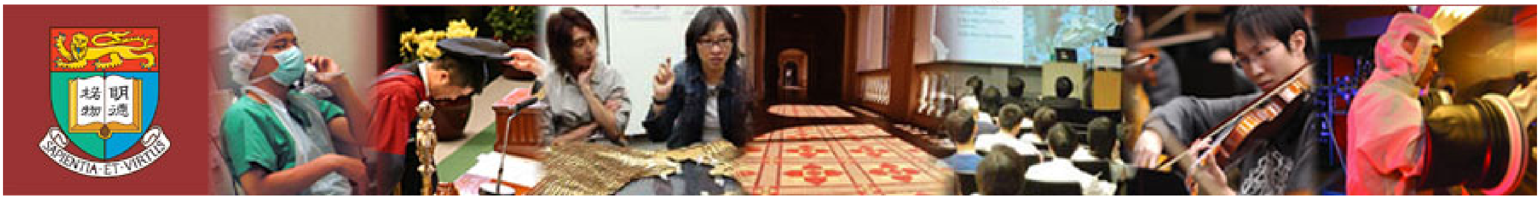

Title	Verbal Short-term memory deficit and its relation to language impairment in Cantonese speakers with aphasia
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Citation	Koon, N. [官念婷]. (2014). Verbal Short-term memory deficit and its relation to language impairment in Cantonese speakers with aphasia. (Thesis). University of Hong Kong, Pokfulam, Hong Kong SAR.
Issued Date	2014
URL	http://hdl.handle.net/10722/238913
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Verbal Short-term memory deficit and its relation to language impairment in Cantonese speakers with aphasia

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A dissertation submitted in partial fulfilment of the requirements for the Bachelor of Science (Speech and Hearing Sciences), The University of Hong Kong, June 30, 2014.

Abstract

Co-occurring verbal short-term memory (STM) and language impairments are often observed in patients with left hemisphere stroke. The aim of this study is to investigate the relationship between performance in verbal STM and auditory linguistic tasks in Cantonese speakers with aphasia. Twenty five stroke participants and the same number of matched controls were assessed with a series of immediate serial recall (ISR) tasks and auditory linguistic tasks. Cantonese version of the Western Aphasia Battery (CAB) was also administered to stroke participants. The results suggested that Cantonese speakers demonstrated more difficulties with non-words and lexical decision tasks, potentially due to the additional linguistic factor of lexical tone. The clinical assessment and rehabilitation of language impairment should take into account of lexical tone processing in tonal languages.

Aphasia co-exists with cognitive impairments in individuals with left hemispheric stroke (Martin & Reilly, 2012). Among all types of deficits in cognitive functions, verbal short-term memory (STM) impairments occur most frequently and are the most persistent deficits in individuals with aphasia (Attout, Van der Kaa, George, & Majerus, 2012). Extensive research on verbal STM and its relation to the language system have been conducted, with evidence suggesting that STM impairment is strongly related to impairment in language processing (Attout et al., 2012; Majerus, 2009; Martin & Ayala, 2004; Martin & Reilly, 2012).

In the studies of STM and language performance, auditory-verbal STM span were mostly measured by immediate serial recall tasks, where participants are usually presented with a sequence of auditory stimuli (digits, words or non-words) and then recall the items with spoken responses (Martin & Ayala, 2004; Potagas, Kasselimis & Evdokimidis, 2011), written responses (Saint-Aubin & Poirier, 2000) or by pointing to targets (Majerus, Lekeu, Van der Linden, & Salmon, 2001; Martin & Ayala, 2004). As for the nature of the stimuli to be recalled, digits, non-words and words have all been used. Notably, recall performance varies across different types of stimuli, and is affected by the psycholinguistic properties of the items, such as word frequency and word imageability (Martin & Ayala, 2004). Language performance measured by standardized tests and auditory linguistic tasks is also variable, for example auditory discrimination tasks (Attout et al., 2012), lexical decision tasks (Majerus et al., 2001) and auditory word identification tasks (Martin & Ayala, 2004).

Most recent studies define the relation between verbal STM deficits and language impairment in aphasia in two different approaches. One major approach is the neuroscience approach. It involves the use of neuroimaging methods, which aims to identify the common neural correlates of verbal STM and language processing (Majerus, 2009). The neuroimaging data from these studies suggests a close relationship between verbal STM performance and language impairment (Buchsbaum & D'Esposito, 2008; Majerus, 2013; Koenigs et al., 2011). Another approach is the behavioral approach. The aim of this approach is to identify and explain the relationship between verbal STM and language with reference to language-based STM models (Attout et al., 2012; Majerus et al., 2001). Associations, as well as dissociations between language impairment and verbal STM deficits have been identified (Attout et al., 2012), which provide evidence that patterns of VSTM performance are related to the integrity of the language processing network (Martin & Saffran, 1997).

Different STM models have been proposed to explain the relationship between verbal STM and language impairment. One of the most influential models is the interactive spreading activation model proposed by Martin and Saffran (1992; 1997). In this framework, activation and maintenance of lexical, phonological and semantic representations within the language network are essential in the verbal STM system. It is assumed that activation of phonological nodes in the phonological network will spread to corresponding lexical nodes, and to associate semantic nodes in the language network. After that, there will be a backward activation from the language network to the decaying phonological nodes (Martin & Lesch, 1996). Lexical, phonological and semantic representations of the corresponding spoken items are temporarily maintained in the verbal STM by the process of spreading activation (Attout et al., 2012; Majerus, 2009), so as to allow more time for comprehension of the spoken words. Individuals with impairment in the language network will have breakdown in the process of spreading activation (Attout et al., 2012; Martin & Ayala, 2004). A more rapid rate of decay of the representations also leads to insufficient duration for obtaining the semantic knowledge of the related item result in language processing deficits (Attout et al., 2012; Kalinyak-Fliszar, Kohen & Martin, 2011).

Another influential view is the reconstruction hypothesis (Majerus, 2009). According to this hypothesis, long-term phonological and/or semantic representation of the items which best fit with the decayed trace will be retrieved, and thus, enable the reconstruction of decayed trace in verbal STM. Therefore, phonological information in the verbal STM can be maintained for output. Under this framework, it is hypothesized that the integrity of both the phonological and semantic representations within the language network are essential in the verbal STM system (Majerus, 2009; Saint-Aubin & Poirier, 2000). In other words, a redintegration process is dependent on the activation efficiency of the phonological and semantic representations. Impairments in the language system might lead to breakdown in the redintegration process, and eventually result in verbal STM deficits (Martin, 2009).

Both the interactive spreading activation model and reconstruction hypothesis explain the co-occurrence of verbal STM and language-processing deficits in individuals with aphasia (Attout et al., 2012). In both, temporary retention of item information including phonological and semantic information is required in the recall process of word lists. It has been reported that verbal STM retains the order information of items as well since serial-order information is essential for one to recall items in an ordered sequence (Attout et al., 2012). Evidence from behavioral studies shows that verbal STM for order information should be distinguished from verbal STM for item information (Attout et al., 2012; Majerus, Poncelet, Elsen, & Van der Linden, 2006). In particular, item retention capacity of verbal STM is closely related to the level of integrity of the language-processing network, whereas the order-specific verbal STM does not depend on the language system (Attout et al., 2012). Studies in normal adults revealed that recall of item information could be facilitated by long term language knowledge. For instance, the immediate serial recall of concrete words (e.g. ‘apple’, ‘tree’), which have richer lexical-semantic representations than abstract words (e.g. ‘suggestion’, ‘concept’), had lead to higher recall accuracy at the level of item information. Such an effect was, however, not observed at the level of order information (Attout et al., 2012; Majerus, 2009). In other words, it only affects the number of items that one can recall correctly, but not the order of items.

In addition to behavioral studies, many recent neuroimaging studies and verbal STM models further suggested the representations of item and order information are located in distinct neuro-networks (Majerus, 2009; Majerus et al., 2010; Majerus, 2013). Neuroimaging studies of verbal short term maintenance revealed that regions associated with phonological and/or semantic processing including superior temporal region, posterior temporo-parietal region and inferior temporal regions were activated in tasks involving item information, suggesting associations between item-specific verbal STM and language knowledge (Majerus et al., 2010; Majerus, 2013). However, verbal STM for order information is found to be less involved in the activation of language processing regions in the temporal lobe (Majerus, 2009, Majerus, 2013). Majerus (2013) also emphasized such a distinction between item and order specific information in the review article: “*…the language network ensures the encoding and representation of phonological and semantic item information during temporary maintenance of verbal information. Critically, this excludes the representation of novel serial order* *information."* (Majerus, 2013, p.3). The above findings suggest that verbal STM for item information will be of higher relevance to one's language knowledge. As the aim of the present study is on investigating the relationship of verbal STM and language impairment of Cantonese speakers with aphasia, the present study will focus on verbal STM for Cantonese item information instead of serial order information.

Given that verbal STM deficits are associated with language impairments, there is growing attention to the effect of verbal STM training on aphasia treatment outcomes (Kalinyak-Fliszar et al., 2011; Murray, 2012). Studies have indicated that treatment of STM deficits generally have positive effect on patients' responses to language therapy (Kalinyak-Fliszar et al., 2011; Majerus et al., 2005). Nevertheless, more studies are needed to establish concrete treatment design and identify variables that contribute to optimal maintenance and transfer of treatment effects (Murray, 2012). In particular, there is a lack of research investigating the performance of and the relationship between verbal STM deficits and language impairments in Chinese speakers with aphasia. Although extensive research on impaired memory and language of individuals with aphasia has been conducted, previous studies mainly focused on alphabetic languages such as English and French. Owing to cross-linguistic differences in Cantonese and alphabetic languages, it is necessary to verify if findings in previous studies involving alphabetic languages can be generalized to Cantonese. Studies of the relationship between verbal STM deficits and language impairments in Cantonese speakers are therefore needed.

Unlike English and other alphabetic languages, Cantonese is a syllable-based language with one syllable corresponding to one morpheme. In addition, Cantonese is a tonal language. There are nine tones to indicate different lexical meanings in a syllable (So, 1996). Similar to other Chinese syllables, Cantonese syllables have simple phonological structures, in consonant-vowel (CV), consonant-vowel-consonant (CVV) or consonant-vowel-consonant

(CVC) configuration (Cheung & Kemper, 1994) while alphabetic languages might involve consonant clusters in syllable initial or final positions (Giegerich, 1992). This simple phonological structure allows Chinese words to be articulated in a faster rate (Cheung & Kemper, 1994). As the amount of phonological information held in verbal STM is dependent on rate of articulation, a faster articulation rate is expected to contribute to better memory span performance (Baddeley, 1986). Chen, Cowell, Varley, and Wang (2009) also suggested that shorter articulation time for digits in spoken Chinese accounts for higher digit spans than English. This evidence suggests that linguistic differences in Cantonese have an effect on recall span.

There are also a tremendous number of homophones in Cantonese, which is less common in English (Li & Yip, 1998). Homophones are words with the same pronunciation, but carrying different semantic meaning. They can be heterographic, e.g. /ts^{h}a^{1}/ for the words 叉(fork) and 差(bad), or homographic, e.g. /fɐn^{1}/ for the words 分(scores) and 分(separate). Homophones have an identical phonological representation and share a common phonological node, but the semantic representations among them are different (Caramazza, Costa, Miozzo & Bi, 2001). With regard to this, Li and Yip (1998) suggested that processing of spoken homophones would involve more levels of cognitive processing. For example, recognition of homophones requires the processing of contextual information, so as to facilitate the activation of corresponding semantic representation. Since the majority of Cantonese words contain homophones, it is expected that the effectiveness of the activation and retrieval of lexical representations of Cantonese words in verbal STM will also differ from that of English words.

Moreover, Cantonese is considered to be a logographic language (Law, Yeung & Chiu, 2008). Native Cantonese speakers, especially those educated in Hong Kong, do not acquire an alphabetic form of their spoken language (Law et al., 2008). There is a lack of grapheme-phoneme relationship in Cantonese, and instead, Cantonese speakers show reliance of phonetic radicals for phonological information. The absence of grapheme-phoneme correspondence in Cantonese results in poor phonological awareness among Cantonese speakers (Law et al., 2008). As suggested in Mann and Liberman (1984), there is a moderate correlation found between phonological awareness and verbal STM span. Therefore, it is expected that poor phonological awareness among Cantonese speakers would give rise to differential performance in verbal STM tasks as well.

Owing to the linguistic differences between Cantonese and alphabetic languages, it is necessary to investigate if findings from previous studies involving alphabetic languages can be generalized to Cantonese. Studies in the Cantonese population will be necessary to identify whether the association between verbal STM deficits and language deficits exist in Cantonese. The present study first compared the verbal STM and language performance of Cantonese individuals with history of left hemispheric stroke (LH group), individuals with history of right hemispheric stroke (RH group) and normal controls. Following that, the relationship of performance in verbal short-term memory tasks and auditory linguistic tasks of Cantonese speakers with aphasia was examined. Such understanding is essential to give insight into future investigations on how the language deficits and co-existing verbal STM deficits can be rehabilitated in Cantonese aphasic population. The hypothesis to be tested is that Cantonese speakers with left hemispheric brain damage will show impairment on verbal STM tasks when compared to Cantonese speakers with right hemispheric brain damage and controls. This hypothesis is motivated by the findings from neuroscientific and behavioral studies showing more left hemisphere involvement in both verbal STM and language processing deficits in aphasia.

Method

Participants

Twenty-five participants with a history of single and unilateral stroke, and 25 normal controls (mean age = 55.00, S.D. = 9.01, range = 33 – 72) were recruited. The 25 individuals with stroke were at least 6-month post onset. Fifteen of them had a history of unilateral left hemispheric stroke (mean age = 54.87, S.D. = 10.07, range = 32 – 72), while the remaining ten of them suffered from unilateral right hemispheric stroke (mean age = 58.50, S.D. = 6.60, range = 47 – 67). In addition, all participants were native Cantonese speakers and right-handed. Individuals with a significant hearing loss (i.e. over 30 dB HL), or motor speech disorders that were moderate or severe in severity were excluded from participation. The age (± five years), gender, and educational background (primary education or below / secondary education / tertiary education or above) of the control participants were matched with the stroke patients. All participants were informed of the details of the study including purpose, procedure and more. Written informed consent (*see* Appendix A) was obtained from all participants.

Table 1. The demographic information of participants with stroke

Subject	Gender	Age	Education	Side of affected hemisphere	Post-onset (Month)
1	M	60	Secondary	L	24
2	M	56	Primary	L	84
3	M	56	Secondary	L	96
4	M	54	Secondary	L	15
5	M	44	Tertiary	L	10
6	F	48	Tertiary	L	72
7	F	56	Primary	L	48
8	M	72	Tertiary	L	216
9	F	57	Secondary	L	156
10	F	63	Primary	L	192
11	M	59	Secondary	L	51
12	M	60	Secondary	L	25
13	F	65	Secondary	L	192
14	F	32	Tertiary	L	16
15	M	41	Tertiary	L	64
16	F	62	Tertiary	R	17
17	M	57	Secondary	R	84
18	M	47	Secondary	R	48

19	M	53	Secondary	R	204
20	F	62	Secondary	R	60
21	M	51	Tertiary	R	11
22	M	67	Secondary	R	264
23	M	65	Tertiary	R	156
24	M	64	Primary	R	96
25	M	57	Secondary	R	36

Note. F = Female; M = Male; L = Left; R = Right; Primary = Primary education or below; Secondary = Secondary education; Tertiary = Tertiary education or above.

Materials

Participants with history of stroke were assessed with the Cantonese version of the Western Aphasia Battery (CAB; Yiu, 1992). In addition, all participants were assessed with a series of immediate serial recall (ISR) tasks and auditory linguistic tasks:

ISR tasks. The ISR tasks contained seven tasks with different stimuli presented auditorily, including (1) digits; (2) monosyllabic high frequency non-words; (2) monosyllabic low frequency non-words; (4) disyllabic non-words; (5) monosyllabic real words; (6) disyllabic high imageability real words; and (7) disyllabic low imageability real words. Each task list contained 2 to 11 item lengths, with four different stimuli at each item length. The items did not repeat in the same list, except for the lists of 11 digits in ISR task for digits. The lists were recorded in a female voice and stored in a computer drive.

In the ISR task for monosyllabic non-words, two sets of stimuli were used, with one set composed of high frequency and another set of low frequency phonemes at onset and rimes. This was to examine the effect of phonotactic frequency on recall of Cantonese nonwords. All non-words in the lists were constructed based on the phoneme frequency table by Leung, Law and Fung (2004). Both sets of stimuli contained task lists of 2 to 7 item lengths, with four different stimuli at each item length (*see* Table 2). The constituent phonemes did not repeat themselves in the same list.

Table 2. Constituent phonemes in the ISR tasks for monosyllabic non-words with reference to phoneme frequency reported by Leung et al. (2004)

	High token frequency	Low token frequency

Onset	k, l, j, h, ts, t (>10000)	t^h, ŋ, n, p^h, kw, kw^h (<3000)
Rimes	ɔ, ɐi, ɐu, i, a, ou, ei, ɛ (>5000)	ɛk, ɔn, ɵn, œ, au, ut, ap, aŋ (<500)

Note: The total token frequencies for onset and rimes are 123,807 and 137,484 respectively.

The ISR task for disyllabic real words had two sets of stimuli, with one set of high and the other set of low imageability items to examine the effect of word imageability on recall of Cantonese materials. The words were sampled from *A Test Battery for Chinese Aphasia* (Law, 2007) and were all nouns. Both sets of stimuli contained task lists of 2 to 7 item lengths, with four different stimuli at each item length. The words did not repeat in the same list.

Auditory linguistic tasks. A series of auditory linguistic tasks were administered, including (1) auditory discrimination task; (2) auditory lexical decision task; and (3) auditory word recognition task. The auditory discrimination task was adapted from *A Test Battery for Chinese Aphasia* (Law, 2007), and the other two were designed with reference to Psycholinguistic Assessments of Language Processing in Aphasia (PALPA) (Kay, Coltheart & Lesser, 1992). The auditory discrimination task included 40 pairs of stimuli which were identical pairs or minimal pairs different in tone, onset, nucleus, or coda. Lexical decision task involved 20 real words and 20 non-words. The non-words were created based on phonotactic rules of Cantonese syllables. The auditory word recognition task had a total of 40 items, which were composed of an equal number of high and low frequency nouns and verbs (i.e. ten items in each category). There were four pictures presented in each trial, including the target picture, phonological distractor, semantic distractor and unrelated distractor.

The stimuli lists are shown in Appendix B.

Procedure

All participants were assessed with a series of ISR tasks and auditory linguistic tasks. The stimuli in all ISR and auditory linguistic tasks were recorded in a female voice and stored in a computer drive. Stimuli were presented once to participants with soundproof headphones connected to a laptop computer. To avoid complication from potential underlying deficits in the orthographic output lexicon and visual analysis, written responses were not used in this study. Participants were instructed to give their answers orally in the ISR tasks, auditory lexical decision task and auditory discrimination task, and by pointing in the auditory word recognition task.

In each of the ISR tasks, all participants began the recall procedure with lists of two item lengths. At each item length, there were four different stimuli. When a participant was able to recall three or more stimuli at certain item length, s/he was required to recall stimuli in the next item length condition. When a participant failed to recall three or more stimuli at certain item length, the task was terminated. The stimuli were presented with an average of 200ms intervals between different stimuli. The end of the sequences was marked by a beep sound (1000Hz, 800ms). Participants were instructed to repeat the items orally after the beep sound.

Two practice trials were presented as an introduction to each of the ISR and auditory linguistic tasks. Participants' responses in the experimental trials were recorded and scored by the experimenter. There was no time limit for each trial. All participants were able to finish each trial within 60 seconds.

For participants with history of stroke, the Cantonese version of the Western Aphasia Battery (CAB; Yiu, 1992) was administered in addition to the ISR recall tasks and the informal auditory linguistic tasks to identify possible types and severity of aphasia in participants with history of stroke**.** The participants in LH and RH group were assessed with sub-tests related to oral language including: spontaneous speech, auditory comprehension, repetition and naming. The scores in the above subtests were obtained. The total aphasia quotient (AQ) was also calculated as an indicator of the severity of aphasia.

Scoring

Immediate serial recall (ISR) tasks. A given trial was regarded as correct when all items were recalled in their exact pronunciation. Phonemic paraphasia and perseveration were not accepted. The span performance was defined as the greatest length at which the participant could recall at or more than 75% accuracy (i.e. correct in three out of four trials). For participants who failed to achieve 75% accuracy at the lists of two items, span length was marked as one if the participant could consistently recall one of the two items in the lists. Otherwise, span length was recorded as zero.

Auditory linguistic tasks. As the auditory lexical decision and auditory discrimination tasks required Yes-No responses, sensitivity indexes (d') of the tasks were calculated as $d' = Z(\text{hit rate}) - Z(\text{false alarm rate})$ (Macmillan & Creelman, 2004). As for the auditory word recognition task, percentage scores of each participant were calculated with the following equation:

$$\text{percentage score} = \frac{\text{number of correct trials}}{\text{total number of trials}} \times 100\%$$

Data and statistical analysis

In order to compare the verbal STM capacity across the three groups, a non-parametric Kruskall-Wallis test was performed using SPSS with $\alpha = .05$. The main effects of groups were examined, followed by pairwise comparisons to indicate the levels which the differences existed. Pairwise comparisons were performed with the use of Mann-Whitney tests, with alpha values adjusted through Bonferroni correction. In addition, Wilcoxon Signed Rank tests were performed in order to compare recall performance between real words and non-words in LH group participants.

To examine the relationship of verbal STM deficits and language impairment in the LH group, their performance in ISR tasks were correlated with AQ and comprehension score in CAB using non-parametric Spearman Rank-Order Correlation. In addition, the relationships between comprehension score in CAB and performance in auditory linguistic tasks were also examined through multiple regression analysis.

Finally, the association between individual memory and auditory linguistic task performance was examined. The LH group performances in seven ISR tasks were correlated with performance in three auditory linguistic tasks, with the use of Spearman Rank-Order correlation.

Results

The descriptive statistical data for performance of all participants on different tasks are summarized in Table 3. The standardized residual plots indicated skewed distribution and kurtosis in most of the dependent variables. The control group had the best performance across all tasks, whereas the performance of the LH group was the poorest. Furthermore, the ranges of performance in LH group were the greatest for all tasks, except for ISR tasks of monosyllabic high frequency non-words.

Table 3. Descriptive statistics of the scores in the three participant groups.

	LH group			**RH group**			**Control**		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
AQ	71.25	27.66	22.80 – 100.00	98.57	2.37	92.20 – 100.00	/	/	/
Comprehension	7.44	2.81	2.25 – 10.00	9.93	0.14	9.55 – 10.00	/	/	/
Auditory discrimination(*d'* score)	2.60	2.00	-0.61 – 5.15	4.39	0.97	2.56 – 5.15	4.41	0.85	2.56 – 5.15
Auditory lexical decision (*d'* score)	2.76	1.12	0.14 – 4.22	3.55	0.51	2.68 – 4.22	3.94	0.71	2.12 – 5.15
Auditory word recognition (% correct)	85.17	21.29	32.50 – 100.00	99.25	1.21	97.50 – 100.00	99.50	1.02	97.50 – 100.00
	LH group			**RH group**			**Control**		
	25th	Median	75th	25th	Median	75th	25th	Median	75th
ISR for digits	3.00	7.00	8.00	7.75	9.00	9.00	9.00	9.00	10.00
ISR for monosyllabic HF NW	1.00	1.00	2.00	1.00	2.00	3.25	2.00	3.00	4.00
ISR for monosyllabic LF NW	0.00	0.00	1.00	1.00	1.00	2.00	1.00	1.00	2.00
ISR for disyllabic NW	0.00	1.00	2.00	2.00	2.00	2.25	2.00	2.00	3.00
ISR for monosyllabic RW	1.00	3.00	5.00	5.00	6.50	7.00	5.00	5.00	7.00
ISR for disyllabic HI RW	1.00	2.00	4.00	3.00	4.00	4.00	4.00	4.00	4.50
ISR for disyllabic LI RW	1.00	2.00	3.00	3.00	3.50	4.00	3.00	3.00	4.00

Note. SD = Standard Deviation; 25th = 25th percentile; 75th = 75th percentile; AQ = Aphasia Quotient; ISR = Immediate Serial Recall; NW = Non-word; RW = Real Word; HF = High Frequency; LF = Low Frequency; HI = High Imageability; LI = Low Imageability. As the control group was not tested on CAB, AQ of participants in the control group were not obtained. A slash indicates that these data are not available.

Since most data sets had a skewed distribution and kurtosis, and had heterogeneous variances, non-parametric Kruskall-Wallis test was performed to compare performances among the three groups. After that, pairwise comparisons were performed with the use of Mann-Whitney tests, with Bonferroni correction to adjust alpha value (0.05/3 = 0.017). The results of the Kruskall-Wallis test main analyses and Mann-Whitney pairwise comparisons are summarized in Table 4. The differences among the performances of the three groups were statistically significant for all tasks. As in the post hoc analyses, differences between the performance of the LH and control groups were statistically significant across all tasks. Significant differences were also found between the performance of LH and RH groups in all tasks, except for ISR for monosyllabic high frequency non-words. However, performance of RH and control groups were not significantly different in any of the tasks

Table 4. Results of Kruskall-Wallis tests in main analyses and Mann Whitney pairwise comparisons between the performance of the three groups.

Tasks	Main effect	Pairwise comparisons (*df* =1)		
	(*df* = 2)	LH vs. RH	RH vs. Con	LH vs. Con
Auditory discrimination (*d'* score)	10.10**	33.50*	122.00	84.50**
Auditory lexical decision (*d'* score)	13.39**	38.50*	80.00	65.50**
Auditory word recognition (% correct)	16.34**	30.50*	112.50	67.50**
ISR for digits	26.48**	19.00**	76.00	16.50**
ISR for monosyllabic HF NW	12.24**	48.00	89.00	67.50**
ISR for monosyllabic LF NW	16.21**	32.50*	109.00	59.00**
ISR for disyllabic NW	17.18**	38.00*	82.50	57.50**
ISR for monosyllabic RW	16.00**	17.50**	98.50	68.50**
ISR for disyllabic HI RW	18.70**	34.00*	77.00	52.00**
ISR for disyllabic LI RW	17.92**	26.00**	110.00	48.00**

Note. LH = LH group; RH = RH group; Con = Control; *df* = degree freedom; ISR = Immediate Serial Recall; NW = Nonword; RW = Real Word; HF = High Frequency; LF = Low Frequency; HI = High Imageability; LI = Low Imageability. *$p \leq .05$ (1-tailed) in main effect / adjusted $p \leq .017$ (1-tailed) in pairwise comparison; **$p \leq .01$ (1-tailed) in main effect / adjusted $p \leq .003$ (1-tailed) in pairwise comparison.

In addition, Wilcoxon Signed Rank tests were performed and indicated that the LH group's recall performance in monosyllabic high frequency non-words were significantly poorer than that in monosyllabic real words ($Z = -2.96$, $p < .01$). Recall performance in monosyllabic low frequency non-words was also significantly poorer than in monosyllabic real words ($Z = -3.42$, $p < .01$). Wilcoxon Signed Rank tests were also performed and indicated significant differences between the group's performance in disyllabic high imageability real words and non-words ($Z = -3.17$, $p < .01$), and between disyllabic low imageability real words and non-words ($Z = -2.49$, $p < .05$). The LH group's recall performance with real words was better than non-words.

Correlations tests were conducted to examine the association between memory and language performance. The analysis was limited to the LH group as all participants in this group were diagnosed with a certain level of language impairment (as diagnosed by CAB). Severity of aphasia (in terms of AQ) in the LH group, and their performance in CAB comprehension sub-tasks were correlated with their performances in different verbal STM tasks. The results of correlations are displayed in Table 5. The Spearman's rank correlation coefficients were statistically significant for all correlations.

Table 5. Spearman's Rank Correlation between AQ, comprehension score of LH group and their performances in different verbal STM tasks

	Correlation Coefficient	
	AQ	**Comprehension**
ISR for digits	.856**	.885**
ISR for monosyllabic HF NW	.486*	.551*
ISR for monosyllabic LF NW	.779**	.832**
ISR for disyllabic NW	.916**	.815**
ISR for monosyllabic RW	.829**	.758**
ISR for disyllabic HI RW	.788**	.822**
ISR for disyllabic LI RW	.687**	.730**

Note. ISR = Immediate Serial Recall; NW = Nonword; RW = Real Word; HF = High Frequency; LF = Low Frequency; HI = High Imageability; LI = Low Imageability; AQ = Aphasia Quotient.
*$p \leq .05$(1-tailed); **$p \leq .01$ (1-tailed).

Besides, the association between individual memory and auditory linguistic tasks performance was examined. The correlation analyses were performed only in the LH group, as the study aims to explore the relationship underneath impaired STM and language processes. Table 6 shows the correlations between the performance of the LH group in all ISR and auditory linguistic tasks. The Spearman's rank correlation coefficients were statistically significant in almost all correlations between ISR tasks with auditory discrimination and auditory word recognition tasks, except ISR task for monosyllabic high frequency non-words with the auditory word recognition task. Performances in five (out of seven) of the ISR tasks did not correlate with that in auditory lexical decision tasks. In addition, Mann-Whitney U test was performed to compare all participants' performance in auditory lexical decision and auditory discrimination tasks. The test indicated significant higher false alarm rate in auditory lexical decision than auditory discrimination tasks (U = 659.5, $p < .001$). This suggested that the participants, regardless of the group they belong, performed significantly poorer in auditory lexical decision task than in auditory discrimination task.

Table 6. Correlations between performance of the LH group in ISR and auditory linguistic tasks (n=15).

	Auditory discrimination (*d'* score)	**Auditory lexical decision (*d'* score)**	**Auditory word recognition (% correct)**
ISR for digits	.902**	.289	.790**
ISR for monosyllabic HF NW	.654**	-.048	.375
ISR for monosyllabic LF NW	.688**	.345	.655**
ISR for disyllabic NW	.737**	.387	.921**
ISR for monosyllabic RW	.733**	.527*	.627**
ISR for disyllabic HI RW	.814**	.353	.664**
ISR for disyllabic LI RW	.738**	.442*	.515*

Note. ISR = Immediate Serial Recall; NW = Nonword; RW = Real Word; HF = High Frequency; LF = Low Frequency; HI = High Imageability; LI = Low Imageability. *$p \leq .05$; **$p \leq .01$ (1-tailed)

Lastly, simultaneous multiple regression analysis was performed to test if the LH group’s performances in auditory linguistic tasks predict comprehension score in CAB. Table 6 shows the result of analysis. The overall regression equation was highly significant [$F(3, 11) = 38.65$, $p < .001$, $R^2 = .913$].

Table 7. Simultaneous Multiple Regression Analysis on Comprehension score in the LH group.

	b	**SE**	***β***	***t***
Auditory discrimination (*d’* score)	.518	.148	.368	3.49**
Auditory lexical decision (*d’* score)	.011	.380	.004	.028
Auditory word recognition (% correct)	.095	.022	.722	4.29**

Note. ***p* ≤ .01 (1-tailed).

Discussion

The aim of this study was to examine the relationship between verbal STM tasks and auditory linguistic tasks for Cantonese speakers with aphasia. Verbal STM performance and language performances (in terms of auditory linguistic performances) were compared between LH, RH and the control groups. The result of comparison confirmed the hypothesis that participants in the LH group would perform significantly worse than those in the RH and control groups in both verbal STM and auditory linguistic tasks. There was no significant difference found between the RH group and the normal controls (*see* Table 4). No significant verbal STM weakness or language impairment was found in the RH group. Therefore, verbal STM deficits and language impairment were considered to be specific to Cantonese individuals with left hemispheric stroke history, in which the pattern is coherent with the hypothesis that left hemisphere is usually involved in verbal processing (Gillespie, Bowen, & Foster, 2006). The result also shows that brain damage per se cannot explain the relationship between verbal STM and language impairments. Only damages in language dominant left hemisphere appear to be associated with verbal STM deficits. Moreover, the fact that verbal STM impairments (as compared to controls) were not observed in RH group participants, who do not have language impairment, implies that verbal STM impairments reflect language processing deficits but not in reverse. Such findings supported the previously mentioned STM models, which suggested that that recall of verbal materials are supported by long term language knowledge (Attout et al., 2012; Majerus, 2009). Individuals with impairment in the language network will lead to breakdown in the process of spreading activation (Martin & Saffran, 1992; Martin & Saffran, 1997) or redintegration (Martin, 2009), and will eventually result in reduced ability to maintain phonological information in the verbal STM.

Correlations tests were conducted to examine the association between verbal STM performance and language performance in the LH group. The correlation measures indicated that language performance in terms of CAB comprehension score was significantly correlated with performance in all ISR tasks (*see* Table 5). This suggests an association between verbal STM performance and receptive language ability. Similar findings were also reported in the study of Leff et al. (2009), which suggested that verbal STM performance is a determining factor of speech comprehension ability. In addition, the LH group's language performance in terms of AQ also showed statistically significant correlation with all ISR tasks. AQ is a combined score of various aspects of language performance, including fluency, receptive and expressive language. Such findings show that that verbal STM performance is not only associated with receptive language performance, it is associated with multiple aspects of language performance. This is consistent with findings in other recent studies, in which links between verbal STM and repetition (Majerus, 2013) and links between verbal STM and language production were reported (Acheson, Hamidi, Binder, & Postle, 2011; Koenigs et al., 2011)

According to the current results, ISR tasks had moderate to high correlations between auditory discrimination and auditory word recognition tasks. However, the auditory lexical decision task, which requires one to discriminate between words and non-words, did not appear to have significant correlation with most ISR tasks (*see* Table 6). As the result showed that the false alarm rate in auditory lexical decision task was significantly higher than that in auditory discrimination tasks, it can be concluded that there is a floor effect in the auditory lexical decision task. Both the stroke participants and controls tend to fail in rejecting non-words. In other words, the task is not sensitive to detect verbal STM problems.

The current results also showed that Cantonese speakers with aphasia had more difficulties with non-words than real words, and this could be attributed to one’s poor performance in auditory lexical decision task regardless his/her verbal STM span performance. According to Cutler and Chen (1997), Cantonese listeners were much slower in lexical decision task involving tone. Besides, they were more likely to recognize a non-word as a real word when the difference was only in tonal value (Cutler & Chen, 1997). The same type of errors in lexical decision was also demonstrated by the LH group participants in the present study. Some participants, who repeated the stimuli after the recording, perceived non-words as real words with another tone, e.g. /ko22/ (a non-word) was perceived as /ko33/ (a real word). Besides participants in the LH group, normal controls in the present study also performed statistically significantly better in recognizing real words than non-words. Nevertheless, normal controls outperformed LH group participants in the tasks. Therefore, it is proposed that Cantonese speakers in general have more difficulties with non-words and lexical decision tasks because of the lexical tone in Cantonese.

In general, the results from this study revealed a correlation of language impairment and verbal STM deficit in Cantonese individuals with aphasia. Such relationship is similar to that found in populations speaking non-tonal languages (Attout et al., 2012; Majerus, 2009; Martin & Ayala, 2004; Papagno, Vernice, & Cecchetto, 2013). But one key difference is that Cantonese speakers demonstrated more difficulties in recall of non-words and in lexical decision tasks. It is therefore expected that treatment on verbal STM in Chinese speakers with aphasia can be done similarly to English for facilitating language rehabilitation. Particular attention could be given to memory for non-word stimuli and training of tone awareness in nonword stimuli.

As for research on aphasia treatment, training on verbal STM by means of recall is reported to be effective. In the studies conducted by Kalinyak-Fliszar et al. (2011) and Majerus et al. (2005), gains were observed in both language and span performance. Individuals with aphasia were first trained with immediate recall of words and non-words lists. The duration of the interval between stimuli would gradually increase, thus aiming to enhance activation of language representations and the participants' ability to maintain those representations in verbal STM for longer periods (Kalinyak-Fliszar et al., 2011; Majerus et al., 2005). When one is able to hold phonological information for longer periods, there would be more buffering time for the comprehension of verbal input. Hence, language performance would be improved (Attout et al., 2012; Kalinyak-Fliszar et al., 2011).

Based on the findings in the present study, the rationale of the recall approach is applicable to Cantonese speaking population as well. As ISR tasks have moderate to high correlations between auditory discrimination and auditory word recognition tasks, it is hypothesized that the recall approach, which is similar to ISR tasks in nature, will have positive effects on auditory discrimination and auditory word recognition in Cantonese speakers with aphasia. Furthermore, the improvement in auditory discrimination and auditory word recognition tasks performance is expected to result in a gain in comprehension ability (Duffy & Coelho, 2001). Regarding the high correlation between the two auditory linguistic tasks and comprehension score, it can be hypothesized that there are common neural processes for auditory discrimination/auditory word recognition and general receptive language ability (in comprehension of words, sentences and questions). Based on this hypothesis, improvement in auditory discrimination and auditory word recognition may potentially facilitate rehabilitation of general comprehension ability. In sum, the recall approach proposed by Kalinyak-Fliszar et al. (2011) and Majerus et al. (2005) is expected to facilitate rehabilitation of receptive language ability in Cantonese speakers as well. But unlike the studies in Kalinyak-Fliszar et al. (2011) and Majerus et al. (2005), recall training for Cantonese speakers with aphasia should pay special attention to the tone differences between words and non-words, as tonal contrast between non-words and real words are significantly more difficult to Cantonese speakers. For example, non-words stimuli which differ from real words in tone can be specifically treated, so as to strengthen the ability to maintain tonal information in verbal STM. Thus, lexical tone perception in individuals with aphasia could be improved.

Besides, as results in the present study showed that performances in auditory discrimination and auditory word recognition tasks had high correlation with comprehension score in CAB, it is expected that assessment in one's auditory discrimination and auditory word recognition ability could give valuable information to evaluate his/her receptive language ability. As mentioned above, improvements in auditory discrimination and auditory word recognition are expected to facilitate rehabilitation of receptive language ability. In addition, according to Schuell's stimulation approaches of language intervention, constant training in auditory discrimination and auditory word recognition tasks would provide repetitive sensory stimulation to auditory cortical regions which are hypothesized to be involved in general receptive language function (Duffy & Coelho, 2001). It is therefore expected that direct training in the two auditory linguistic tasks would be facilitative to rehabilitation of receptive language function.

In contrast, performance in auditory lexical decision task was found unrelated to one's performance in CAB comprehension sub-task, probably due to Cantonese non-words in relation to processing of lexical tone. Despite the fact that the auditory lexical decision task is a common assessment task in studies with non-tonal languages (Majerus et al., 2001; Martin

& Gupta, 2004; Papagno et al., 2013), it is not sensitive to comprehension ability in Cantonese speakers. Nevertheless, treatment in auditory lexical decision task might help to improve tone awareness in Cantonese speakers with aphasia. As the recognition of spoken Cantonese words relies on the acuity in lexical tone perception (Cutler & Chen, 1997), improvement in tone perception is expected to have positive effect in comprehension ability.

Limitations

One of the limitations of the present study is the small sample size in each group. As the number of participants was small, this led to inflation in error rates and resulted in a lack of representation of the population (Cantonese speakers with aphasia). The sample was less reflective of the population. Therefore, generalizability of the results was reduced. Readers should be cautious in the interpretation of the results. Another limitation is the exclusion of patients with more severe grade of aphasia. This group of patients was not included in the study because most of these patients presented co-occurring motor speech disorder, at moderate or severe level of impairment. Therefore, the findings in the current study might not be reflective of Cantonese individuals with severe language impairment.

Recommendations for future studies

The hypothesis that the auditory lexical decision task is not related to comprehension ability should be further verified. Further testing shall be done on auditory discrimination of different types of non-words and real words, including (1) Cantonese non-words and real words which differ only in tonal value; (2) Cantonese non-words and real words which differ only in one phoneme (onset, nucleus, rime); and (3) non-words which do not follow phonotactic rules in Cantonese words (for example, syllabic structure of V/CV/CVC) as this will have implications for whether speech pathologists should assess and/or provide treatment using lexical decision tasks for Cantonese speakers with aphasia.

As training on verbal STM tasks and direct treatment in two auditory linguistic tasks (auditory discrimination and auditory word recognition) are hypothesized to facilitate the rehabilitation of receptive language ability, future research may evaluate and compare the treatment efficacy in these two approaches. This would have implications for models of language processing in aphasia and help to distinguish between the importance of verbal short term memory and linguistic knowledge in explaining comprehension impairment.

Conclusion

In the present study, the LH group performance in auditory discrimination and word recognition tasks showed moderate to high correlations with their performance in almost all ISR tasks. But the LH group's performance in lexical decision task did not appear to have a significant correlation with their performance in most ISR tasks. It is hypothesized that treatment on ISR tasks will have positive effects on auditory discrimination and auditory word recognition in Cantonese speakers with aphasia, which further facilitate rehabilitation of receptive language ability. Moreover, the results suggest that Cantonese speakers have more difficulties correctly identifying non-words than real words. It is suggested that lexical tone processing in Cantonese give rise to additional difficulty in non-word processing and lexical decision tasks. The role of lexical tone in phonological processing of tonal languages should be further investigated, as this will have implication on whether lexical decision tasks should be implemented in assessment and/or treatment for Cantonese speakers with aphasia.

Acknowledgements

I would like to express my sincere gratitude to my supervisors, Dr. Diana Ho, former Research Assistant Professor in the Division of Speech and Hearing Sciences at the University of Hong Kong, and Dr. Anthony Kong, Associate Professor in the Department of Communication Sciences and Disorders at the University of Central Florida, for their support and patience throughout the study. This dissertation could not have been finished without their constant guidance and full support. Thanks very much for staying with me, and helped me through the hard times.

I would also like to thank Professor Brendan Weekes, Chair Professor in the Division of Speech and Hearing Sciences at the University of Hong Kong, for his invaluable comments and suggestions to the study. In addition, I would like to express my sincere appreciation to the Hong Kong Society for Rehabilitation and the Hong Kong Stroke Association for their support and assistance in participant recruitment and in data collection. Finally, I am grateful to all participants who took their time to participate. This study would not be possible without their participation.

References

Acheson, D. J., Hamidi, M., Binder, J. R., & Postle, B. R. (2011). A common neural substrate for language production and verbal working memory. *Journal of Cognitive Neuroscience, 23*(6), 1358-1367. doi:10.1162/jocn.2010.21519

Attout, L., Van der Kaa, M. A., George, M., & Majerus, S. (2012). Dissociating short-term memory and language impairment: The importance of item and serial order information. *Aphasiology, 26*(3-4), 355-382. doi:10.1080/02687038.2011.604303

Baddeley, A. D. (1986). *Working memory*. Oxford: Clarendon Press.

Buchsbaum, B. R., & D'Esposito, M. (2008). The search for the phonological store: from loop to convolution. *Journal of Cognitive Neuroscience, 20*(5), 762-778. doi:10.1162/jocn.2008.20501

Caramazza, A., Costa, A., Miozzo, M., & Bi, Y. (2001). The specific-word frequency effect: implications for the representation of homophones in speech production. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*(6), 1430-1449. doi:10.1037/0278-7393.27.6.1430

Chen, Z.Y., Cowell, P.E., Varley, R. & Wang, Y.C. (2009). A cross-language study of verbal and visuospatial working memory span. *Journal of Clinical and Experimental Psychology, 31(4),* 385-391. doi:10.1080/13803390802195195.

Cheung, H., & Kemper, S. (1994). Recall and articulation of English and Chinese words under memory preload conditions. *Language and Speech, 37*(2), 147-161.

Cutler, A. & Chen, H.C. (1997). Lexical tone in Cantonese spoken-word processing. *Perception & Psychophysics, 59(2),* 165-179. doi:10.3758/BF03211886

Duffy, J.R. & Coelho, C.A. (2001). Schuell's Stimulation Approach to Rehabilitation. In Chapey, R. (Ed). *Language intervention strategies in aphasia and related neurogenic communication disorders* (pp. 341-382). Baltimore: Lippincott Williams & Wilkins.

Giegerich, H. J. (1992). *English phonology: An introduction*. Cambridge: Cambridge University Press.

Gillespie, D. C., Bowen, A., & Foster, J. K. (2006). Memory impairment following right hemisphere stroke: a comparative meta-analytic and narrative review. *The Clinical Neuropsychologist*, *20*(1), 59-75. doi:10.1080/13854040500203308

Kalinyak-Fliszar, M., Kohen, F., & Martin, N. (2011). Remediation of language processing in aphasia: Improving activation and maintenance of linguistic representations in (verbal) short-term memory. *Aphasiology*, *25*(10), 1095-1131. doi:10.1080/02687038.2011.577284

Kay, J., Coltheart, M. & Lesser, R. (1992). *Psycholinguistic Assessments of Language Processing in Aphasia.* London: Lawrence Erlbaum Associates.

Koenigs, M., Acheson, D. J., Barbey, A. K., Solomon, J., Postle, B. R., & Grafman, J. (2011). Areas of left perisylvian cortex mediate auditory–verbal short-term memory. *Neuropsychologia*, *49*(13), 3612-3619. doi:10.1016/j.neuropsychologia.2011.09.013.

Law, S. P. (2007). *A test battery for Chinese aphasia.* Retrieved October 20, 2013, from the University of Hong Kong, Faculty of Education Website: http://www.speech.hku.hk/spl-1.htm

Law, S. P., Yeung, O., & Chiu, K. M. (2008). Treatment for anomia in Chinese using an ortho-phonological cueing method. *Aphasiology*, *22*(2), 139-163. doi:10.1080/02687030701191358

Leff, A. P., Schofield, T. M., Crinion, J. T., Seghier, M. L., Grogan, A., Green, D. W., & Price, C. J. (2009). The left superior temporal gyrus is a shared substrate for auditory short-term memory and speech comprehension: evidence from 210 patients with stroke. *Brain*, *132*(12), 3401-3410. doi:10.1093/brain/awp273

Leung, M. T., Law, S. P., & Fung, S. Y. (2004). Type and token frequencies of phonological units in Hong Kong Cantonese. *Behavior Research Methods, Instruments, & Computers*, *36*(3), 500-505. doi:10.3758/BF03195596

Li, P., & Yip, M. C. (1998). Context effects and the processing of spoken homophones. *Reading and Writing*, *10*(3-5), 223-243. doi:10.1023/A:1008091816322

Majerus, S. (2009). Verbal short-term memory and temporary activation of language representations: The importance of distinguishing item and order information. In A. Thorn & M. Page (Eds.), *Interactions between short-term and long-term memory in the verbal domain* (pp. 244–276). Hove, UK: Psychology Press.

Majerus, S. (2013). Language repetition and short-term memory: an integrative framework. *Frontiers in human neuroscience*, *7:*357. doi:10.3389/fnhum.2013.00357

Majerus, S., D'Argembeau, A., Perez, T. M., Belayachi, S., Van der Linden, M., Collette, F., Salmon, E., Seyrinck, R., Rias, W. & Maquet, P. (2010). The commonality of neural networks for verbal and visual short-term memory. *Journal of cognitive neuroscience*, *22*(11), 2570-2593. doi:10.1162/jocn.2009.21378

Majerus, S., Lekeu, F., Van der Linden, M. V., & Salmon, E. (2001). Deep dysphasia: Further evidence on the relationship between phonological short-term memory and language processing impairments. *Cognitive Neuropsychology*, *18*(5), 385-410. doi:10.1080/02643290042000152

Majerus, S., Poncelet, M., Elsen, B., & Van der Linden, M. (2006). Exploring the relationship between new word learning and short-term memory for serial order recall, item recall, and item recognition. *European Journal of Cognitive Psychology*, *18*(6), 848-873. doi:10.1080/09541440500446476

Marjerus, S., Van der Kaa, M.A., Renard, C. & Van der Linden, M. (2005). Treating verbal short-term memory deficits by increasing the duration of temporary phonological representations: a case study. *Brain and Language*, *95*(1), 174-175. doi:10.1016/j.bandl.2005.07.094

Macmillan, N. A., & Creelman, C. D. (2004). *Detection theory: A user's guide*. Psychology press.

Mann, V. A., & Liberman, I. Y. (1984). Phonological awareness and verbal short-term memory. *Journal of learning disabilities, 17*(10), 592-599.

Martin, N. (2009). The roles of semantic and phonological processing in short-term memory and learning: Evidence from aphasia. In A. Thorn & M. Page (Eds.), *Interactions between short-term and long-term memory in the verbal domain* (pp. 220–243). Hove, UK: Psychology Press.

Martin, N., & Ayala, J. (2004). Measurements of auditory-verbal STM span in aphasia: Effects of item, task, and lexical impairment. *Brain and Language*, *89*(3), 464-483. doi:10.1016/j.bandl.2003.12.004

Martin, N., & Gupta, P. (2004). Exploring the relationship between word processing and verbal short-term memory: Evidence from associations and dissociations. *Cognitive Neuropsychology*, *21*(2-4), 213-228. doi:10.1080/02643290342000447

Martin, N., & Reilly, J. (2012). Short-term/working memory impairments in aphasia: Data, models, and their application to aphasia rehabilitation. *Aphasiology*, *26*(3-4), 253-257. doi:10.1080/02687038.2011.648163

Martin, N. & Saffran, E.M. (1992). A computational account of deep dysphasia: Evidence from a single case study. *Brain and Language*, *43*(2), 240–274. doi:10.1016/0093-934X(92)90130-7

Martin, N. & Saffran, E. M. (1997). Language and auditory-verbal short-term memory impairments: Evidence for common underlying processes. *Cognitive Neuropsychology*, *14*(5), 641-682. doi:10.1080/026432997381402

Martin, R. C., & Lesch, M. F. (1996). Associations and dissociations between language impairment and list recall: Implications for models of STM. In S. E. Gathercole (Ed.), *Models of short-term memory* (pp. 149-178). Hove, UK: Psychology Press.

Murray, L.L. (2012). Direct and indirect treatment approaches for addressing short term or working memory deficits in aphasia. *Aphasialogy, 26*(3-4), 317-337. doi:10.1080/02687038.2011.589894

Papagno, C., Vernice, M., & Cecchetto, C. (2013). Phonology without semantics? Good enough for verbal short-term memory. Evidence from a patient with semantic dementia. *Cortex*, *49*(3), 626-636. doi:10.1016/j.cortex.2012.04.015

Potagas, C., Kasselimis, D., & Evdokimidis, I. (2011). Short-term and working memory impairments in aphasia. *Neuropsychologia*, *49*(10), 2874-2878. doi:10.1016/j.neuropsychologia.2011.06.013

Saint-Aubin, J., & Poirier, M. (2000). Immediate serial recall of words and nonwords: Tests of the retrieval-based hypothesis. *Psychonomic Bulletin & Review*, *7*(2), 332-340. doi:10.3758/BF03212990

So, L. K. (1996). Tonal changes in Hong Kong Cantonese. *Current Issues in Language & Society*, *3*(2), 186-189. doi:10.1080/13520529609615467

Yiu, E. M. (1992). Linguistic assessment of Chinese-speaking aphasics: Development of a Cantonese aphasia battery. *Journal of Neurolinguistics*, *7*(4), 379-424. doi:10.1016/0911-6044(92)90025-R

Appendix A – Sample Consent Form

Participant Information
Research study: Verbal STM deficit and its relation to language impairment in Cantonese speakers with aphasia

You are invited to take part in a research study as part of a student project conducted by Year 4 student, Koon Nim Ting, in the Division of Speech and Hearing Sciences at the University of Hong Kong. The project is under the supervision of Professor Brendan Weekes and Dr. Diana Ho from Division of Speech and Hearing Sciences, the University Hong Kong and Dr. Anthony Kong from Department of Communication Science and Disorders, the University of Central Florida.

Please read this information sheet to understand the details before you decide if you will participate in this study. You can also discuss with your relatives, friends and other health care professionals about participation in this study. If you want to know even more details, you are welcome to ask the researchers any questions.

Purpose of the study
The aim of this research is to find out how aphasic patients at the age of 18 or above process language in the brain, and how language processing is related with short term memory.

Procedures
In this study, you will be asked a few questions about your background and medical history. After that, you will be required to participate in three memory testing (Digit Span Test, Non-word Repetition Test, and Immediate Word Recall Test) and three language testing (Auditory Discrimination Test, Same/Different Judgment Test, and Word Recognition Test). The assessments will be performed at Hong Kong Society for Rehabilitation Community Rehabilitation Network, elderly centres, elderly homes or at the clinic of Division of Speech and Hearing Sciences, the University Hong Kong. The whole procedure will take approximately 1 hour.

Potential risks / Discomforts and their minimization
The memory and language testing will not do any harm to you. Nevertheless, high level of attention and concentration is required to complete the tests. You may feel tired during the testing. We will try to minimize your tiredness as you can use different speed and time to finish the testing. You can ask for breaks when you feel tired. We will give you breaks every 30 minutes.

Video-recording
In addition, for research purposes, we would like to videotape your participation for further data checking. You can accept or reject being videotaped before the testing. If you accept to be videotaped, we will use video-camera to record the whole procedure. You can review the video-recording at any time and ask us to erase part or whole of the video-recording. The video-record will be converted into a computer file. It will be stored in a computer of the Division with password protection. After the research study, the entire videorecord will be erased.

Potential benefits
We will tell you the assessment results and treatment directions briefly after the assessments.

Your participation will provide valuable information for our understanding in language processing and its relationship with short term memory.

Confidentiality
Any information obtained in connection with this project and that can identify you will remain confidential. The data and test results will be stored securely without the participants' names on them. Participant codes will be used to label data instead of using names such that participants cannot be identified. Information about your identity will not be shared with anyone outside of the research team.

Participation and withdrawal
Your participation is voluntary. This means that you can choose to stop at any time without negative consequences.

Questions and concerns
If you have any questions or enquiries regarding this study now or in the future, please feel free to contact the investigator Ms. Koon Nim Ting (Tel: 6842-6922, Email: koonnt@hku.hk). If you have questions about your rights as a research participant, please contact the Human Research Ethics Committee for Non-Clinical Faculties, HKU (2241-5267).

Thank you for your interest in this research project. If you wish to take part in the research

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Participant Consent Form

1. I ______________________________ hereby consent to take part in the research study: "The relationship between memory and language impairment in aphasic patients".

2. I have carefully read the information sheet, and I had been fully explained the details of the study, including the procedures, arrangements and potential risks of the experiment.

3. I □ give □ do not give my permission for the researchers to videotape the assessment sessions for research purposes.

4. I have been told that my privacy will be maintained at all times. Any information that reveal my identity, including medical history, assessment results and video recordings, will not be disclosed.

5. I understand that I am free to withdraw from the study at any stage, and that my withdrawal will not cause any harm to my relationship with Division of Speech and Hearing Sciences, the University of Hong Kong.

____________________	____________________	____________________
Name of participant	Signature	Date
____________________	____________________	____________________
Name of investigator	Signature	Date

Appendix B – List of stimuli

Immediate Serial Recall (ISR) Tasks

1. ISR for digits

Length	Stimuli	Length	Stimuli
2	82 14 60 75	7	2541730 7296180 9042783 6089213
3	207 193 051 684	8	64392781 13925047 34205681 82316497
4	3209 1785 9743 8256	9	894613702 281073495 627931584 713024918
5	90237 86541 27398 40615	10	5746932081 0261749538 8215369740 4028936517
6	957186 508394 910562 642973	11	18392064057 86293051741 20914725836 31750928604

2. ISR for monosyllabic nonwords

Length	High frequency (HF)	Low frequency (LF)
2	ki1 tɔ3 lɛ3 ti3 jei1 lɔ5 jɐi2 hɛ1	kwœ1 naŋ1 phɔn1 kwhut9 thœ1 kwaŋ1 ŋɛk7 thɔn1
3	tsei1 hɐu1 kɛ1 hi1 kei4 la2 jɐi2 ta3 lɔ5 li2 jou1 tɛ3	nɵn1 kwhap7 ŋut7 thɛk7 kwau1 nut7 kwhɔn1 phœ1 ŋau1 phut7 kwau1 thœ1
4	hou1 lɛ3 tsɔ1 jei2 ki1 tsou4 hɐi3 tei1 tsɐu4 lɛ3 ka4 hou1 ti3 kɐi4 la6 hɔ3	kwhɔn1 thau1 nœ1 kwɵn1 thau1 kwɔn1 phaŋ3 nœ1 kwau1 ŋɔn2 kwhap7 thut7 phaŋ3 kwɔn1 ŋœ1 thɛk7
5	tsa5 lɔ5 jɛ1 kei4 hi1 tsei1 kɛ1 li2 jou1 ta3 kɔ6 hɐu1 jɛ1 ti3 lɐi1 ja1 tei1 tsou4 hɐi3 lɐu3	thœ1 nap7 phɵn1 ŋau1 kwut7 nœ1 phɵn1 kwɛk7 thau1 ŋɔn2 kwɵn1 thɛk7 phɔn1 ŋœ1 nau1 kwhap7 ŋut7 thœ1 phɔn1 kwɛk7
6	tsɐu4 jɛ1 ta3 lɐi1 hɔ3 kei4 jɐi1 hɔ3 tei1 ki1 lɛ3 tsɐu4	naŋ1 kwɵn1 phap7 thɛk7 ŋau1 kwhœ1 phap7 kwaŋ1 nɵn1 thœ1 kwhɔn1 ŋau1
	hou1 tɔ3 kei4 tsi4 lɛ3 ja1 lei3 hi1 tsou4 jɛ1 kɔ6 ta3	kwhut7 phaŋ3 ŋœ1 thɛk7 nap7 kwau1 thap7 kwɛk7 kwhœ1 nau1 phɵn1 ŋut7
7	ti3 ka4 lou3 ha3 tsei1 jɐi1 kei4 hɐu1 ta3 kɔ6 jɛ1 tsou4 tei1 lɐi1 tsɔ1lɐi1 kou4 hi1 ta3 jɛ1 li2 hɐi3 lɛ3 ti3 tsou4 jɐi1 ki1 hɔ3	thut7 nœ1 ŋɛk7 phɔn1 kwap7 nau1 kwhaŋ6 kwhap7 thaŋ1 ŋut7 phɔn1 nɵn1 kwut7 thœ1 phœ1 nut7 thɛk7 kwau1 ŋɵn1 phɔn1 kwhap7 kwɔn1 thau1 ŋœ1 phut7 kwhap7 nɛk9 thaŋ1

3. ISR for disyllabic NW

Length	Stimuli
2	術神　笑有 史失　語卜 擁象　意配 神過　書額
3	想中　雨卻　起言 作原　猜用　足試 幻外　道很　龍客 事額　田法　土全
4	心約　上口　非千　有動 方班　中病　古介　在管 強再　大免　火時　現約 土先　未木　好回　角差
5	女理　卜日　子用　何木　十明 保兆　知土　他出　立仔　和定 是夫　了發　本食　要免　包分 報甘　會絕　亮意　門習　水言
6	溫工　品合　用能　力北　山法　而安 方去　家改　於卡　花進　等果　成電 利方　活福　作到　多成　生信　任式 影學　列子　文柔　泰化　公經　得平
7	消如　定自　息因　本合　安又　程全　回比 向了　節樂　任立　推明　羊才　想利　之工 直空　決山　分入　各波　大必　少回　任感 光東　先正　海給　交奇　求平　美代　名公

4. ISR for monosyllabic RW

Length	Stimuli
2	游 翠
	火 所
	沙 容
	忽 河
3	晚 子 星
	象 片 花
	才 包 古
	天 工 樹
4	黃 中 蒜 寶
	連 琴 高 電
	地 本 風 十
	氣 光 野 悲
5	周 同 白 福 剪
	支 球 沙 雷 人
	流 圍 波 生 大
	蟲 油 老 全 海
6	金 堂 兒 道 配 毛
	浪 包 飛 樓 頭 食
	田 現 火 棉 元 琴
	電 林 一 圖 國 得
7	光 心 例 別 火 皮 日
	時 海 丹 化 烏 學 禮
	雨 車 紅 鉛 市 件 寸
	早 女 口 兆 罩 膠 日
8	消 自 因 合 又 全 回 感
	向 節 立 推 羊 利 之 東
	直 山 分 波 必 少 任 海
	光 給 正 交 平 美 公 拖
9	溫 品 能 北 法 而 去 在 花
	進 卡 等 電 方 福 作 成 生
	式 學 列 文 泰 經 得 卻 起
	原 猜 足 外 很 龍 事 田 全
10	神 笑 失 卜 擁 意 過 書 再 大
	心 千 非 之 方 病 介 管 火 現
	先 木 好 何 明 角 理 日 杰 用
	兆 土 他 仔 和 是 發 食 要 分
11	甘 會 亮 門 水 所 餐 子 夾 天 彗
	白 怎 野 幹 絨 稻 診 篷 石 黃 物
	堂 河 洲 光 功 口 先 限 價 笑 約
	配 綠 失 放 品 途 絕 理 兒 總 報

5. ISR for disyllabic real words

Length	High imageability (HI)	Low imageability (LI)
2	枕頭 樹幹	術語 笑柄
	黃蜂 天線	廉恥 差事
	蒜頭 寶石	過失 配額
	氣泡 燭光	功績 品格
3	野獸 珊瑚 綠洲	用途 限額 禮儀
	溝渠 獵人 蘿蔔	意圖 中樞 總額
	笑聲 昆蟲 油畫	竅門 寓言 憲法
	面頰 稻草 海豹	言辭 起源 境況
4	帳篷 胸膛 診所 穀物	條約 藉口 邏輯 動機
	河馬 絨布 晚餐 子彈	先驅 原理 報應 價值
	彗星 天使 枕頭 黃蜂	假設 絶境 術語 用途
	蒜頭 氣泡 野獸 溝渠	條約 廉恥 意圖 先驅
5	面頰 笑聲 樹幹 珊瑚 胸膛	過失 竅門 假設 功績 言辭
	天線 獵人 絨布 寶石 昆蟲	笑柄 限額 藉口 差事 中樞
	天使 燭光 稻草 帳篷 河馬	原理 配額 寓言 絶境 品格
	彗星 綠洲 診所 蘿蔔 晚餐	起源 禮儀 邏輯 總額 報應
6	油畫 海豹 穀物 子彈 枕頭 野獸	憲法 動機 境況 價值 術語 廉恥
	帳篷 黃蜂 溝渠 河馬 蒜頭 笑聲	過失 功績 用途 竅門 意圖 言辭
	彗星 氣泡 面頰 樹幹 天線 寶石	條約 先驅 假設 笑柄 差事 配額
	燭光 珊瑚 獵人 稻草 昆蟲 胸膛	品格 限額 中樞 寓言 起源 藉口
7	絨布 天使 綠洲 穀物 蘿蔔 油畫 海豹	原理 禮儀 總額 憲法 境況 邏輯 報應
	診所 晚餐 子彈 面頰 天線 彗星 蘿蔔	動機 價值 差事 術語 竅門 配額 廉恥
	枕頭 野獸 樹幹 絨布 稻草 診所 帳篷	功績 藉口 先驅 限額 假設 笑柄 條約
	寶石 黃蜂 穀物 胸膛 河馬 綠洲 燭光	配額 邏輯 過失 境況 品格 用途 絶境

Auditory Linguistic Tasks

1. Auditory lexical decision task

Item no.	Target	IPA
1	門	/mun4/
2	/	/jɛ1/
3	鳥	/niu3/
4	/	/lɐi1/
5	/	/thœ1/
6	狗	/kɐu2/
7	雷	/lœy4/
8	/	/kwɔn1/
9	杯	/bui1/
10	/	/fa2/
11	雞	/kɐi1/
12	/	/ki1/
13	糖	/ t^hɔŋ2 /
14	/	/tei1/
15	/	/li2/
16	龜	/kwɐi1/
17	雲	/wɐn4/
18	/	/thau1/
19	鏡	/kɛn3/
20	/	/phɔn1/
21	花	/fa1/
22	水	/sœy2/
23	/	/ja1/
24	/	/lɛ3/
25	/	/kɔ6/
26	豬	/tsy1/
27	鞋	/hai4/
28	/	/hi1/
29	鐘	/tsɔŋ1/
30	/	/nau1/
31	樹	/sy6/
32	槍	/ts^hœŋ1/
33	/	/tsɔ1/
34	/	/ti3/
35	/	/kwɵn1/
36	錢	/ts^hin2/
37	眼	/ŋan5/
38	/	kwœ1
39	筆	/bak1/
40	/	/kwhɔn1/

2. Auditory discrimination task

Item no.	Minus	Stimulus 1	Stimulus 2
1	tone	唱	搶
2	/	北	北
3	/	匹	匹
4	onset	困	印
5	/	艇	艇
6	/	割	割
7	nucleus	冷	領
8	/	給	咳
9	coda	鴨	押
10	/	滿	滿
11	onset	望	臟
12	tone	骨	掘
13	/	放	放
14	/	述	述
15	coda	亨	堪
16	/	雀	雀
17	tone	扁	變
18	/	宏	宏
19	nucleus	叻	溺
20	/	殿	殿
21	onset	寧	成
22	/	拍	拍
23	/	葉	葉
24	nucleus	肉	藥
25	coda	甜	田
26	/	力	力
27	nucleus	雪	薛
28	onset	活	撥
29	/	簽	簽
30	nucleus	發	闊
31	/	罕	罕
32	/	弄	弄
33	tone	鈍	噸
34	/	庵	庵
35	/	郭	郭
36	/	曲	曲
37	onset	遠	暖
38	coda	潔	刧
39	/	裙	裙
40	tone	潘	判

3. Auditory word recognition tasks

Category	Item no.	Target	Phonological distractor	Semantic distractor	Unrelated distractor
Noun (High frequency)	1	豬	樹	狗	帽
	2	裙	雲	褲	槍
	3	貓	包	羊	杯
	4	手	酒	腳	鼠
	5	梳	波	鏡	菜
	6	櫃	龜	枱	扇
	7	門	盆	窗	水
	8	枱	袋	凳	煙
	9	鞋	蟹	襪	蛇
	10	蕉	錶	橙	遮
Noun (Low frequency)	1	蟲	蔥	蛇	鎖
	2	羊	槍	牛	遮
	3	龜	梯	魚	飯
	4	鑽	蒜	鎚	鼓
	5	尺	笛	筆	衫
	6	雲	裙	星	眼
	7	旗	眉	布	凳
	8	鏈	剪	繩	書
	9	鎖	梳	匙	鼻
	10	針	心	線	兔
Verb (High frequency)	1	笑	跳	喊	叉
	2	坐	鎖	企	門
	3	洗(手)	睇	抹	波
	4	寫	蛇	睇(書)	杯
	5	切	結	炒	筆
	6	飲	枕(頭)	食	遮
	7	瞓(覺)	飯	床	鼓
	8	喊	衫	笑	刀
	9	食	翼	飲	眼
	10	跑	包	跳	書
Verb (Low frequency)	1	搽	花	抹	地
	2	送	掃	買	書
	3	彈(琴)	欄	打(鼓)	跳
	4	剪	鏈	撕	笑
	5	擦	八	掃	草
	6	跳	笑	跑	波
	7	燒	蕉	煮(飯)	湖
	8	踢	石	拍(波)	杯
	9	爬	茶	行	衫
	10	綁	糖	摺	木