Journal of Experimental Psychology:
Learning, Memory, and Cognition
1986, Vol. 12, No. 3, 419–425

0278-7393/86/$00.75

Short-Term Memory Capacity: Magic Number or Magic Spell?

Richard Schweickert
Purdue University

Brian Boruff
University of Florida

Previous experiments have found that memory span is greater for items that can be pronounced more quickly. For a variety of materials the span equals the number of items that can be pronounced in about 1.5 s, presumably the duration of the verbal trace. This suggests a model for immediate recall: The probability of correctly recalling a list equals the probability that the time to recite the list is less than the variable duration of the trace. Recall probability for lists of various lengths was determined for six materials. Later, subjects read the lists aloud. The standard normal deviates corresponding to probability of correct recall were linear in pronunciation time. Evidently, over subjects, a normal distribution is a reasonable approximation of the distribution of the trace duration. The mean and variance of the trace duration were estimated. The mean (1.88 s) agrees well with previous estimates, and the model accounts for 95% of the variance in immediate recall.

The capacity of the short-term store is a fundamental quantity, but its nature has eluded understanding. One hypothesis is that the short-term store holds a fixed number of items. This is ruled out because the memory span is different for different types of items (e.g., Brener, 1940; Watkins, 1914). Brener (1940) found, for example, that the memory span for digits was 7.98 whereas that for four-letter concrete nouns was 5.76.

Another idea is that the short-term store holds a constant amount of information in bits (Kleinberg & Kaufman, 1971; Miller, 1956). Support for this idea comes from Watkins (1977) who found that the span is greater for high-frequency words than for low-frequency words. But Experiment IV by Baddeley, Thomson, and Buchanan (1975) is evidence against the idea. They found the span to be different for two sets of words matched for frequency, although different in average pronunciation time.

One could still argue that the store has a fixed space for memory code, but that the code is based on some aspect of items other than frequency. This underlies the popular hypothesis of Miller (1956) that the capacity is a constant number of chunks, 7 plus or minus 2. But how does one define a chunk, other than to empirically determine the span for a type of item, and divide this by 7? (Simon, 1974).

The idea that the short-term store is limited to some maximum amount of material has lead to no constant, noncircular measure of capacity. A competing hypothesis is that items reside in the store for only a limited time. The weight of evidence for this hypothesis has tipped back and forth over the years (Brown, 1958; Peterson & Peterson, 1959; Reitman, 1971, 1974; Roediger, Knight, & Kantowitz, 1977; Shiffrin, 1973). A particularly compelling argument for it is that a constant storage time has emerged from several experiments. Because this time seems to be the same for all types of items, it points to a measure of capacity.

According to the trace-decay hypothesis, when stimuli are presented for immediate verbal recall, a verbal trace is formed and begins to decay. Recall will be correct if it is completed before the trace has decayed (unless errors arise from other sources). The verbal trace can be refreshed by rehearsal, provided the time required to pronounce the material internally is less than the trace decay time. A consequence of this hypothesis is that the time required to recite a list can be used as a measuring stick to estimate the trace decay time. The memory span is the number of items that can be recalled in order with a probability of one half. Therefore, the time required to pronounce a list exactly one span long equals the time at which the probability of trace decay is one half. We call this time the *verbal trace duration.*

Estimates of Verbal Trace Duration

The earliest measurement of this quantity known to us was by Mackworth (1963a). When a subject recalled digits displayed in a tachistoscope, "50 percent of the responses were still completely correct when the response had lasted for 1.7 seconds" (Mackworth, 1963a, p. 68). Another experiment used digits, colors, and letters. The number of items correctly reported was different for the different types of items, but the durations of the spoken reports were not. The durations averaged 1.41 s.

Mackworth first interpreted these times as the duration of the visual image. Mackworth (1963b) later made a more explicit connection between memory span and reading rate. Since Schiano and Watkins (1981) found that span is greater for pictures with short names than with long ones, the trace is probably not visual.

This research was supported by National Science Foundation Grant IST 81-10535 and National Institute of Mental Health Grant 1 R01 MH 38675-01. This paper was presented at the Mathematical Psychology Meeting, Boulder, Colorado, 1983.

We would like to thank Robert Fulford for help in designing and conducting the experiment and Leslie Kane and Angela Terry for help with data analysis. We have had useful discussions with Bruce Bloxom, Mary Kay Busemeyer, Catherin Hayt, Gordon Logan, Peter Schonemann, James T. Townsend, and especially James Neely.

Correspondence concerning this article should be addressed to Richard Schweickert, Department of Psychological Sciences, Purdue University, West Lafayette, Indiana 47907.

Baddeley, Thomson, and Buchanan (1975, Experiment VI) proposed a simple relation between span and pronunciation rate. They presented lists visually for immediate spoken recall, and for each type of word, the pronunciation rate was found by timing the subjects as they read 50 words aloud. The result was that memory span[1] was a linear function of pronunciation rate, that is,

$$s_i = r_i\tau_v + b, \tag{1}$$

where for words of type i, s_i is the span, r_i is the pronunciation rate in items per second, and τ_v is the verbal trace duration, estimated to be 1.87 s. The intercept, $b = .17$, was small but significantly different from zero.

Standing, Bond, Smith, and Isely (1980) replicated this result. Using Equation 1, we calculate the verbal trace duration to be 1.89 s and 1.50 s, respectively, for their Experiments 1 and 2 (using corrected spans and whispered subvocalization).

As a last example, Hulme, Thomson, Muir, and Lawrence (1984) showed that the differences in memory spans for children and adults can be accounted for by differences in pronunciation rates. In their two experiments, which used aural presentation, the estimates of the verbal trace duration were 1.5 s and 1.32 s. The estimates did not differ for children and adults and memory span was a linear function of pronunciation rate for both.

The mean of these trace duration estimates is 1.6 s. Considering the variety of methods for presenting the stimuli and measuring the spans and pronunciation rates, one is struck more by the agreement than by the differences. The short-term store is not limited by a fixed number of items or chunks but by the short spell of time for which the verbal trace endures. It was not a magic number that persecuted Miller in 1956, but a magic spell.

The previous work is restricted in two ways. First, the experiments have focused on memory span, the length of a list that can be recalled correctly with a probability of one half. However, there is nothing special about a probability of one half, and we should be able to predict the probability of immediate recall for any list, regardless of the probability. Second, previous experiments estimate only the mean of the trace duration. Presumably, the trace duration is a random variable, and we would like to know not only its mean, but its variance and its distribution.

A Model

There are several ways the trace-decay hypothesis could be formalized, but the model introduced here is one of the simplest and should be tested before more complicated versions are considered. The model is based on the similarity between the trace-decay hypothesis and the common assumption made in psychophysics that the probability of detecting a stimulus equals the probability that its intensity is greater than a fluctuating threshold. According to the trace-decay hypothesis, a list will be correctly recalled if the time T_r required to recall it is less than the duration T_v of the verbal trace. Then the probability P of correct recall is

$$P = P[T_r \leq T_v]. \tag{2}$$

This equation will give the probability of a correct rehearsal if T_r is the time required for rehearsing the list rather than recalling it. The probability of k consecutive correct independent rehearsals is $P[T_r \leq T_v]^k$.

Suppose T_r and T_v are stochastically independent random variables with means τ_r and τ_v, respectively, and variances σ_r^2 and σ_v^2, respectively. Then, by rewriting Equation 2 in terms of the standard score for $T_r - T_v$ we find

$$P = P\left[\frac{T_r - T_v - (\tau_r - \tau_v)}{\sqrt{\sigma^2_r + \sigma^2_v}} \leq z\right], \tag{3}$$

where

$$z = -(\tau_r - \tau_v)/\sqrt{\sigma^2_r + \sigma^2_v}. \tag{4}$$

Equation 3 is a function for probability of immediate recall analogous to the psychophysical function for probability of detection. We call the model in Equation 3 the trace threshold model. For a list of span length, $z = 0$ in Equation 4, so $\tau_r = \tau_v$. That is, the mean time to pronounce a list of span length equals the mean verbal trace duration. (Because the span is defined in terms of the median, this actually requires the mean and median of $T_r - T_v$ to be equal.)

There are two parameters to estimate in Equation 3, τ_v and σ_v^2, the mean and variance of the verbal trace duration. To find values for z we assume the time to recall a list is normally distributed. Furthermore, whatever the distribution of the verbal trace duration may be for an individual subject, a normal distribution may be a good approximation for a group of subjects; and z in Equation 4 will be the normal standard deviate corresponding to P.

The model will be used to analyze the following experiment. Usually, in immediate memory experiments the items of a list are presented one at a time. In this experiment the items were presented simultaneously. This was done because the correlation of memory span with reading speed is slightly better for simultaneous presentation (Mackworth, 1963b), perhaps because there is less storage of the initial items in secondary memory. There is often a pause of a second or two between presentation of the last item and beginning of recall (e.g., Brener, 1940; Watkins, 1977). To follow this procedure, there was a 2-s pause between removal of the list and beginning of recall. A drawback to this procedure is that there is no information about rehearsal during this 2-s pause.

Method

Subjects

Eighteen students participated as subjects to fulfill part of an introductory psychology course requirement.

[1] Baddeley, Thomson, and Buchanan (1975) state that memory span is linearly related to pronunciation rate. The evidence for this in their Figure 4 depicts probability of correct recall of a single word, not memory span. These variables are not ordinarily interchangable. However, each list to be recalled contained five items, so that the memory span is pretty well approximated by $5p$, where p is the probability of recall of a single word.

Stimuli

Six item types were used: the digits 0–9, color names, the 20 consonants, three-letter words, shape names, and CVC nonsense syllables. The items are listed in the Appendix.

Six list lengths were used for each item type (see Table 1). For each item type, 10 lists of each of the 6 list lengths were made. One list of each length was used for practice, and the other 9 lists were used for testing.

Each list was formed by sampling items of the appropriate type randomly, without replacement. The sets of colors and shapes were those used by Brener (1940). There are only nine items of these types so, as in his experiment, every list of 10 colors or 10 shapes had exactly one repeated item. (Inadvertently, one item was repeated in a list of 9 colors and also in a list of 7 CVCs.)

Each list was typed on a white 3″ × 5″ card with one item per line, double spaced.

Design and Procedure

Each subject served in three 1-hr sessions. One type of item was presented in the first half of each session and another in the second. Each subject encountered the six types of items in a different randomly selected order.

All the items of the type to be tested were studied by the subject until he or she could recite the set correctly three times consecutively. To ensure that subjects pronounced the nonsense syllables in approximately the same way, each subject practiced them aloud until he or she could pronounce them to the experimenter's satisfaction.

After learning the items of the type to be tested, the subject was given lists for immediate recall, first the 6 practice lists and then the 54 test lists. List lengths were in random order, and each list was displayed for 5 s while the subject read it silently. This display time was ample to read even the longest lists. The list was then removed, and after 2 more seconds a tone signaled the subject to try to recall the list in order. Lists were presented manually, and the experimenter used a clock with a large sweep second hand to time the displays. A list was scored as correct if all the items in the list were recalled in order with no intrusions of extra items.

After the recall of the last list, the cards were shuffled. The lists were then presented again, one by one, starting with the six practice lists. When a list was displayed, the subject took a deep breath and read the items aloud. The instructions were to read quickly but without making errors. If the subject paused to take a breath or mispronounced an item, the trial was repeated. This part of the session was recorded on tape.

Later, an experimenter listened to the tapes and timed the recitation of each list with an electronic stopwatch. Each list was timed on two separate occasions, and the average was used as a measure of pronunciation time.

Table 1
Frequency of Correct Recall and Pronunciation Time

List length	Frequency of correct recall	Pronunciation time: Mean (s)	Pronunciation time: Variance (s^2)
	Digits		
5	157	1.29	.04
6	147	1.56	.05
7	114	1.87	.08
8	74	2.15	.11
9	35	2.43	.16
10	13	2.71	.17
	Colors		
5	136	1.47	.06
6	93	1.82	.08
7	49	2.11	.09
8	15	2.47	.14
9	13	2.75	.13
10	2	3.17	.19
	Consonants		
4	159	1.05	.04
5	142	1.35	.09
6	96	1.69	.13
7	52	2.08	.13
8	14	2.42	.19
9	7	2.74	.20
	Nouns		
3	160	.82	.02
4	153	1.18	.03
5	119	1.45	.05
6	66	1.81	.07
7	27	2.18	.11
8	1	2.50	.14
	Shapes		
3	156	1.12	.04
4	138	1.62	.06
5	74	2.01	.07
6	43	2.40	.10
7	9	2.78	.12
8	1	3.30	.17
	CVCs		
2	159	.63	.02
3	148	1.11	.08
4	102	1.60	.20
5	50	2.05	.19
6	12	2.52	.29
7	2	2.95	.37

Results

Table 1 gives the frequency of correct recall and the mean and variance of the pronunciation time for each list length. There are 162 trials for each list length except for lists of 6 digits. On one trial in this condition the experimenter failed to record whether the list was recalled or not, so recall and pronunciation times for these lists are based on 161 trials.

One might wonder how well probability of correct recall can be predicted simply from the number of items in the list. Probability of recall is an S-shaped function of list length. Figure 1 gives a typical example from our data. The normal standard deviate (normal z score) corresponding to recall probability is approximately a linear function of list length. The slope for predicting the z score from list length is $-.57$ per item and the intercept is 3.39. The correlation between predicted and observed frequencies of correct recall is .849, so 72% of the variance is accounted for by list length. On the other hand, the chi square for goodness of fit, based on frequencies of correct and incorrect recall, is 1340.99 with 34 degrees of freedom, so the errors in prediction are quite large.

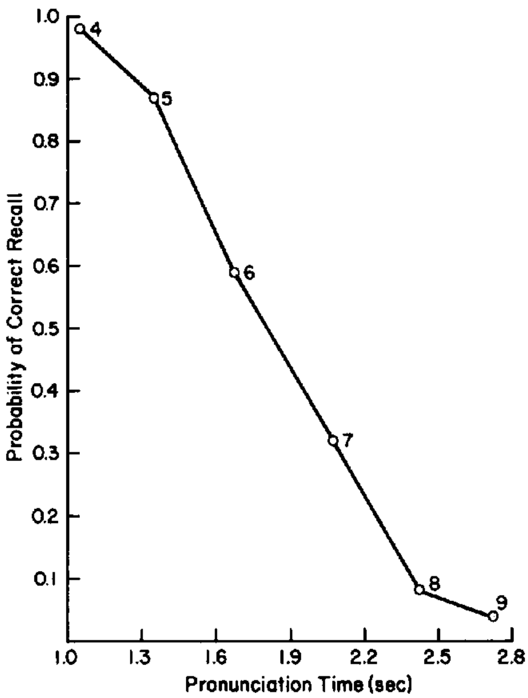

Figure 1. The psychometric function for recall of consonants. Probability of immediate recall of a list is an S-shaped function of the time required to pronounce it. The number near each point is the corresponding list length.

To test the trace threshold model in Equation 3, estimates of τ_v and σ_v^2 were made using Chandler's (1965) STEPIT program to minimize chi square. The mean verbal trace duration τ_v was 1.88 s. This agrees remarkably well with the previous estimates, especially when the difference in the estimation procedure used here is considered. The variance of the verbal trace decay time was .187 s^2.

The correlation between predicted and observed frequencies of correct responses is .975, so 95% of the variance is accounted for by the model in Equation 3. The chi square for goodness of fit, calculated from frequencies of correct and incorrect recall, is 238.55 ($df = 34$). Although there is room for improvement, the fit for the trace threshold model is considerably better than that based on the number of items in the lists.

The predicted values from Equation 3 are plotted in Figure 2. On the whole, the model agrees well with the data, although there are discrepancies. For example, for all list lengths it underestimates the recall of digits, whereas it overestimates recall of nonsense syllables.

Consider a related model. Probability of correct recall is an S-shaped function when plotted against pronunciation time. This psychometric function is illustrated in Figure 1. For each type of item, the function is approximately linear when plotted on Gaussian paper (Figure 2). That is, the normal standard deviate corresponding to the probability of recall for a list is

$$z = b_1\tau_v + b_0. \qquad (5)$$

The least squares estimates of the regression coefficients are $b_1 = -2.02$ items/s and $b_0 = 3.87$.

The correlation between predicted and observed frequencies of correct recall is .977, so 95% of the variance is accounted for by this model, almost the same as for the model in Equation 4. The chi square for goodness of fit is slightly better, $\chi^2(34) = 215.97$, based on frequencies of correct and incorrect recall. Actually, Equation 5 is a special case of Equation 4, with $\sqrt{\sigma^2_r + \sigma^2_v}$ constant.

The regression coefficients in Equation 5 provide an estimate of the mean verbal trace duration, that is, the time to pronounce a list of span length. For such a list the probability of recall is 1/2, so $z = 0$. From Equation 5 the time to pronounce such a list is $-b_0/b_1 = 1.91$ s. This is in close agreement with the other estimates we have discussed. If we suppose $\sigma_r^2 = 0$, then an estimate of the variance of the verbal trace duration is $1/b_2{}^2 = .4\ s^2$.

Discussion

The trace threshold model presented here is borrowed from classical psychophysics. It gives a fairly good account of the probability of correct recall for a wide range of list lengths and types of items in terms of the single variable, time.

Can a single variable completely account for immediate recall? This is unlikely. Although the amount that can be maintained in storage might be determined by a single quantity, recall also requires encoding and retrieval, both of which can have an enormous effect on memory span. For example, a subject in an experiment by Ericsson, Chase, and Faloon (1980) learned to increase his span to 79 digits. Yet he probably did not increase the capacity of his short-term store, since extensive practice with digits did not increase his span for consonants.

The model presented here is only for the maintenance component. But maintenance itself is complicated because more than one store might hold the items. For example, Frick (1984) showed that under the proper conditions, span can be increased if some items are presented visually and some auditorily, probably because both visual and auditory stores are used.

Clearly, a full account of immediate recall must consider many variables. An excellent review of factors affecting memory span is given by Dempster (1981). Drewnowski (1980) proposed a general model in which recall is the combined effect of such factors as list length, type of item, familiarity, vocabulary size, and acoustic similarity.

There are, however, indications that some single uncapricious variable predominates. One finding is that the span for a mixture of item types can be predicted from the spans of the separate item types. For example, in Brener's (1940) experiment, the span for paired associates (three-letter concrete nouns followed by two digits) can be predicted from the span for digits and that for concrete nouns. Let c be the capacity of the short-term store, whatever this may be. Then from Brenner's data,

$$c = 5.76 \text{ four-letter concrete nouns}$$
$$c = 7.98 \text{ digits.}$$

Now,

$$\begin{aligned} 1 \text{ paired associate} &= 1 \text{ three-letter concrete noun} \\ &\quad + 2 \text{ digits} \\ &= (c/5.76) + (2c/7.98). \end{aligned}$$

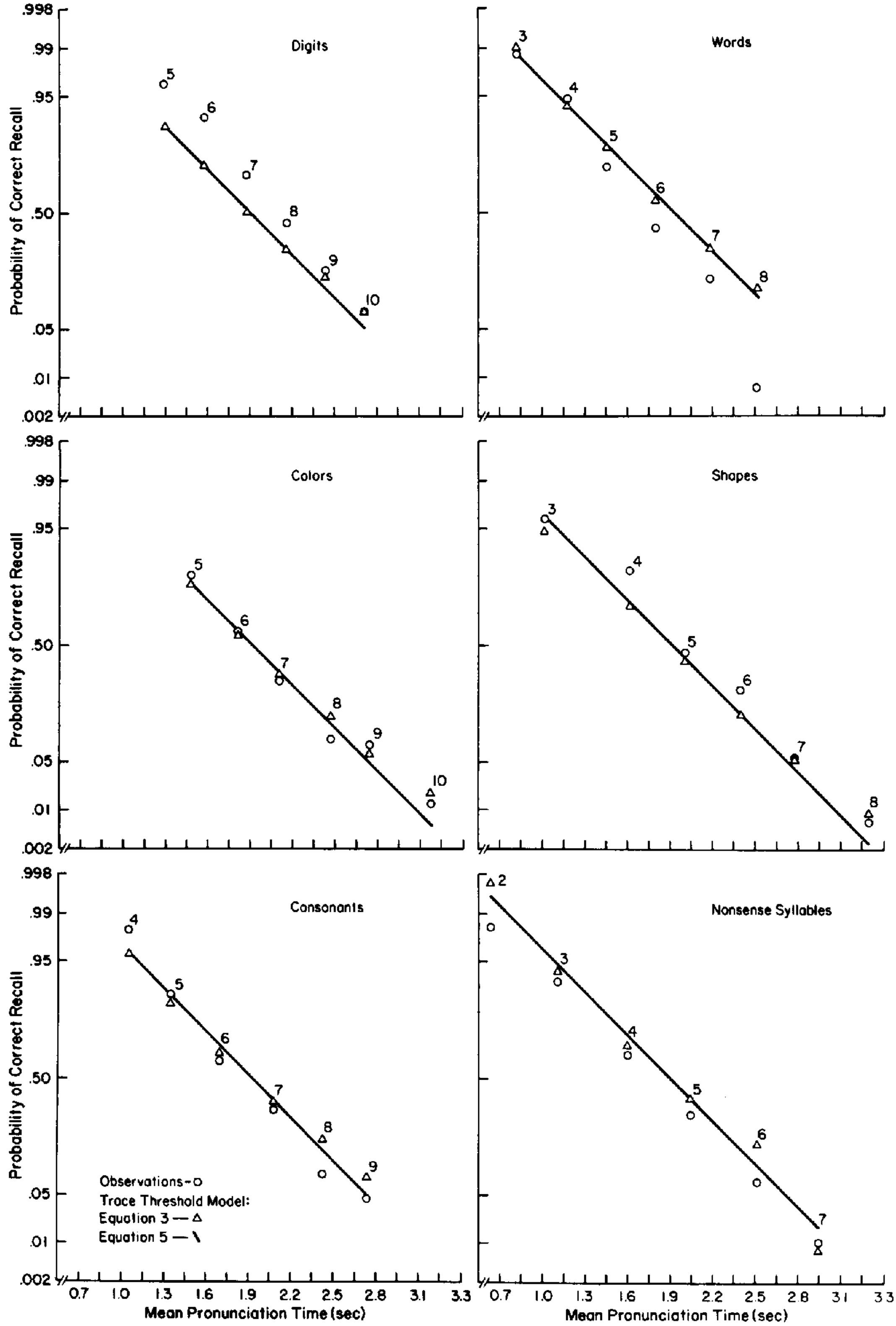

Figure 2. The z score corresponding to probability of immediate recall as a function of pronunciation time on Gaussian paper. Pronunciation time is uniformly spaced on the horizontal axes, number of items is not. The number near each point is the corresponding list length. Predictions from Equation 3 (triangles) depend on pronunciation time variance and do not fall on a straight line.

Solving the above equation for c, we find

$$c = 2.36 \text{ paired associates.} \quad 10$$

This agrees well with the observed span of 2.50, especially because the prediction is based on four-letter concrete nouns and the observation is based on three-letter concrete nouns.

Watkins (1977) found that span is greater for lists having both high- and low-frequency words when the high-frequency words are at the beginning of the list, rather than at the end. This result is a challenge for any unitary theory of short-term memory. But even in this experiment, if we collapse over the item positions, the span for lists made of half high-frequency words and half of low-frequency words is approximately equal to the average of the separate spans for high- and low-frequency words. The average of the former is 4.92, and the latter is 5.03.

A plausible explanation of Watkin's finding in terms of pronunciation time has been given by Wright (1979). He found that low-frequency words take longer to pronounce than high-frequency words, even when the number of syllables and letters are equated. Therefore, the time between presentation and recall of items at the end of the list is shorter when the high-frequency words come at the beginning rather than at the end.

To see this, consider lists of two items: one high frequency and one low. The argument is the same for longer lists. Let S be the time to pronounce the short item and let L be the time for the long one. Suppose the subject rehearses the two items once, and then recalls them. If the short item comes first, the time elapsing from beginning of rehearsal until beginning the output of the last item is $S + L + S$. If the long item comes first, the time is longer, $L + S + L$. Fewer features of the last item will have decayed in the former case, so the subject's chance of a successful reconstruction is greater.

Another indication that the magnitudes of the spans may be a function of some single variable is the extremely important relation discovered by Cavanagh (1972). The number of items scanned per second in a memory scanning task depends on the type of item used. Cavanagh found that the scanning rate for a type of item is related to the memory span for this type of item in a simple way. Let s_i be the memory span for items of type i and let m_i be the rate of scanning such items (in items per second). Then

$$s_i = m_i \tau, \tag{6}$$

where $\tau = .2432$ s is a constant.

Further investigations of Cavanagh's relation have been carried out by Brown and Kirsner (1980) and by Puckett and Kausler (1984). The value of τ averaged over their experiments is .2523 s, close to the value found by Cavanagh (1972).[2] Puckett and Kausler propose the interesting hypothesis that memory span is mediated by pronunciation rate whereas scanning rate is mediated by familiarity.

Equations 1 and 6 both express memory span as the product of a rate and a time. What is the relation between these equations? It is commonly supposed that working memory is made of several distinct subsystems (Baddeley and Hitch, 1974; Hitch, 1980). One of these is the short-term store. Suppose the processor where memory scanning takes place is another system whose decay time τ is faster than that of the short-term store τ_v. There is little use in having more in the short-term store than could be scanned by the processor. If both systems are capable of handling one span of material, the rate of scanning m_i must be faster than the rate of rehearsing r_i. The rates must be inversely proportional to the decay times, that is (Little, 1961),

$$s_i = r_i \tau_v = m_i \tau. \tag{7}$$

A result supporting this idea would be that the size of the positive set in a memory-scanning task and the presence or absence of an extra memory load have additive effects on reaction time. An interaction need not be evidence against the idea (Schweickert, 1983; Sternberg, 1969). Logan (1978) found additivity in his Experiment 1, using fixed sets. But he found an interaction in Experiment 2, using a new fixed set for every session. Sternberg (1969), using a somewhat different procedure, found an interaction. Hence, the evidence that the short-term store is different from the system used in memory scanning is inconclusive.

A final encouraging experiment for the unitary point of view on the short-term store is a variation by Muter (1980) of the paradigm used by Brown (1958) and Peterson and Peterson (1959). In the original paradigm, subjects were given a subspan list followed by a distracting task, such as counting backwards by threes, followed by recall. There was rapid forgetting, but some items were still recalled after 18 s. This is an order of magnitude different from the roughly 2-s verbal trace duration we have been discussing. In Muter's variation of the paradigm, subjects were presented with items, but were led to expect that if a distracting task followed, there was no need for recall of the items. Under these conditions, subjects probably did not attempt to rehearse, and the items usually decayed within 2 s. Therefore, the memory span procedure and the modified Brown–Peterson procedure may be measuring the same quantity.

To summarize, the capacity of the short-term store is not determined by a fixed number of items, bits or chunks, but by the limited time for which the verbal trace endures. Probability of correct immediate recall of a list is predicted fairly well by the probability that the time required to recite the list is less than the verbal trace duration. More refined predictions will no doubt incorporate assumptions about encoding, retrieval, and the use of stores other than the verbal short-term store. But much can be accounted for in terms of trace decay time.

---

[2] It is of interest to note that the variance of the trace duration estimated from Equation 6 to be .24 s^2 is numerically very close to the constant found by Cavanaugh, .2432 s. This may be a coincidence; furthermore, the physical dimensions of these two quantities are not the same.

References

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. Bower (Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47–90). New York: Academic Press.

Baddeley, A. D., Thomson, N., & Buchanan, M. (1975). Word-length and the structure of short-term memory. *Journal of Verbal Learning and Verbal Behavior, 14,* 575–589.

Brener, R. (1940). An experimental investigation of memory span. *Journal of Experimental Psychology, 26,* 467–482.

Brown, H. L., & Kirsner, K. (1980). A within-subjects analysis of the relationship between memory span and processing rate in short-term memory. *Cognitive Psychology, 12,* 177–187.

Brown, J. (1958). Some tests of the decay theory of immediate memory. *Quarterly Journal of Experimental Psychology, 10,* 12–21.

Cavanagh, J. P. (1972). Relation between the immediate memory span and the memory search rate. *Psychological Review, 79,* 525–530.

Chandler, J. P. (1965). *Subroutine STEPIT: An algorithm that finds the values of the parameters which minimize a given continuous function* [Computer program]. Bloomington, IN: Indiana University Quantum Chemistry Program Exchange.

Dempster, F. N. (1981). Memory span: Sources of individual and developmental differences. *Psychological Bulletin, 89,* 63–100.

Drewnowski, A. (1980). Attributes and priorities in short-term recall: A new model of memory span. *Journal of Experimental Psychology: General, 109,* 208–250.

Ericsson, K. A., Chase, W. G., & Faloon, S. (1980). Acquisition of a memory skill. *Science, 208,* 1181–1182.

Frick, R. W. (1984). Using both an auditory and a visual short-term store to increase digit span. *Memory & Cognition, 12,* 507–514.

Hitch, G. J. (1980). Developing the concept of working memory. In G. Claxton (Ed.), *Cognitive psychology: New directions* (pp. 154–196). London: Routledge & Kegan Paul.

Hulme, C., Thomson, N., Muir, C., & Lawrence, A. (1984). Speech rate and the development of short-term memory span. *Journal of Experimental Child Psychology, 38,* 241–253.

Kleinberg, J., & Kaufman, H. (1971). Constancy in short-term memory: Bits and chunks. *Journal of Experimental Psychology, 90,* 326–333.

Little, J. D. C. (1961). A proof for the queuing formula $L = \lambda W$. *Operations Research, 9,* 383–387.

Logan, G. D. (1978). Attention in character-classification tasks: Evidence for the automaticity of component stages. *Journal of Experimental Psychology: General, 107,* 32–63.

Mackworth, J. F. (1963a). The duration of the visual image. *Canadian Journal of Psychology, 17,* 62–81.

Mackworth, J. F. (1963b). The relation between the visual image and post-perceptual immediate memory. *Journal of Verbal Learning and Verbal Behavior, 2,* 75–85.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63,* 81–97.

Muter, P. (1980). Very rapid forgetting. *Memory & Cognition, 8,* 174–179.

Peterson, L. R., & Peterson, M. J. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology, 58,* 193–198.

Puckett, J. M., & Kausler, D. H. (1984). Individual differences and models of memory span: A role for memory search rate? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10,* 72–82.

Reitman, J. S. (1971). Mechanisms of forgetting in short-term memory. *Cognitive Psychology, 2,* 185–195.

Reitman, J. S. (1974). Without surreptitious rehearsal, information in short-term memory decays. *Journal of Verbal Learning and Verbal Behavior, 13,* 365–377.

Roediger, H. L., Knight, J. L., & Kantowitz, B. H. (1977). Inferring decay in short-term memory: The issue of capacity. *Memory & Cognition, 5,* 167–176.

Schiano, D. J., & Watkins, M. J. (1981). Speech-like coding of pictures in short-term memory. *Memory & Cognition, 9,* 110–114.

Schweickert, R. (1983). Latent network theory: Scheduling of processes in sentence verification and the Stroop effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9,* 353–383.

Shiffrin, R. M. (1973). Information persistence in short-term memory. *Journal of Experimental Psychology, 100,* 39–49.

Simon, H. A. (1974). How big is a chunk? *Science, 183,* 482–488.

Standing, L., Bond, B., Smith, P., & Isely, C. (1980). Is the immediate memory span determined by subvocalization rate? *British Journal of Psychology, 71,* 525–539.

Sternberg, S. (1969). Memory scanning: Mental processes revealed by reaction-time experiments. *American Scientist, 57,* 421–457.

Watkins, M. J. (1977). The intricacy of memory span. *Memory & Cognition, 5,* 529–534.

Watkins, S. H. (1914). Immediate memory and its evaluation. *British Journal of Psychology, 7,* 319–348.

Wright, C. E. (1979). Duration differences between rare and common words and their implications for the interpretation of word frequency effects. *Memory & Cognition, 7,* 411–419.

Appendix

Items Used as Stimuli

Colors: RED, ORANGE, YELLOW, GREEN, BLUE, PURPLE, WHITE, BLACK, GRAY.

Three letter concrete nouns: ANT, ARM, BUD, COW, DOG, FLY, FOX, INN, KEY, VAN.

Shapes: OVAL, TRIANGLE, SQUARE, SPADE, HEART, DIAMOND, TRAPEZOID, CIRCLE, SEMICIRCLE.

CVC nonsense syllables: BIP, COJ, DAX, KUQ, MAF, NEH, RIY, TEV, WUG, ZOS. All vowels were short, except for RIY (ree).

The colors and shapes were those used by Brener (1940). The three letter concrete nouns were slected with the same constraints as those in Brown and Kirsner (1980).

The stimuli used by Brown and Kirsner (1980) were as follows (H. Brown, personal communication, April 6, 1981):

Three letter concrete nouns: FIG, RUG, KEY, BOY, PIN, VAN, JAR, COW, SUN, BED.

CVC nonsense syllables: MEF, KEB, YAV, NAH, PIW, GID, QOS, XOP, ZUT, JUC.

Received February 5, 1985
Revision received August 2, 1985 ■