WORKING MEMORY, LANGUAGE PRODUCTION RATE, AND READING COMPREHENSION OF CHINESE DEAF READERS[*]

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The study aims to examine the relationships among working memory span(WM), language production rate (LPR), and reading comprehension (COMP) of mature Chinese deaf readers.   Sixty prelingually-deaf adults, and 30 hearing bilinguals who speak and sign fluently participated in the study.   Hearing participants were teachers of deaf schools or sign interpreters.   All participants were college educated.   Thirty of the deaf, with background in manuals, are Taiwanese Sign Language Signers and are not able to speak orally.   Another 30, educated in oral programs, speak orally and are not able to sign.

The first part of the study was associational in nature.   Participants' working memory spans, language production rates, and scores of a reading comprehension test were collected. The results showed that: 1. WM was the best predictor of COMP. 2. LPR correlated negatively with WM, that is, the longer one took to articulate given words, the shorter the WM. 3. Means of WM were significantly different among groups. However, after statistically controlling the effect of LPR, the differences of WM means were no longer significant.   4. Based on Baddeley's (1986) WM model, the retention capacities for Central Executive (CE) and Phonological Loop (PL), respectively, in each group were estimated.   According to the model, the WM variance could be accounted for by PL, rather than CE.   The results supported the stated hypotheses.

The second part of the study was a within-participant experiment.   The 30 hearing bilinguals participated in the experiment. To control the effect of word frequency and participants' prior knowledge, pseudo-words and pseudo-characters were used as experimental

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materials.　Participants were asked to memorize the artificial relationships between the pseudo-characters and their corresponding pseudo-signs, and the pseudo-characters and their corresponding pseudo-spoken-words.　WM spans and LPRs of signed and spoken character lists were measured. The results indicated that the difference between signed and spoken WM spans was no longer significant when LPR was statistically controlled.

Key words: reading, deaf, hearing-impaired, working memory, language production rate

PURPOSES AND MOTIVATION

Research has shown that the reading achievement of children with severe to profound hearing impairment typically lags behind that of their peers with normal hearing (Allen, 1986; King & Quigley, 1985; Quigley & Paul, 1986, 1989; Trybus, 1985; Trybus & Karchmer, 1977).　Surveys in both the United States and United Kingdom placed the reading of 15-year-olds who have severe to profound hearing impairment at about the third-grade level and that of high school graduates at about the fourth-grade level. (Conrad, 1979).　Similar results were obtained in Taiwan, where a logographic written system was used（林寶貴，民76；張蓓莉，民76）.

Many possible causes of the reading failure of deaf readers, such as early language deprivation, the inefficient processing of phonological information, and the limited capacity of working memory, have been proposed. However, the present study will only focus on the limited capacity of working memory.　According to the working memory model proposed by Baddeley (1986),

the production rate of a language accounts for verbal working memory capacity.　Having two different modes of language, namely signed and spoken, the deaf population provides an opportunity to examine Baddeley's model.　The purpose of the study is to examine the relationships among working memory, language production rate, and reading comprehension of Chinese deaf readers. According to Baddeley (1986), it is very likely that deaf speakers and signers are relatively slow in language production which results in the shortage of working memory capacity and reading failures.　Besides academic research, this study also includes practical implications for deaf education.　This study may shed light on why deaf readers have reading difficulties.

LITERATURE REVIEW

The researcher first states the significant role of working memory during reading comprehension.　Questions arise when studies have shown that deaf readers are very deficient in working memory retention, so do hearing poor readers.　What's wrong with their working memory?　Baddeley's (1986)

and his colleagues' (1975) efforts in this respect are to be discussed in details and the research hypothesis of the study will be generated via this line of argument.

Working memory and the reading of the deaf

The term "short-term memory" is similar to the concept of working memory. In cognitive psychology, short-term memory only refers to the storage functions of short-term processing; however, working memory refers to a broader conception that includes both storage and computational functions. Nonetheless, because the difference between short-term memory and working memory is not the subject of interest, the present researcher treats them as synonymous in this article.

Reading makes heavy demands on working memory. The reader must keep track of the current word while understanding the phrase, clause, and sentence in which it is involved. He must also keep track of and integrate the current information with preceding portions of the text. Although the linguistic and prior-knowledge-based information reduces some of the burden, working memory demands can still be great.

The fact that young children who are poor readers are deficient in working memory has been repeatedly reported. Typically they remember fewer items than age-matched good readers (Mann, Liberman & Shanweiler, 1980; Shankweiler, Smith, & Mann, 1984; Wagner & Torgesen, 1987). However, memory difficulties for poor readers appear to arise only under specific conditions; chiefly,

they occur when the items to be retained are words and nameable objects. When the test materials are not verbal (i.e., phonological) encoded, as in memory for nonsense shapes or unfamiliar faces, memory testing does not find poor readers at a disadvantage (Katz, Shankweiler, & Liberman, 1981). The problem seems, therefore, to be a language-related one, not a general memory impairment. In fact, working-memory capacity has been found to be a good predictor of the ability of young children to learn English syntactic rules (Daneman & Case, 1981). These studies of poor readers are by no means trivial for the study of the reading of the deaf. Firstly, most deaf readers are poor readers. Secondly, there have been studies indicating that the short-term retention span of deaf readers was significantly shorter than that of their hearing counterparts (Bellugi, Klima, & Siple, 1975; Bonvillian, Rea, Orlansky & Slade, 1987; Conrad, 1979; Krakow & Hanson, 1985).

Why do deaf individuals have a shorter WM span? We shall discuss what have been reported in related literature in the following paragraphs.

Language production rate of the deaf

Language production rate has been considered one of the major factors influencing working memory span. Baddeley, Thomson, and Buchanan (1975) reported that the number of words an individual can hold in WM is limited, not by the number of "chunks" of information presented, but rather by the amount of time it takes to pronounce the words. Thus, more words can be remem-

bered when their pronunciation requires a smaller amount of time.   Using his working memory model, Baddeley (1986) proposed two hypotheses to account for the growth of memory span with age.   In the first hypothesis, Baddeley proposed that memory span might be dependent on the limited capacity of the central executive.   He stated that,

The executive will use processes such as the articulatory loop system to store information, thereby freeing capacity for storing more items, either directly within the central executive, or indirectly by the more efficient use of control processes.   As a child develops, the articulatory speech programmes will become more and more efficient, and as such require progressively less monitoring by the central executive.   When an adult is required to articulate unfamiliar material, this too will require more attention from the central executive, hence reducing the amount of capacity remaining for storing subsequent items (pp. 195-196)

However, after reviewing the studies conducted by three research groups in Britain, Baddeley (1986) proposed his second hypothesis, an "articulatory loop hypothesis". He argued that the developmental progress of memory span could be explained in terms of the articulatory loop, without recourse to further assumptions about the central executive. He said, *...we can at present account for the development of memory span in children purely in terms of the articulatory loop. ...as the children become older, their articulatory skills improve, either as a result of practice, maturation of the central nervous system or*

both.   This allows them to rehearse subvocally at a faster rate (in the articulatory loop) and hence maintain more items in the phonological store....it may seem intuitively unlikely that the only difference in performance between younger and older children is the rate at which they articulate....this simple hypothesis does fit the data remarkably well....the sensible thing seems to be in favour of the simple hypothesis--at least until further data show it to be inadequate (p.204).

To summarize briefly, Baddeley (1986) strongly argued that the amount of storage in the central executive is a constant which does not change as the memory span increases with age.   The articulation rate can entirely account for the developmental growth of memory span.   This viewpoint was consistent with the results of an earlier study. Baddeley, Thomson, and Buchanan (1975) reported that their participants could recall as many words as they could read in approximately 1.8 seconds.   They claimed that the capacity of the WM can be expressed as the time taken to articulate a sequence of items. Thus, more words can be remembered when their pronunciation requires a smaller amount of time.

This argument is not confined to a within-participant situation. Researchers have also used it to interpret the memory span discrepancy between groups.   For example, after comparing his results with those of an experiment using hearing participants, Lichtenstein (1983) indicated that the amount of storage in the central executive of his hearing-impaired participants was at least as effi-

cient as that of the hearing participants. The span difference between hearing and hearing-impaired groups could be interpreted totally by the inefficient articulatory loop of the hearing-impaired subjects. Chen and Stevenson (1986) reported cross-linguistic differences in forward digit span among 4-, 5-, and 6-year-old American and Chinese children. Chinese children outperformed their American counterparts in all three age groups. Because the pronunciation duration of digits in Chinese (mean was 320 msec) was found to be much shorter than that of English (420 msec), the finding was considered as evidence supporting Baddeley's model.

The above empirical findings can be summarized as follows:

1. Most individuals with severe to profound hearing impairment have reading difficulties. They are poor readers.

2. Poor readers are deficient in working memory.

3. The short-term retention span of deaf readers is significantly shorter than that of their hearing counterparts.

4. The articulation time accounts for the working memory differences among groups.

5. Sign language is slower than spoken language in producing words (Bellugi & Fischer, 1972). Besides, the articulation duration of deaf speakers was longer than that of their hearing peers.

HYPOTHESIS AND METHODOLOGY

Part One of the Study-- An Associational Study

Hypothesis   The reasons why deaf readers have reading difficulties are not clear. Based on the previous research described earlier, the present researcher proposed the running hypothesis for this study. The researcher speculated that the fact deaf readers take longer to produce language results in a limited working memory capacity, which consequently has a negative effect on reading comprehension.

Under this big picture, more specific hypotheses can be generated.

1. The reading comprehension score of groups from different language backgrounds will be significantly different.

2. WM will be positively correlated with reading comprehension.

3. WM spans in different language backgrounds will be significantly different, regardless whether the materials being real words or pseudo words..

4. The language production rate of groups from different language backgrounds will be significantly different.

5. After controlling for the language production rate statistically, the differences in WM span between groups will be no longer significant.

Participants   There were 90 adults, composed of 30 hearing bilinguals who spoke and signed fluently and 60 prelingually-deaf people, participated in the study. The 30

hearing participants were teachers at deaf schools or sign interpreters, whereas the deaf participants were adults with prelingual hearing loss greater than 90 dB in the better, unaided ear. The participants were all college educated. Thirty of the deaf participants, with a background in manual programs, were Taiwanese Sign Language signers and were not able to speak orally. The other 30, educated in oral programs, spoke orally and were not able to sign.

Procedures   Participants were instructed to complete the following tests.

The Chinese reading comprehension test. There are 6 articles, either essays or stories, in the researcher-developed reading comprehension test. Each article has 5 multiple-choice test items. Thus the total number of test items is 30. Articles and items are arranged in order of their difficulty according to a pilot study using junior high school students as subjects. Participants were asked to read the articles and complete the multiple-choice items in 9 minutes. The full score was 30. The two-week test-retest reliability was .84.

Language production rates (LPR). To avoid misunderstanding, the researcher decided to use the term "language production rate" (LPR) instead of "articulation time" because "articulation" is often mistaken for the movements only related to "speaking." The researcher collected "real-word" and "pseudo- word" production rates in the study. In the real-word task, experimenters selected 5 words from the materials of the verbal working memory test. Participants were

presented a word list of the 5 words and asked to read the words in the original order 5 times as quickly as possible (ABCDE ABCDE ABCDE…). Experimenters measured the articulation time twice up to second with a stop watch. The average time of the two trials was the LPR. Participants with either oral or sign language background read the word list in speech or sign respectively, whereas bilingual participants were tested in both formats. As to the pseudo-word-list, readers are referred to the second part of the study for detailed information.

Verbal working memory span. Fifty-four two-syllable, high-frequency Chinese words that are concrete nouns were selected for the study. Each word of the list was printed on a separate card. To control the effect of word frequency, the experimenter conducted a pilot study and selected words that even first graders could understand. Experimenters presented one card at a time in a 2-second interval in a determined sequence. The test began with a 3-item level. Higher levels of 4-, 5-, 6-, and 7-item followed if a participant passed any one of the two trials in an earlier level. Each word appeared only once in the test. The test was stopped if a participant failed to answer both items correctly in a given level. To include the computation and storage functions of working memory in the test, the experimenters asked a simple question first, then read several words. Participants were required to pick the correct answers and recall them in the original order. For example, the first item of the 2-word level reads:

"**Please read the animals that have
wings in the original order**.

(cards presented in a determined order)

'**rabbit**', '**butterfly**', '**beetle**', '**frog**' "

Participants were supposed to answer
"**butterfly**," and "**beetle**". The test-retest
reliability of the test was .76 to .82 in another
study conducted by the author.

Part Two of the Study—
A Within-Participant Experiment

The second part of the study used pseudo
characters, signs, and syllables to control the
effect of word frequency and participants'
prior knowledge. In addition, the researcher
used a within-participant design to avoid the
confounding effect of demographic variables.
According to Baddeley & Gathercole (1993),
the only factor contributing to WM span
should be the language production rates (LPR)
of the pseudo signs and syllables. Therefore,
if the effect of LPR was removed using sta-
tistical technique, the WM spans for sign or
speech recall were expected to be equal. If
it is not the case, there must be factors other
than LPR having an influence on WM.

Participants   The 30 hearing bilin-
guals in the first part of the study participated
in the experiment.

Experimental materials and proce-
dures   Twelve pseudo written characters
were created as experimental materials. These
characters were randomly assigned to 2 lists.
Each list contained 6 characters. One list was
for oral recall and the other for sign recall.
For the sake of convenience, the characters in
the oral list were named as "A, B, C, D, E, F"
and the sign list as "U, V, W, X, Y, Z."

Each pseudo character in the oral/sign list has
a corresponding nonsense syllable/sign.
None of the syllables/signs held any infor-
mation that could be related to participants'
prior knowledge about their spoken/sign lan-
guage. Participants were required to memo-
rize the artificial relationships between the
pseudo characters and corresponding non-
sense signs and syllables. After a participant
successfully passed 5 continuous trials in
which s/he responded to the pseudo charac-
ters with correct pseudo signs and syllables,
the test began. Half of the participants be-
gan with oral tasks while the rest began with
sign tasks.

Pseudo word WM span   The experi-
menter presented pseudo characters by flash
cards in an interval of 2 seconds. Partici-
pants were instructed to recall the items pre-
sented in the original order.

Nonsense syllable/sign LPR   Partici-
pants were asked to repeat "UVWXYZ
UVWXYZ UVWXYZ...." in speech, and
"ABCDEF ABCDEF....." in sign 5 times re-
spectively as quickly as possible. The ex-
perimenter measured the articulation time up
to second with a stop watch.

Hypothesis   After controlling for the
effect of LPR, there will be no significant
difference between signed and spoken WM
spans.

RESULTS AND
DISCUSSION

The Associational Study

Table 1 presents intercorrelations be-
tween working memory span (WM), language

production rate (LPR), and reading comprehension (COMP) for all participants (N=90) and for each group (N=30). WM positively correlated with reading comprehension. This finding was especially true in hearing bilinguals and deaf signers. WM was the best predictor of reading comprehension in both groups. Table1-1 also shows that the LPR negatively correlated with WM and COMP. These findings were consistent with the original hypothesis. That is, in general, the longer one takes to produce words, the shorter the WM span and the poorer the COMP s/he has.

There is a somewhat different picture when statistical procedures were conducted in three independent sample groups. WM still positively correlated with COMP in all three conditions. However, the coefficients between LPR and COMP, as well as between LPR and WM, were marginal or not significant in most cases. The researcher believes this might be explained by the small number of the participants.

Table 1　Intercorrelations between working memory span (WM), language production rate (LPR), and reading comprehension (COMP) for each group.

1-1 All participants, N=90					
Variables	1	2	3	4	5
1.COMP	1				
2. Real word LPR[1]	-.301**	1			
3. Pseudo word LPR[1]	-.582***	.347**	1		
4. Pseudo word WM	.514***	-.356***	-.529***	1	
5. WM Span	.558***	-.387***	-.408***	.348**	1
1-2 Hearing bilinguals , N=30					
Variables	1	2	3	4	5
1.COMP	1				
2. Real word LPR[1]	-.146	1			
3. Pseudo word LPR[1]	.035	.324#	1		
4. Pseudo word WM	.355*	-.278	-.151	1	
5. WM Span	.559**	.070	-.023	.292	1
1-3 Deaf speakers (N=30)					
Variables	1	2	3	4	5
1.COMP	1				
2. Real word LPR[1]	-.349#	1			
3. Pseudo word LPR[1]	-.384*	.640***	1		
4. Pseudo word WM	.317	-.223	-.214	1	
5. WM Span	.360*	-.490**	-.570**	.083	1
1-4 Deaf signers (N=30)					
Variables	1	2	3	4	5
1.COMP	1				
2. Real word LPR[1]	-.172	1			
3. Pseudo word LPR[1]	-.310#	.147	1		
4. Pseudo word WM	.212	-.298	-.256	1	
5. WM Span	.572**	-.132	-.320#	.249	1

*P＜.05　　**P＜.01　　***P＜.001　　# marginal

1. Participants used their strongest language during the tasks.

Table 2　Means (STDs) of variables and the comparisons between group means

Variables	All partici- pants (N=90)	Speakers (N=30)	Hearings (N=30)	Signers (N=30)	F (p)	Post-hoc Comparison
1. reading	21.10(5.93)	23.00(4.57)	24.10(5.25)	16.27(4.67)	F=22.91***	Hearings >Signers; Speakers > Signers
2. pseudo-word WM	3.80(1.19)	3.96(0.96)	4.49(1.07)	2.94(1.00)	F=18.19**	Hearings > Signers; Speakers > Signers
3. Real word LPR	14.98(4.32)	17.07(5.11)	11.77(5.11)	16.10(3.33)	F=17.55***	Signers > Hearings; Speakers>Hearings
4. Pseudo word LPR	10.30(6.15)	7.13(2.40)	6.30(2.80)	17.46(4.37)	F=96.69**	Signers > Hearings; Signers > Speakers
WM Span	4.07(0.69)	4.01(0.77)	4.37(0.60)	3.77(0.57)	F=18.18**	Hearings > Signers

**P＜.01　　　***P＜.001

Given the scarcity and geographically widespread nature of the deaf population and hearing bilinguals, this study could only have 30 participants in each group. When the sample size is 30, a correlation coefficient must be larger than .35 to reach the .05 significance level. If the sample size could be enlarged, several coefficients that were marked "marginal" would become significant. Besides, in table 1-3 and 1-4, the coefficients between LPR and WM were all negative, as was observed in Table 1-1. It seems very unlikely that the patterns of these coefficients were caused by chance.

Table 2 presents means and standard deviations of variables and the results of analysis of variance, with reading comprehension, memory span, and LPR as dependent variables, and GROUP as independent variable.

Reading comprehension　Three group means of COMP differed significantly ($F_{(2,86)}$ =22.91, P<.001). Scheffe post-hoc comparisons indicated that there is no significant difference between the COMP means of hearing bilinguals and deaf speakers. But the deaf signers' COMP mean was significantly smaller than those of the other two groups.

Working memory span　The mean WM span of deaf signers in both pseudo-word and real-word conditions was significantly smaller than those of hearing bilinguals and deaf speakers.

Language Production Rate　Hearing participants produced words much faster than deaf participants in both real- and pseudo-word conditions. There was no significant difference between deaf signers and deaf speakers in real-word LPR. However, deaf signers' LPR was significantly slower than that of deaf speakers. Notably, in LPR tasks, deaf speakers produced the materials in their dominant language. In other words, deaf signers used Sign and deaf speakers used Mandarin. Even all participants were using their dominant languages, the deaf signers remained relatively weak in pseudo-word LPR tasks.

Newport (1984) has found that signers who first learned to sign after childhood showed decreased accuracy in producing ASL morphology compared with early-childhood learners despite considerable experience. Similarly, Mayberry (1991) found that age of sign language and spoken language acquisition has a lifelong effect on participants' sentence processing. Given the fact that the hearing-impaired participants in this study were prelingually deaf, it seems to be reasonable to suppose that they had language developmental delay during their early years and consequently resulted in an inefficient language processing, as reflected in their longer language production rates.

In summary, the general impression of the above findings is that, compared with hearing people, deaf people were at a disadvantage position in these tasks. It seemed that deaf signers had particular difficulty producing pseudo-words.

Baddeley (1986) indicated that LPR accounts for the individual differences of working memory span. According to his model, the more efficient the language production is, the faster the rehearsal process will be, which consequently results in a better performance of WM. In addition, the LPR can also be considered as an index of verbal automaticity. As the automaticity increases, individuals use fewer and fewer cognitive resources in the basic processes of language and reading. More resources can go to higher-level processing and aid comprehension. If this is the case, the researcher then predicted that when LPRs were controlled statistically, the differences of WM means among groups should disappear. An ANCOVA (analysis of covariance) procedure, using pseudo-word LPR as covariate, and pseudo-word WM as dependent variable, was then conducted to test this hypothesis.

Table 3　Means (raw data) and adjusted means (ANCOVA, using LPR as covariate) of pseudo-word WM span for each groups

	Hearings	Speakers	Signers	F	comparisons of means
Means	4.49	3.96	2.94	18.19(p<.01)	Hearings > Signers
					Speakers > Signers
Adjusted means	4.25	3.77	3.37	2.81(p>.05)	Hearings=signers=speakers

As shown in table 3, the results of ANCOVA revealed that WM group mean differences were no longer significant after the language production rate was controlled. This finding supported the hypothesis generated from Baddeley's (1986) working memory model.

The within-participant experiment

Only the 30 hearing bilinguals participated in this experiment. The first part of the study controlled the effect of word frequency and participants' prior knowledge by using pseudo words and pseudo characters as WM materials. However, the researcher was unable to interpret the between-group WM

differences because differences caused by other factors, such as reading comprehension, might also exist. It is possible that deaf signers differ from the other two groups in the amount of time they spend on learning reading-related skills, in their socioeconomic and cultural background, and so on. The WM capacity may, therefore, be the result of many complex interactions, rather than a single independent variable. The second part of the study used a within-participant design to control the effect of these possible demographic variables. In this experiment, participants were asked to complete the tasks both in oral or sign modes. The researcher compared the means of dependent variables *within participants*, which means that participants were compared with themselves rather than individuals from different backgrounds. Table 4 showed that WM spans in different experimental conditions differ significantly (paired-t=4.41, p<.000). However, after statistically controlling the effect of language production rate, the difference was no longer significant (p>.05). This result again supported the hypotheses generated from Baddeley's (1986) WM model.

Table 4   Means (raw data) and adjusted means (ANCOVA, using LPR as covariate) of pseudo-character WM span in two experimental conditions (hearing bilinguals, N=30)

	Recall in speech	Recall in sign	Test of mean difference
Means	4.49	3.57	Paired-t =4.41, df=29, p<.000
Adjusted means	4.11	3.92	$F_{(1, 28)}$=.23, p=.639

DISCUSSION

Working memory and reading comprehension   In the present study, verbal working memory span was a good predictor of both deaf and hearing readers' reading comprehension. Reading comprehension score increased with working memory span. This was consistent with previous researchers' findings (Daneman & Carpenter, 1980; Baddeley, 1986; 1992; Siegel, 1994). These results support the notion that working memory plays a significant role during the reading process.

Language background and working memory   Although deaf signers performed more pooly than either deaf speakers or hearing bilinguals on WM tasks, there was no evidence indicating that the between- group WM difference was a function of language background. The WM difference disappeared after the language production rate was controlled. The language production rate could reasonably and empirically account for the between-group differences of working memory span. This statement continued to be true when possible confounding variables, such as word frequency, demographic background, and prior knowledge, were removed by the design. In sum, this study supports

the hypothesis generated from Baddeley's (1986) working memory model. The results lead the researcher to consider the possibility that it was the "language processing", and not the "linguistic nature" of the deaf population that had a negative influence on working memory, and consequently resulted in failures of reading comprehension.

For prelingually-deaf speakers, to acquire a spoken/aural language is difficult enough. To articulate the written representation of the language in an automatic way is even harder. The discrepancy of LPR means between deaf and hearing speakers in this study addressed this difficulty.

Deaf speakers who grew up in an oral environment confronted difficulties in language processing. The same is true for deaf signers, whose dominant communication mode is relatively time-consuming (Bellugi and Fischer, 1972), which results in inefficient language production, as shown in the comparisons of LPR means in Table 2. It is the author's speculation that, when the items to be remembered were real words, deaf signers used semantic and orthographic information about the words to aid language production. Therefore, deaf signers' average LPR was not significantly different from the other two groups. However, when semantic and orthographic information was removed, as in the pseudo-word materials, the processing became extremely difficult. Also, for most deaf signers, reading makes heavy cognitive demands because the text represents a language they are not familiar with. The processing and transformation of

internal linguistic representation may occupy too many mental resources and result in a shortage of WM capacity, as is observed in Table 2, in which all of the statistics for the deaf signers are the lowest among the three groups.

Conclusions and Implications　　The first part of the study examined the relationships among language production rate, working memory capacity, and reading comprehension in adult Chinese deaf readers. Similar to what has been found by previous researchers, the results of the present study indicated that WM is highly correlated with reading comprehension. Also, as predicted, the average WM spans in the three groups were significantly different. It was found that the efficiency of language production (LPR) contributed to working memory span. Whenever the LPR was controlled, the between-group WM difference disappeared. These findings, of course, do not necessarily indicate cause-and-effect relationships. However, the second part of the study tested the effect of LPR on WM with an experimental design. With demographic variables and prior knowledge being controlled and the LPR removed, the researcher again found that the WM differences disappeared. Do these findings provide any direct implications for educational practice? As what was reported by Lovett, Steinbach and Frijters (2000), reading disabled children could benefit from remedial programs aimed at naming speed training. Automaticity training of language processing may be a useful target for future research, for we have seen how

language production rate has an influence on working memory, a factor which has been considered by different researchers to be the best predictor of reading comprehension.

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工作記憶、語言產生效率與
聾人的中文閱讀理解

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摘　　要

　　本研究旨在探討成熟聾人「工作記憶容量」、「語言產出效率（speech of sign production rate）」與「中文閱讀理解」之間的關係。六十名學習語言前成聾的成人及30名聽力正常的口語-手語的雙語成人參與了本研究，所有的參與者都是大專以上教育程度。聾參與者中有30名使用手語溝通，不會說話；另外30以口語溝通，不會手語。雙語聽人取自啓聰學校教師及國內的手語譯員。

　　研究的第一部分是相關性研究，研究者蒐集參與者的工作記憶廣度（WM）、語言產出效率（LPR）及閱讀理解分數（COMP）。研究結果指出：1.工作記憶可以有效預測閱讀理解；2.LPR和WM成顯著負相關，唸一系列指定詞彙的時間愈長，WM的容量愈短。3.不同組的WM間有顯著差異，但以統計技術控制了LPR的影響後，各組WM平均值的差異不再顯著。

　　研究的第二部分是參與者內（within-participant）的真實驗研究。爲了控制詞頻及參與者的先備經驗，實驗用的都是假漢字、假口語詞、假手語詞。研究要求參與者硬記十二個假漢字與其相對應的假口語詞、假手語詞。假漢字與假口語詞、假手語詞間的關係都是強制規定的，完全沒有既定的規則可循。研究者測量參與者的假漢字在兩種狀況的工作記憶廣度，及假口語詞、假手語詞的LPR。研究結果指出，當以統計技術控制LPR時，手語和口語模式的工作記憶容量，就沒有顯著差異了。

關鍵詞：閱讀、聾人、聽覺障礙、工作記憶、語言產出效率