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RETENTION OF SPOKEN AND WRITTEN (KANA AND KANJI) WORDS IN NORMAL SUBJECTS AND PATIENTS WITH CONDUCTION APHASIA

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1. Introduction

Since the comprehension processes of both spoken and written language are essentially sequential, it is necessary for the incoming flow of linguistic information to be stored temporarily. In an initial version of a model for the human memory system, it was assumed that precategorical sensory registers and at least two categorical memory components, i.e.. short-term and long-term memories, exist. While the short-term memory (STM) was supposed to be a temporary storehouse which retained a fixed number of phonemically coded items (7 ± 2 of whatever units are presented), the long-term memory (LTM) was supposed to be a permanent storehouse which retained a vast amount of semantic information (Miller, 1956, Conrad, 1964, Waugh and Norman, 1965).

However, the results of many experiments do not support the above model. For example, Posner, Boies, Eichelman and Taylor (1969) provided evidence for the existence of visual codes in STM, while Shulman (1972) provided evidence for the presence of semantic codes in STM. In addition, Baddeley, Thomson and Buchanan (1975) showed that "memory span for unrelated words is not constant, but varies with the length of the words to be recalled."

As such, it appears necessary to modify the above view of human memory. Loftus and Loftus (1976), for example, proposed a model in which STM retains the addresses of items existing in LTM instead of their phonemic codes. Craik and Lockhart (1972), on the other hand, advocated a levels-of-processing theory in which short- and long-term memories are seen not as two separate memory structures but as different processes. Shiffrin and Schneider (1977) suggested that STM is an activated subset of LTM.

Although these models provide an interesting framework concerning the concept of STM, their specific details are yet to be worked out. For instance, they do not specify the flow of linguistic information presented in the auditory and visual modalities. In Experiment I of the present study, therefore, we first aimed to investigate the level of processing where information in the two modalities merges, and second to show how phonemic, graphemic (or visual) and semantic levels of information are related to each other.

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2. Experiment I

2.1 Method

Subjects

The subjects were four undergraduate students with normal hearing and visual acuities. One subject (S_4) participated only in parts of this experiment.

Materials

As shown in Table 1. five categories of stimulus words. digits, one- and three-mora meaningful words, three-mora meaningless nonwords. and homophonic kanji characters (or homonyms), were used to evaluate the following variables which may affect the memory span for words: (1) number of morae contained in the words, or word length, (2) phonemic cue, (3) stimulus modality, (4) meaningfulness, and (5) type of orthographic system used (kana vs. kanji). Whereas the one- and three-mora meaningful words consisted of high frequency words, the homophonic kanji characters consisted of less frequently used words. All the stimulus words except those in the homophonic kanji category had different phonemic codes.

Table 1 *Stimulus words used for short-term memory experiments*

WORD CATEGORIES		DIGITS	ONE-MORA MEANINGFUL WORDS	THREE-MORA MEANINGFUL WORDS	THREE-MORA NONWORDS	HOMOPHONIC KANJI [ki]
VISUAL PRESENTATION	KANJI OR ARABIC NUMERAL	0 — 9	字蚊尾胃湯 矢木芽酢田	机光車心泉 卵畑刀袋氷		季期奇軌紀 規毀揮希気
	KANA	ぜろ－きゅう	じ，か，・ ・・・，た	つくえ，・・・ ・・，こおり	くえつ，・・・ ・・，りおこ	
AUDITORY PRESENTATION		[zero.….kyu:]	[zi,ka,… ……,ta]	[tsukue.… …,ko:ri]	[kuetsu,… … ,rioko]	

Fig. 1 illustrates the generation processes of the auditory and visual stimuli. In the preparation of the auditory stimuli. 10 stimulus words in each word category were pronounced by a male speaker and read into a PDP-11/34 computer through

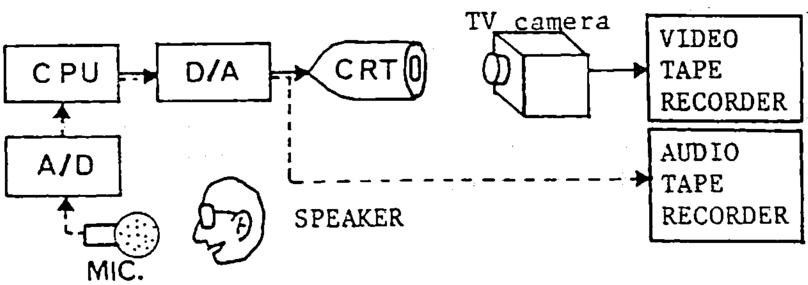
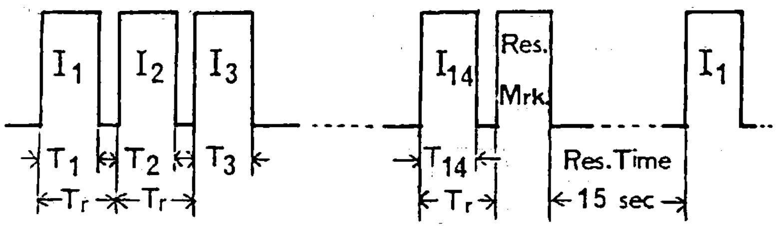


Fig. 1 *Preparation of auditory and visual stimuli.*

an A/D converter with an accuracy of 12 bits and a sampling rate of 12 kHz. A randomized sequence of 14 stimulus words followed by a 500 Hz pure tone signaling the beginning of the response (response marker) was then generated by the computer. Fifty such sequences were converted to analog signals through a D/A converter and recorded on an audio tape for the off-line experiments. The visual stimuli consisted of randomized sequences of 14 computer-generated kana and kanji words followed by the response marker "!?". They were recorded on a video tape.

Procedures

The mode of stimulus presentation is illustrated in Fig. 2, in which I_1 through I_{14} represent 14 stimulus words or items in each trial, and T_1 through T_{14} their presentation duration summarized in Table 2. Because of the CRT (cathode-ray tube) afterglow of the TV monitor, the duration for the visual stimulus words was always shorter by approximately 100 msec than the mean duration of the 10 auditory stimulus words in the same word category. Each item was presented at a constant rate of 0.5 sec/item, and a response time of 15 sec separated the successive trials.



I_1-I_{14} : items in one trial

T_1-T_{14} : duration of items

T_r : presentation rate of items (0.5 sec/item)

Res. Mrk.: response marker
(500 Hz tone for auditory stimulus and "!?" mark for visual stimulus)

Fig. 2 *Mode of stimulus presentation. Items are presented sequentially.*

Table 2 *Duration of items in each word category*

PRESENTATION RATE		0.5 SEC/ITEM				
WORD CATEGORIES		DIGITS	ONE-MORA MEANINGFUL WORDS	THREE-MORA MEANINGFUL WORDS	THREE-MORA NONWORDS**	HOMOPHONIC KANJI [ki]
VISUAL PRESEN-TATION	KANJI OR ARABIC NUMERAL	154	139	211	—	139
	KANA	159	139	205	271	—
AUDITORY PRESENTATION*		255	239	309	367	—

* Mean word duration. (UNIT: MSEC)
** A presentation rate of 0.53 sec/item was adopted in this word category.

Kana and kanji characters were displayed in a 2 X 2 cm square on the TV monitor, placed at a distance of approximately 70 cm away from the subjects. Each character of the three-mora kana words was displayed simultaneously in a vertical array.

Subjects sat in front of a loudspeaker or TV monitor (Fig. 3), and were required to point to as many words printed on a card as they could retain, starting from the first member of the sequence. The number of correctly identified stimulus words starting from the first member of the sequence was defined as the short-term memory span. Vocalized rehearsal was prohibited.

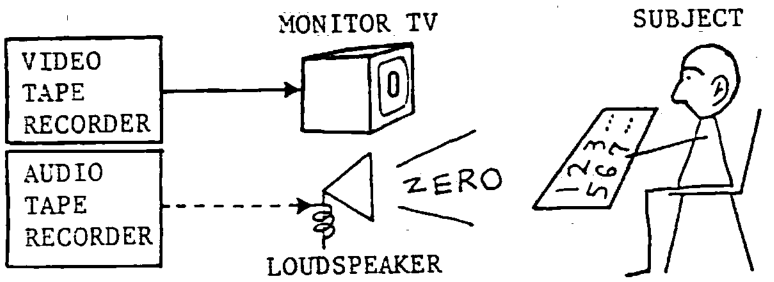


Fig. 3 *Presentation of auditory and visual stimuli.*

2.2 Results

In Fig. 4 the mean memory spans of individual subjects for digits, and one- and three-mora meaningful words are plotted against the number of morae (the mean number of morae for digits is 1.8). All four subjects exhibited a word length effect irrespective of the stimulus modality: i.e., memory span is inversely related to the word length. No systematic difference was observed between the words written in kana and kanji.

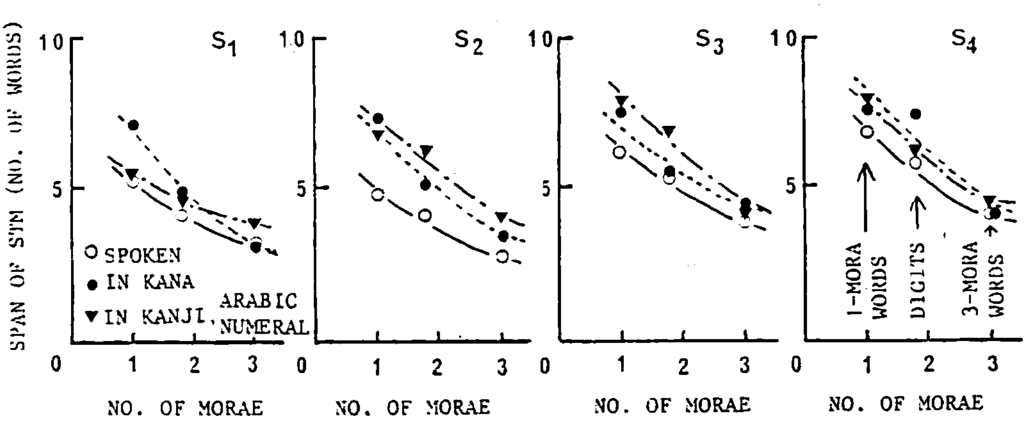


Fig. 4 *Short-term memory span for meaningful words plotted against the number of morae.*

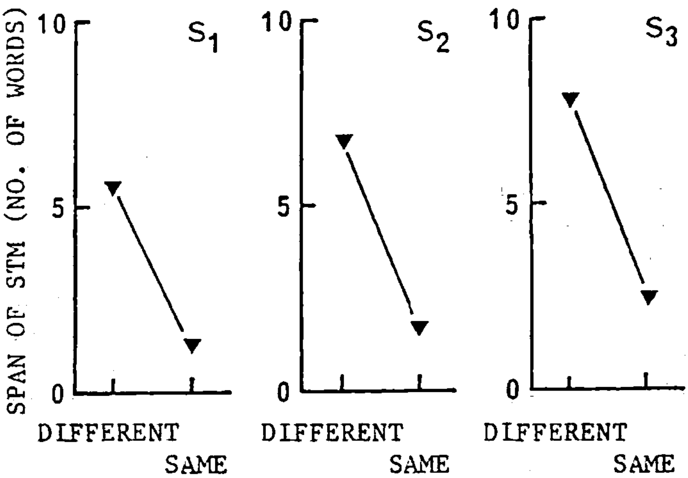


Fig. 5 *Span of STM for kanji with different phonemic codes and that for homophonic kanji.*

The memory span for the one-mora (meaningful) kanji with a different phonemic code is compared with that for the homophonic kanji in Fig. 5. The former is clearly larger than the latter. However, the fact that homophonic kanji characters were retained at all indicates that words can be retained in STM not only by means of phonemic codes but also by means of graphemic codes.

Fig. 6 shows the difference between the memory spans for the three-mora meaningful words and meaningless nonwords. It is evident that meaningfulness slightly increases the memory span.

It can be seen from Fig. 3 and Fig. 6 that visually presented words tend to be retained better than auditorily presented words regardless of word length or meaningfulness.

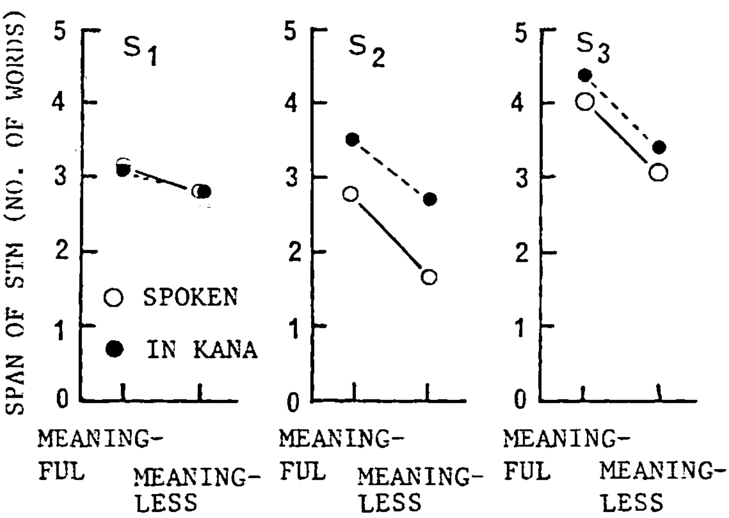


Fig. 6 *Effect of word meaning upon spans of STM (three-mora meaningful words and meaningless nonwords).*

2.3 Discussion

The fact that the word length effect was observed not only for auditorily presented words but also for visually presented kana and kanji words indicates that the incoming information is primarily retained in the form of phonemic codes as suggested by Conrad (1964), and Baddeley, Thomson and Buchanan (1975). However, the finding that short-term retention was possible even for homophonic kanii characters indicates the existence of a storehouse for graphemic information also, although its capacity is quite small. The advantage of visual over auditory presentation, i.e., the modality effect, suggests that graphemic memory plays a supplementary role even in the retention of words with phonemic cues. Similarly, the longer memory span for meaningful words, or the meaningfulness effect, appears to indicate that there is a semantic memory and that information in it also assists retention.

These considerations led us to hypothesize the STM model shown in Fig. 7. The model consists of two sensory registers that hold precategorical analog information, and three categorical STMs that hold phonemic, graphemic and semantic information. In this model identification processes of phenemes, graphemes and meanings, and decision processes are represented simply by using arrows connecting the memories. Therefore, these arrows indicate not only flow of information but also the processes themselves. While the visual sensory register, or iconic memory, stores information for a fraction of a second (Sperling, 1960), the auditory sensory register, or echoic memory, stores information 10 times longer (Darwin, Turvey and Crowder, 1972). The conscious rehearsal of information is not possible for the sensory registers, but possible for the categorical STMs.

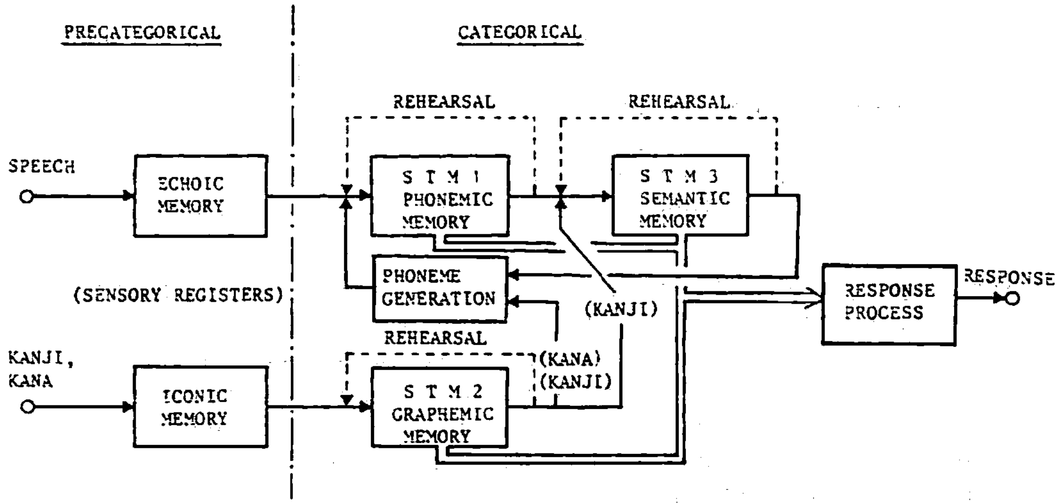


Fig. 7 *Model for the mechanisms and processes of short-term memory for spoken and written (kanji and kana) words.*

In this model, the following assumptions are required: (1) words are retained primarily as phonemic codes under usual circumstances, (2) in meaningful words semantic information is retrieved automatically, and (3) phonemic codes can be generated internally from graphemic or semantic codes.

Furthermore, speech information is assumed to flow from echoic memory to the phonemic memory (STM1), and to semantic memory (STM3). On the other hand, visual information is assumed to flow from iconic memory to the graphemic memory (STM2). Here the path divides. For kana, information is transferred into STM1 (and into STM3 for meaningful kana words), but directly into STM3 for kanji. That is, the semantic information contained in kana words is extracted via phonemic mediation, while the semantic information contained in kanji words is extracted directly from graphemes. Phonemic codes for kanji are generated from semantic information in STM3.

Based on this model, the data of Experiment I can be explained as follows:

(1) In the memory span task incoming information is usually retained in STM1 irrespective of the modality or orthographic systems used. For maintaining items in STM1, rehearsal is required because memory strength of these items declines with the passage of time. As the rehearsal rate for long words is slower than that for short words, memory span is inversely related to word length.

(2) Since the graphemic information in STM2 is available, the homophonic kanji characters (with no phonemic and minimal semantic cues) are retained.

(3) In the auditory modality stimulus words are successively identified and converted into phonemic codes. When these phonemic codes are transferred into STM1, however, the rehearsal of items in STM1 is interrupted. In the visual modality, on the other hand, successively incoming information can be temporarily stored in STM2 until a complete cycle of rehearsal of a word-string is executed. That is, STM2 acts as a buffer memory for STM1. Therefore, memory span in the visual modality is larger than that in the auditory modality.

(4) The memory span for meaningful words is greater than that for meaningless words, since meaningful words have a buffer memory (STM3) for STM1, whereas meaningless nonwords do not.
(5) Although the paths along which information flows are not the same for processing words in kana and kanji, both STM2 and STM3 work as buffers for STM1 in these words. Thus, the memory spans for kana and kanji words are comparable.

The adequacy of the STM model such as the one presented above can be evaluated using data on the retention ability of pathological cases who show memory deficits following brain damage. Warrington and Shallice (1969), for example, examined various aspects of the memory ability of a patient exhibiting a variant of conduction aphasia.[1] They carried out a series of experiments including a memory span task, and found a smaller memory span for the auditory than for the visual materials. The authors interpreted this finding as a selective impairment in the auditory-verbal STM, and hypothesized that "a visual STM exists which can be spared when the auditory-verbal STM system is damaged" (Shallice and Warrington, 1977). Similar results were reported in studies by Luria, Sokolov and Klimkowski (1967), Shallice and Warrington (1970), Warrington, Logue and Pratt (1971), Saffran and Marin (1975), Caramazza, Basili, Koller and Berndt (1981), and Basso, Spinnler, Vallar and Zanobio (1982).

Kinsbourne (1972), Tzortzis and Albert (1974), and Strub and Gardner (1974) also found deficits in auditory retention span compared to visual retention span in conduction aphasic patients, but their interpretations were quite different from those of the above authors. Kinsbourne, for instance, attempted to explain the repetition impairment in these patients in terms of the dysconnection theory, while Tzortzis and Albert did so in terms of an impairment of memory for sequence, and Strub and Gardner explained in terms of a linguistic deficit "in the processing, synthesis, and ordering of phonemes." None of these explanations, however, appears acceptable because of the inadequate interpretation of their results, as pointed out by Shallice and Warrington.

Whereas Warrington and Shallice's explanation of repetition inability in their conduction aphasic patient is based upon the auditory inferiority of the retention span compared to the visual retention span, we observed this tendency in young and aged normal subjects also (Fujisaki, Mizuno and Tazaki, 1973, and Tatsumi, Itoh, Konno, Sasanuma and Fujisaki, 1982). However, the presentation rates of items adopted in the two investigations were not the same, i.e., 1 sec/item in the study by Warrington and Shallice vs. 0.5 sec/item in our studies. This makes it difficult to directly compare the results of these two studies.

Therefore, in Experiment II of the present study we examined the performance of patients with conduction aphasia as well as the performance of normal subjects on the memory span tasks, where digits were presented at the same rate as in Warrington and Shallice's experiment.

3. Experiment II

3.1 Method

Subjects

The subjects were two patients with conduction aphasia (P_1 and P_2), and the four undergraduate students who participated in Experiment I. Table 3 summarizes their ages, hearing and visual acuities, and the lesion sites indicated by the CT scans of the two aphasic patients.

Table 3 *List of patients*

PATIENTS	AGE	HEARING ACUITY	(CORRECTED) VISUAL ACUITY	VISUAL FIELD DEFECT	LESION SITES
P1	73	mild presby-cusis	normal	nil	left angular gyrus involving the white matter
P2	61	normal	normal	nil	left inferior parietal lobe involving the white matter

The major symptom exhibited by both P_1 and P_2 was their inability to repeat words, phrases and sentences, despite their relatively well preserved comprehension and production abilities. P_1 had fluent but paraphasic speech, and mild difficulties in naming and oral reading of words and sentences due to literal paraphasia. P_2, on the other hand, had mild difficulties in word-finding, auditory identification of digits, and writing of sentences. Paraphasia was infrequent in P_2's spontaneous speech.

Test materials

The materials used were digits from zero to nine, presented in the auditory and visual (kana and Arabic numeral) modalities in a manner similar to that used in Experiment I.

Procedures

The procedures were the same as those in Experiment I, except that the digits were presented at a rate of 1 sec/item, and that the number of digits in a trial was reduced from 14 to seven for the aphasic patients.

Prior to the memory span task, P_1 and P_2 were given an identification test in which they were asked to tap the desk immediately after they heard or saw the target digit given orally by the experimenter at the beginning of each trial. Stimuli for the identification were the same as those in the memory span task.

3.2 Results

Identification of stimuli

P_1 identified all the stimuli perfectly. The identification score of P_2 for auditorily presented digits was 90%, although he made no errors in the other identification tests. These results indicate that the identification performances of P_1 and P_2 are almost normal.

Memory span task

Fig. 8 shows the memory span performances of normal subjects at two different rates of stimulus presentation, i.e., 0.5 and 1 sec/item. Obviously, the memory span tends to increase when items are presented more slowly. This result seems to indicate that at a slower rate subjects have enough time to rehearse a digit sequence while the stimuli are being presented.

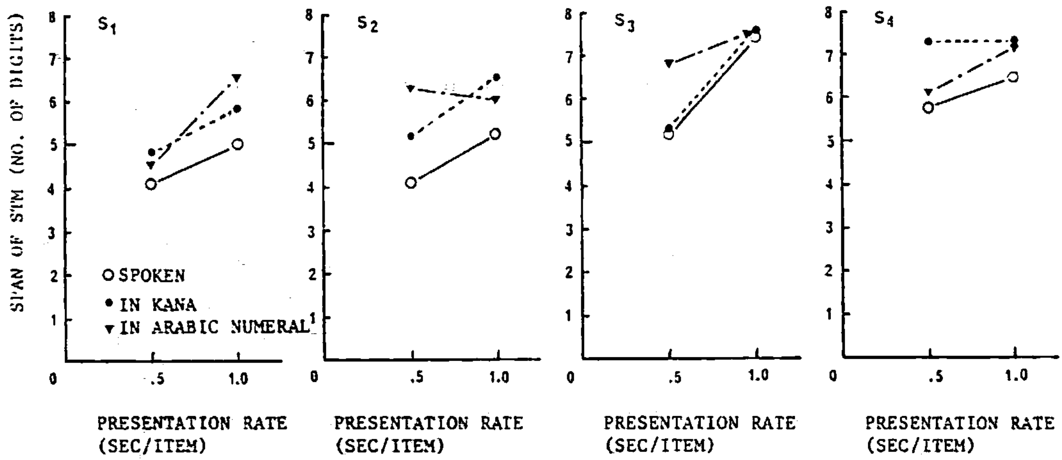


Fig. 8 *STM spans for digits presented at rates of 0.5 and 1 sec/item in normal subjects.*

Fig. 9 shows the digit memory span of normal subjects and conduction aphasic patients at a 1 sec/item rate. In the normal subjects, the memory span in the visual presentation test is greater than that in the auditory presentation test. A similar tendency was observed in P_1 and P_2, though their memory spans were smaller.

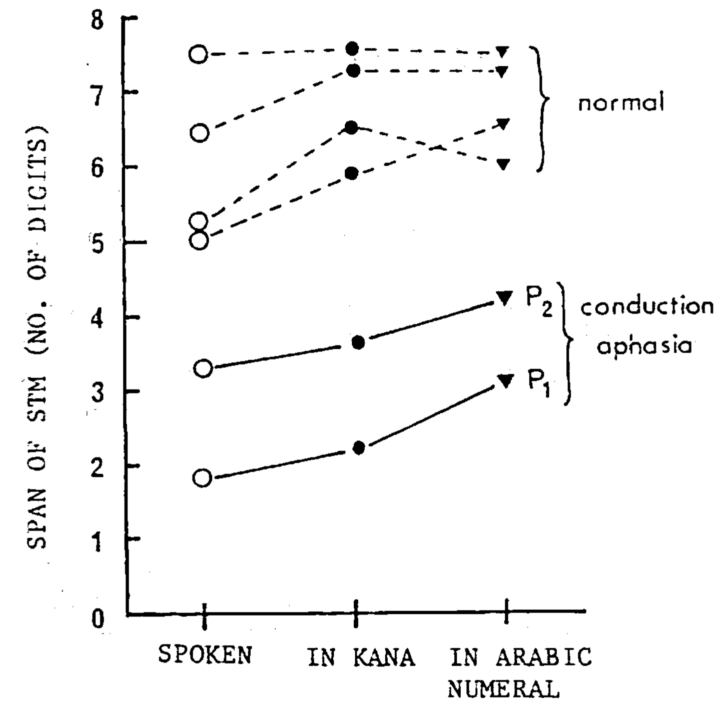


Fig. 9 *STM spans for spoken and written digits (in kana and Arabic numerals) in normal subjects and patients with conduction aphasia.*

3.3 Discussion

P_1 and P_2 exhibited a reduction in the memory span for auditorily presented digits, as compared to visually presented digits. This is a tendency consistent with Warrington and Shallice's results. It must be noted, however, that the same tendency was also found in normal subjects. Thus, it is quite unlikely that such an auditory disadvantage indicates the selective impairment in the auditory-verbal STM in patients with conduction aphasia. Rather, a deficiency in retention ability for both auditory and visual materials can be suggested, hence an impairment in the phonemic and/or semantic memories (STM1 and/or STM3) as well, according to our model.

4. Summary

In Experiment I the retention ability of normal subjects for various types of unrelated words was investigated. The major findings were: (1) the memory span for both auditory and visual (kana, and kanji or digit) materials was inversely related to the word length, (2) even homophonic kanji characters with no phonemic and minimal semantic cues were retained, although the memory span was quite small, (3) the memory span for visual materials was greater than that for auditory materials, and (4) word meaningfulness increased retention span slightly.

Based on these findings, a model for a short-term memory system consisting of two precategorical echoic and iconic memories as well as three categorical phonemic, graphemic and semantic memories was proposed. In this model, it was assumed that words are primarily retained as phonemic codes in the memory span task, and that the meaning of a word is extracted automatically. Information from meaningful speech was expected to flow from echoic memory to the phonemic memory, and then to the semantic memory. On the other hand, information from visually presented words was expected to flow from iconic memory to the graphemic memory. Here the information path branches. While kana words were assumed to require phonemic mediation to extract semantic information, kanji words were not. For kanji words phenemic codes were assumed to be generated internally from the semantic information.

In Experiment II the retention ability of patients with conduction aphasia was examined. Materials were digits presented at a 1 sec/item rate. Both the aphasic patients and the normal subjects performed more poorly in the auditory presentation as compared to the visual presentation of stimuli. The results were interpreted as indicating that the patients with conduction aphasia have an impairment in STM that is used for retaining both auditorily and visually presented materials, viz. an impairment in the phonemic and/or semantic memories.

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Note

1. The patient with this type of conduction aphasia does not usually have an impairment in his ability for "reproduction" of a single word, but has an impairment in his ability for "repetition" of a number of unconnected words; Paraphasic errors in their spontaneous speech are infrequent (Shallice and Warrington, 1977).

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