A bilingual word-length effect: Implications for intelligence testing and the relative ease of mental calculation in Welsh and English

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Five experiments are reported. These demonstrate that, in bilingual subjects, Welsh digits take longer to articulate than their English equivalents, and this difference is paralleled by the finding that digit span in Welsh is significantly smaller than that in English. These differences are attributable to bilingual word-length differences, and it is this, rather than intellectual differences, which explains why the norms for Welsh children on the digit span test of the Welsh Children's Intelligence Scale are reliably less than those for the same age American children tested on the similar digit span procedure of the Wechsler Intelligence Scale for Children. These findings lead to the prediction that mental calculation in the Welsh language will be more difficult than that in English.

An interaction between translation and storage in working memory is demonstrated. This finding accords with the working memory formalization of Baddeley & Hitch (1974). It is shown that translation towards the language of preference is faster than that in the reverse direction.

Individual differences in the span of immediate memory, as measured using strings of random digits as stimuli, have commonly been utilized as subcomponents of intelligence tests. In the Terman–Merrill (1974), for example, a 10 year old child is tested on his ability to repeat six-digit strings in the correct order. Similarly, in the Wechsler Intelligence Scale for Children (WISC, 1949) the same age child is tested for his ability to repeat digit strings both in their original and reversed order. The sum of forwards and reversed spans measured on this test are compared with the norm score of 9 for a child of this age.

Recently, however, Baddeley *et al.* (1975) have demonstrated that the immediate memory span for short words is greater than that for long words. This effect cannot be solely attributed to the number of syllables or phonemes in the stimulus. Rather the effect is truly one of word length: even when the number of syllables and phonemes is held constant, the memory span for words which take a short time to articulate (e.g. wicket, phallic) is greater than that for words which take a long time to articulate (e.g. zygote, coerce). In general the span could be predicted on the basis of the number of words which the subject could read in approximately 2 s.

This word-length effect is relevant to the use of memory span as a subcomponent of intelligence tests if the following three cases are considered.

(i) When norms for subject populations of different language are being compared, if the articulation time for digits is longer in one language than the other, it is to be expected that the average span will be smaller in speakers of the former language. This difference would be attributable to this effect rather than to any intellectual differences between the two populations.

(ii) When performance in each of two spoken languages is compared for bilingual subjects it again follows that, if digit articulation time differs across these languages, one must also expect a difference in span. This implies that this task cannot be used as a predictor of relative language competence for bilingual subjects.

(iii) In the development or modification of intelligence tests for use in different languages or dialects, it might seem reasonable to assume, because its information content is similar across languages, for the purpose of testing 'a number is a number, whatever the language', and thus simple test translation would suffice. Thus a test normalized and written for English subjects might be thought suitable in a translated form for use with

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subjects of a different language. This is not the case, normalization must again be performed whenever a test is modified for new languages or dialects.

It is argued that the following three experiments demonstrate these points.

Experiment 1

Casual observation led to the suggestion that it takes longer to articulate digits in the Welsh language (dim, un, dau, tri, pedwar, pump, chwech, saith, wyth, naw) than their English equivalents (nought, one, two, three, four, five, six, seven, eight, nine). This was therefore tested experimentally.

Subjects

Twelve bilingual subjects in the 20–30 year age range were tested. The minimum criteria for bilingualism were:

(1) Subjects had to have been educated in both Welsh and English and to regularly speak both these languages.

(2) Having assigned performance in his stronger language the score 10, in ranking his ability on his secondary language on the arbitrary scale 0–10, the subject was not to assign to this a value of 5 or less. Thus any person rating himself as having a spoken ability in his weaker language less than half that in his primary language was excluded from the study.

Of the 12 subjects participating in this experiment only four considered themselves to be more competent in the English language.

Method

A sheet of 20 lines each containing the 10 digit numbers 0 to 9 in random order was prepared. The subjects were required to read these numbers aloud as fast as possible. They read this list eight times, alternating language on each trial. Six subjects performed the first trial in English, six in Welsh. Reading times for the 200 digits was recorded on each trial, and a mean time calculated for each language.

Results and discussion

The resultant data were analysed as a two-factor ANOVA with replications (12 subjects × 2 languages × 4 replications). Individual differences were seen: the subjects factor was significant at the 1 per cent level ($F = 73{\cdot}5$, d.f. = 11, 72, $P < 0{\cdot}01$). There was a significant difference in reading time for the two languages: the mean reading time for the 200 digits in Welsh was 77·1 s compared with that in English of 64·2 s ($F = 383{\cdot}0$, d.f. = 1, 72, $P < 0{\cdot}01$). The two-way interaction ($F = 21{\cdot}4$, d.f. = 11, 72, $P < 0{\cdot}01$) demonstrates that individual differences are present re the relative difficulty of the Welsh condition compared to the English condition.

The intial hypothesis was therefore confirmed: even though only one-third of the subjects rated themselves more competent in English than in Welsh, every subject read the digits faster in English. It took on average 385 ms to read a Welsh digit compared with 321 ms to read an English digit. That is, on average, a subject would read six digits in English in the time taken to read five in Welsh.

Experiment 2

The findings of Expt 1 lead to the prediction that these subjects would have a greater immediate memory span for English digits than for Welsh digits, even though the majority of them considered themselves more competent in the Welsh language. The same 12 subjects were therefore tested in Expt 2 to assess this prediction.

Two translation conditions, where the subject was to report the digits in a language other than that in which they were given, were included for two reasons:

(1) To investigate if translation is equally easy in both directions: from English to Welsh, and Welsh to English.

(2) To investigate the interaction in working memory between the processing necessary for translation and the storage necessary in the span task. This is, in effect, the same paradigm as used by Baddeley & Hitch (1974), who investigated the effects of memory preloads on the processing involved in verbal reasoning and comprehension. They found that with preloads of up to three items there was no significant effect on either speed or accuracy on these tasks, whereas six-item preloads caused a reduction in performance levels. They suggest from these and other findings that working memory can be usefully regarded as consisting of a central processor unit (CPU) which undertakes executive functions and which can be used for storage should processing demands be small. In addition there is postulated an articulatory loop (AL), the phonemic part of working memory, which can store up to about three items. This schema is used to explain the preload results – with small preloads storage is primarily AL based, with no resultant interaction between storage and CPU processing. Should storage demands exceed the capacity of the AL, the remainder must be stored in the CPU resulting in less 'work space' available for processing functions and thus reduced processing performance.

Following this line of reasoning, in the present experiment the subject is to remember as many items as possible. Thus storage demands will exceed the capacity of the AL, and a storage/translation trade is thus predicted. Here, however, the effect of processing (translation) on storage is being investigated, as opposed to the effects of storage on processing as studied by Baddeley & Hitch (1974) and Hitch & Baddeley (1976).

Method

A cassette recorder was used for stimulus presentation. A bilingual person prepared recordings by reading strings of digit stimuli at a rate of one per second, with the warning signal 'ready' preceding every string.

There were four experimental conditions, two used Welsh digits and two English digits. For each condition the stimuli consisted of three trials at each length of string from two to 10 digits, and these were presented in ascending order of length. Digits were chosen at random with the restriction that no digit could be repeated within any string.

The presentation order of the four conditions was randomized across subjects. The four conditions were: same language condition 1: English stimuli, English response; same language condition 2: Welsh stimuli, Welsh response; translation condition 3: English stimuli; Welsh response; and translation condition 4: Welsh stimuli, English response.

The subject was to listen to the strings and, upon a cue to respond, either to repeat the digits he had heard in the correct order and the same language, or, in the translation conditions, to report those digits he had heard in the correct order but in a different language: if the stimuli were presented in Welsh he was to respond in English, and vice versa. Within any condition he continued in this fashion until he had made incorrect responses on three consecutive trials. His span was calculated by application of the formula: span = 1 + (number of trials correct/3).

Results and discussion

The mean spans for the four conditions are shown in Table 1. A two-way ANOVA (12 subjects × 4 conditions) resulted in both main factors and the interaction being significant at the 1 per cent level. Individual differences are again present ($F = 18{\cdot}3$, d.f. = 11, 33, $P < 0{\cdot}01$). The conditions factor ($F = 15{\cdot}4$, d.f. = 3, 33, $P < 0{\cdot}01$) was broken down using a Duncan Multiple Range Test which demonstrates a significant superiority of performance in English over that in Welsh (EE > WW, $P < 0{\cdot}01$). This is the case even though the majority of subjects rated themselves more proficient in the Welsh language, and it is suggested in the light of the results of Expt 1 that this differential is the result of Welsh digits taking longer to articulate than English digits.

Table 1. Effects of language and translation upon mean memory span for the 12 subjects of Expt 2

	Same language conditions		Translation conditions	
	EE	WW	EW	WE
Language of stimulus	English	Welsh	English	Welsh
Language of response	English	Welsh	Welsh	English
Mean digit span	6·55	5·77	5·11	5·64

The application of an *a posteriori* Scheffé test confirms the interaction between translation and storage: the contrast between the same language conditions (EE and WW) and the translation conditions (EW and WE) is significant at the 1 per cent level. Thus the need to translate from a stimulus of one language to a response of another reduces the item storage levels from those attained when storage alone is involved. This storage/processing trade is of interest in two lights. Firstly it is further evidence which accords with the working memory formalization of Baddeley & Hitch (1976). A more practical consideration, however, is that in situations where translation is necessitated, especially in the early stages of second language learning, it is predictable that memory span will be reduced, and this will result, for example, in lower levels of comprehension of sentences as a whole – a task which necessitates the remembering of not only the words constituting the sentences but also their relative position.

The superiority of the English response (EE – EW = 1·44, $P < 0{\cdot}01$) is greater than the superiority of the English stimulus (EE – WE = 0·91, $P < 0{\cdot}01$). This difference is in effect the contrast between the EW and WE conditions which are significantly different at the 0·05 level. This might suggest that whilst both stimulus and response effects contribute to the superiority of English span over Welsh span (EE – WW = 0·78, $P < 0{\cdot}01$), the main contribution is from the English response effects. It should however be noted that this finding can also be explained by the suggestion that translation from Welsh to English requires more processing than that from English to Welsh. This contrast between the decremental storage differences resultant from Welsh to English translation (EE – WE = 0·91) and that resultant from English to Welsh translation (WW – EW = 0·66) is however insignificant.

Baddeley *et al.* (1975) demonstrated that a subject's span could be predicted to be the number of words that could be read in approximately 2 s, and in parallel to this found a significant correlation between a subject's reading speed and his memory span. Both of these findings are confirmed here:

(i) a Spearman rank-order correlation performed on the digit reading times determined in Expt 1 and the spans resultant in Expt 2 yields a significant correlation of −0·47, $P < 0{\cdot}05$;

(ii) the mean time taken to read a Welsh digit in Expt 1 was 385 ms, the mean Welsh span in Expt 2 was 5·77: these digits could be read in 2·22 s; comparable figures for the English language are a digit span of 6·55 items which at a reading rate of 321 ms/digit could be read in 2·10 s.

Experiment 3

The differential found between the two conditions of Expt 1 are attributable to response effects since the numerical stimuli were the same in the two conditions. If, however, digit names rather than figures are used as stimuli, it is possible to additionally investigate both stimulus effects and the effects of translation demand in a reading task. This latter investigation, Expt 3b, will test the suggestion proposed in Expt 2 that, for subjects whose preferred language is Welsh, translation to their preferred language (English to Welsh) is easier than that in the reverse direction.

The memory span differential obtained in Expt 2 was again attributed to factors operating at the response level. However, it is unclear whether this is the result of language differences in word length (and thus the digit names of Welsh are more difficult to remember than those of English) or whether it is a result of differential familiarity (the Welsh speakers who were tested may have dealt more with numbers in the English language). These hypotheses are investigated in Expt 3c.

Experiment 3a

Method. Eight new subjects were found who fulfilled the criteria of bilingualism outlined in Expt 1. To ensure that this sample was consistent with the earlier one, the subjects were tested using the procedure of Expt 1.

Results. The data, analysed as a two-factor ANOVA with replications, yield a similar pattern to that of Expt 1: the subjects factor ($F = 12{\cdot}5$, d.f. = 7, 48, $P < 0{\cdot}01$), language factor ($F = 100{\cdot}33$, d.f. = 1, 48, $P < 0{\cdot}01$), and two way interaction ($F = 6{\cdot}05$, d.f. = 7, 48, $P < 0{\cdot}01$) were all significant at the 1 per cent level.

The subjects were again slower at reading the 200 digits in Welsh ($X = 66{\cdot}6$ s) than in English ($X = 57{\cdot}6$ s). These figures yield estimates of reading times of 333 ms per Welsh digit (cf. 385 ms in Expt 1) and 288 ms per English digit (cf. 321 ms in Expt 1).

This second sample therefore shows similar bilingual characteristics to the first.

Experiment 3b

The procedure of Expts 1 and 3a involves presentation of digit figures (e.g. '9') and either English ('nine') or Welsh ('naw') responses. Thus any difference between the conditions is attributable to the differing responses. If, however, the digit words are used as stimuli, it is possible to investigate stimulus effects, and also to study the effects of translation demand in the reading task.

Method. The eight subjects of Expt 3a were therefore next tested for their overt reading speed of (i) 200 English digit words with English response, (ii) 200 Welsh digit words with Welsh response, (iii) 200 English digit words with Welsh response, and (iv) 200 Welsh digit words with English response. Conditions (i) and (ii) are same language conditions, (iii) and (iv) are translation conditions. The stimuli were again presented as a sheet of 20 lines, each line containing the 10 digit names in a random order. All the subjects were tested twice on each condition, the order of presentation of conditions being counterbalanced across subjects. Reading times were measured with a stopwatch.

Results and discussion. Mean reading times for the 200 words of each condition are shown in Table 2, as are the corresponding item-processing times.

The data, analysed as a two-factor ANOVA with replications (8 subjects × 4 conditions × 2 blocks) demonstrated individual differences of reading speed ($F = 9{\cdot}32$, d.f. = 7, 31, $P < 0{\cdot}01$), a highly significant condition factor ($F = 639{\cdot}7$, d.f. = 3, 31, $P < 0{\cdot}01$), and a significant subject × condition interaction ($F = 138{\cdot}9$, d.f. = 21,31, $P < 0{\cdot}01$).

The conditions factor was further analysed using a Duncan Multiple Range Test which demonstrated no significant difference between the reading times in the EE and WW conditions. This result is in striking contrast to that of Expt 3a where the digit figures were read more slowly in Welsh than in English. The response effect operating in Expt 3a which biases towards slower responses in Welsh is therefore being counteracted in Expt 3b by a factor which differentially facilitates Welsh stimulus processing. The most likely explanation of this factor is one of familiarity: the majority of the subjects considered themselves more

Table 2. Effects of language and translation upon mean digit word reading speed for the 8 subjects of Expt 3b

	Same language conditions		Translation conditions	
	EE	WW	EW	WE
Language of stimulus	English	Welsh	English	Welsh
Language of response	English	Welsh	Welsh	English
Mean 200 item reading time (s)	61·5	58·5	107·3	131·3
Mean item processing time (ms)	308	293	537	657

proficient in the Welsh language, and therefore it can be assumed that they preferentially process Welsh, as opposed to English, words since they are more familiar with them (familiarity/frequency effects in word recognition have long been demonstrated, see e.g. Howes & Soloman, 1951; Tulving & Gold, 1963).

To investigate the effects of translation, the results of Expt 3b were analysed as a three-factor ANOVA with replications (8 subjects × 2 condition types (same language vs. translation) × 2 response languages × 2 blocks). A highly significant effect of translation demand emerges ($F = 1771{\cdot}6$, d.f. = 1, 31, $P < 0{\cdot}01$): the need to translate results in reading times which are almost double those of the same language conditions. As there is no significant difference between reading times on the EE and WW conditions, the significant condition type × response language interaction ($F = 55{\cdot}5$, d.f. = 1, 31, $P < 0{\cdot}01$) demonstrates that for those subjects who are Welsh dominant translation from Welsh to English requires more processing than translation into the preferred language, viz. from English to Welsh.

The EE and WW digit spans obtained in Expt 2 could be predicted as the number of digits that could be read in approximately 2 s, using reading rates determined for figural stimuli in Expt 1. If the spans of the 12 subjects in Expt 2 are used as indicators of the levels to be expected of the eight subjects of this experiment, it can be seen that a similar prediction could be made from these subjects' same language reading rates: for the EE span 6·55 digits could be read at a rate of 308 ms/item in 2·0 s; for the WW span 5·77 digits at a rate of 293 ms/item could be read in 1·7 s. This is not the case, however, with the translation conditions; the number of digits read and translated in 2 s as estimated in Expt 3b yields a severe underestimate of the Translation condition spans of Expt 2: for the EW span 5·11 digits at a rate of 537 ms/item could only be read in 2·7 s; for the WE span 5·64 digits at a rate of 657 ms/item could only be read in 3·7 s. This is not surprising. The reading times for the translation conditions can be assumed to be bipartite, one component representing the time taken to translate from the language of stimulus to that of response, the other the time to articulate this response. Baddeley *et al.* (1975) suggest that the memory span is constant when measured in units of time because the rehearsal system is of temporally limited capacity. Thus the more words which can be articulated within this temporal limitation, the more words that can be rehearsed, and the greater the span. It is the articulation time component of the translation condition reading times which will be operative in determining the number of items which can be rehearsed. The translation component will limit rehearsal time to a lesser extent: either (i) by delaying the initial rehearsal loop loading stage (assuming immediate translation and rehearsal in the language of response) or (ii) by delaying response production after rehearsal (assuming rehearsal in the language of the stimulus and translation immediately before response production). The amount that can be read in 2 s at a speed derived from the translation condition reading times therefore yields an underestimate of span, the articulation time component of this measure will produce a closer estimate, although this will itself be an overestimate.

Experiment 3c

Digit span measured in the Welsh Language is smaller than that measured in English. It is not possible to conclude, however, that this is necessarily an effect of word length: both the span and reading rate differences might be attributable either to word-length differentials or to differences in degree of familiarity. This latter possibility must be considered as it seems that Welsh speakers do on occasion preferentially use English number names. For example, the present year is sometimes referred to as 'nineteen seventy-eight' in preference to 'mil naw saith wyth' or the more clumsy 'un mil naw cant saith deg wyth'. It is thus possible that numbers are a special case of language usage, and therefore the language competence self-ratings obtained for our bilingual subjects may not represent their language of preference when dealing with numbers.

Effects of word length and familiarity can be distinguished if articulatory suppression is used as an interference task. The word-length effect, which Baddeley *et al.* (1975) attribute to the functioning of the articulatory loop, is much reduced with visual stimulus presentation if the subject is undergoing articulatory suppression (repeatedly whispering the sequence 1–2–3...8). Therefore if the difference between English and Welsh digit spans is a result of the differential articulation time of the digit names, i.e. if it is a word-length effect, this difference should be either absent under articulatory suppression, or, if present, present in a much reduced form.

Method. The eight subjects of Expt 3a were again tested here. The EE and WW conditions of Expt 2 were modified to allow for visual presentation and the interference task. Thus the digits constituting the strings were presented sequentially on a memory drum at a rate of one item per second. To ensure that the stimuli were processed in the required language, digit words were presented, e.g. 'pedwar' or 'four', as opposed to the digit figures. The subjects were required, as in the same language conditions of Expt 2, to report the component digits of the strings in the correct order at the end of string presentation. The major difference between this procedure and that of Expt 2 was that throughout the period of digit string presentation the subject was to whisper the sequence 'a–b–c–d' in a continuous cycle at the fastest rate compatible with clarity of pronunciation. The subjects were tested on both conditions with order of presentation counterbalanced.

Results and discussion. The mean digit spans for the WW and EE conditions were 3·75 and 4·00 respectively; they are not significantly different ($t = 1{\cdot}40$, d.f. $= 7$). These figures are to be compared with those of WW span 5·77 and EE span 6·55 for the 12 subjects of Expt 2 where no suppression was used and stimulus presentation was auditory.

It must therefore be concluded that the bilingual digit span differential is a word-length effect. Even for subjects who consider themselves more proficient in Welsh, the structure of the Welsh digit names necessitates that it is easier to remember lists of numbers in English. This effect, albeit relatively small (the English span being 114 per cent that of the Welsh span) must be assumed to be operative in everyday situations such as the short-term remembering of telephone numbers.

This finding also leads to a prediction of greater importance. Hunter (1957) stressed that short-term memory plays an important part in calculation. Using a multiplication problem as an example, he suggests that short-term memory is involved in at least two ways: (a) as problems of this nature are solved through a succession of stages, as he proceeds from one stage to the next, the subject 'needs to keep remembering which particular stage he is at in the calculation as a whole. He needs to remember what the original problem was, and must not lose his way, as he progresses from one stage of working to the next.' (b) Often he has also to remember the outcome of previous stages.

Thus any factors which limit short-term storage will make mental arithmetic more difficult. These factors can be organismic, for example the limitations in the short-term memory of dyslexic children (dyslexia is commonly associated with problems in arithmetic), or linguistic. It has been shown that Welsh digits are, as a result of their word length, more difficult to remember in working memory than their English equivalents. It must therefore be proposed that, for subjects with equal practice in both languages, mental arithmetic carried out in Welsh will be more difficult than in English.

General discussion

It has been demonstrated that cross-lingual differences in word length may result in different magnitudes of digit span as measured in those languages. For this reason digit span norms cannot be compared across languages as an indicator of cultural intellectual differences.

Wiliam & Roberts (1972) developed a Welsh Children's Intelligence Scale (WCIS) by modifying and translating the Wechsler Intelligence Scale for Children (WISC). The WISC was experimentally adjusted to Welsh idioms and to Welsh customs, and norms were statistically deduced from extensive trials with Welsh-speaking children taught in Welsh schools. The digit span subtest of the WCIS, was in effect, a direct translation of that of the WISC, the same digit strings are used. If the norms on this test are compared to those of the original WISC (see Table 3 where the digit span figures represent the sum of digit span forwards and digit span reversed) it can be seen that the norms for the Welsh sample are reliably less than those of the American sample. It is proposed that these findings cannot be taken to imply intellectual differences between the two populations, rather they are the result of the differing languages, English digits being easier to remember than Welsh digits.

The effect of a language's number-name word length upon number memorability has been demonstrated here for Welsh and English, and it has been proposed that number-name word length will also affect the ease of mental calculation. There is no reason to doubt that this effect also operates in other languages. It is therefore suggested that languages will be more or less conducive to number memorability and manipulation/calculation, and that these language differences will be dependent upon a seemingly unlikely factor, viz. the word length of the languages' number names. A useful area of further experimentation is therefore a survey of the word length of languages' number names.

The following conclusions are drawn:

(1) There is a translation/storage interaction in working memory which results in a reduced memory span when translation is necessitated.

(2) For bilingual subjects who consider themselves stronger in Welsh, translation from English to Welsh is easier than that in the reverse direction.

Table 3. Digit span scores (sum of digit spans forwards and reversed) for the American population tested in English on the WISC procedure, and the Welsh population tested in Welsh on the WCIS translation of WISC digit span procedure

Subject age at test (years)	6·10	7·10	8·10	9·10	10·10	11·10	12·10	13·10	14·10	15·10
WISC digit span score	7	8	8	9	9	10	10	10	11	11
WCIS digit span score	7	7	8	8	8	9	9	9	9	10

(3) The development or modification of intelligence tests for use with different languages or dialects must be accompanied by renormalization. As Burt (1939) stated in reference to the use of the WISC in England: testers in England 'should be supplied with a standardised procedure and with standardised norms – a procedure which has been experimentally adjusted to English idioms and to English customs, norms which have been statistically deduced from extensive trials with English children, trained in English homes, and taught in English schools.' It follows from this that norms for different adaptations of an intelligence test should not be directly compared with an aim to deducing intellectual differences between the populations from which these norms were derived.

(4) English digit names can be articulated faster than their Welsh equivalents.

(5) For bilingual subjects, even those who consider themselves to be more competent in Welsh than in English, digit span measured in the Welsh language is reliably less than measured in English. This finding is an effect of word length, and leads to the suggestion that any operation which involves remembering numbers (anything from mental arithmetic to the remembering of telephone numbers) will be more difficult to perform in the Welsh language than in the English language.

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