables or phonemes per item) did not completely determine reading rate in items per second (e.g., the ratio of syllables per item between English and Arabic was 2.25, while the ratio of speeded digit-reading rates between those languages was only 1.48). Why don't the ratios between reading rates, on the one hand, and memory span and item length, on the other hand, coincide for the languages used?

Part of the answer could lie with variables other than structural features of the languages. For example, reading rate may have varied across subject populations for various reasons (e.g., motivation or background) despite attempts to match groups and standardize procedures. This, however, would still not explain why the cross-linguistic memory span and reading-rate ratios disagreed. A simpler interpretation, however, given the regularity of the trend described above across the four languages, would involve a trade-off between syllable number and syllable speed.

The mechanism of this trade-off remains to be elucidated. One possibility is that some languages with more syllables per word may, in fact, not be more demanding to articulate if the high syllable count is compensated for by a low average number of phonemes per syllable. Our data, however, do not support such a claim, since the differences between languages in number of phonemes per syllable, in both the digits and the stories used, were very small. Another mechanism by which this trade-off may be accomplished is speech habits related to each language. Speakers of articulatorily complex languages (possessing a high number of syllables or phonemes per word) may learn to shorten the time necessary to read a given word; this could involve slurring, cutting of syllables, shortening of pauses, and so on.

Whatever the mechanism for the trade-off, it leads to a further question: why should this trade-off exist? Why would users of languages with more syllables per message tend to produce those syllables more quickly? We are tempted to speculate that there is some universal (biologically determined) optimum rate of information flow towards which all languages naturally evolve in order to suit the human capacity for message transmission and reception (see Zipf, 1935; Miller and Newman, 1958; Miller and Chomsky, 1963).

A dramatic illustration of this principle is provided by American Sign Language (Bellugi and Fischer, 1972). On the average, signs take much longer to produce than spoken words. Bilingual speakers of American Sign Language and English nevertheless manage to tell a given story as quickly in signs as in English by using fewer signs than they do words.

Bellugi and Fischer proposed a common limit on the rate of "propositionalizing". Thus, the trade-off between syllables (or units of production) per word (or unit of meaning) and the rate of production is not restricted to articulatorily codable material; instead, it seems appropriate at least for verbal material in general. Such a trade-off, based on a universal processing-rate bottleneck rather than a universal store capacity, would represent an important limitation to surface-structure linguistic relativity.

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