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Working Memory Capacity in Australian Sign Language (Auslan)/English Interpreters and Deaf Signers

Jihong Wang

***Abstract*—**Little research has examined working memory capacity (WMC) in signed language interpreters and deaf signers. This paper presents the findings of a study that investigated WMC in professional Australian Sign Language (Auslan)/English interpreters and deaf signers. Thirty-one professional Auslan/English interpreters (14 hearing native signers and 17 hearing non-native signers) completed an English listening span task and then an Auslan working memory span task, which tested their English WMC and their Auslan WMC, respectively. Moreover, 26 deaf signers (6 deaf native signers and 20 deaf non-native signers) completed the Auslan working memory span task. The results revealed a non-significant difference between the hearing native signers and the hearing non-native signers in their English WMC, and a non-significant difference between the hearing native signers and the hearing non-native signers in their Auslan WMC. Moreover, the results yielded a non-significant difference between the hearing native signers' English WMC and their Auslan WMC, and a non-significant difference between the hearing non-native signers' English WMC and their Auslan WMC. Furthermore, a non-significant difference was found between the deaf native signers and the deaf non-native signers in their Auslan WMC.

***Keywords*—**deaf signers, signed language interpreters, working memory capacity

I. Introduction

A large volume of research in cognitive psychology and cognitive neuroscience has been devoted to working memory (WM). According to Baddeley [1, p. 189], "working memory involves the temporary storage and manipulation of information that is assumed to be necessary for a wide range of complex cognitive activities." Working memory capacity (WMC) is typically measured by WM span tasks (e.g., the reading span task, the listening span task) that involve concurrent processing and storage of information. Despite numerous studies on hearing people's spoken language WMC, few studies have examined signed language WMC in hearing signers (e.g., signed language interpreters, bilinguals who use a spoken language and a signed language) and deaf signers.

Australian Sign Language (Auslan) is the natural sign language of the Australian Deaf community. Although most deaf people in Australia use Auslan as their primary or preferred language, only a small percentage (less than 10%) are actually native signers [2], who acquired Auslan from birth from signing deaf parents. The majority of deaf people were born to hearing parents, and usually learned Auslan as a second language later in life, and hence are considered as non-native signers. Deaf signers in Australia often rely on Auslan/English interpreters to communicate with hearing people and access government services in their daily lives. Signed language interpreting, a higher order cognitive activity in itself, is an online process of transferring meaning between a spoken language and a signed language (e.g., English and Auslan). Auslan/English interpreters also comprise: native signers who frequently are hearing children of signing deaf parents, and non-native signers who learned Auslan as a second language and have no family connection to the Deaf community.

This paper presents the findings of an empirical study that examined WMC in professional Auslan/English interpreters (comprising hearing native signers and hearing non-native signers) and deaf signers (comprising deaf native signers and deaf non-native signers). In order to contextualize the present study, an overview is provided of the most relevant literature.

II. Literature Review

A. Professional Interpreters' Working Memory Capacity

Only three studies have examined signed language interpreters' WMC. Gran Tarabocchia and Kellett Bidoli [3] reported that six spoken language interpreting students' performance on an Italian listening span task was similar to one professional Italian Sign Language (LIS)/Italian interpreter's performance on an LIS WM span task. In the LIS WM span task, the signed language interpreter watched sets of LIS sentences and at the end of each set reproduced sentence-final signs in serial order. In the Italian listening span task, the spoken language interpreting students were required to listen to sets of Italian sentences and at the end of each set recall sentence-final words in the same order as presented. However, their small sample may reduce the statistical power of their results. Additionally, Macnamara, Moore, Kegl, & Conway [4] found no statistical differences between highly skilled and less skilled American Sign Language (ASL)/English interpreters in terms of their WMC. Moreover, Van Dijk, Christoffels, Postma, and Hermans [5] found no considerable differences between experienced Sign Language of the Netherlands (SLN)/Dutch interpreters' Dutch WMC and their SLN WMC. This result indicates an absence of the test language effect on the professional signed language interpreters' WMC. Their experienced interpreters consisted

Jihong Wang is with the Department of Linguistics, Macquarie University, NSW 2109, Australia (phone: + 61 430437361; e-mail: jihong.wang@students.mq.edu.au).

of native signers and non-native signers of SLN. Furthermore, Van Dijk et al. reported no substantial differences between the native signers and the non-native signers in their Dutch WMC, and no significant differences between the native signers and the non-native signers in their SLN WMC. Further investigations are required to verify these findings.

Signed language interpreters interpret between a spoken language and a signed language (e.g., English and French Sign Language); whereas spoken language interpreters work between two different spoken languages (e.g., English and French). Christoffels, De Groot, and Kroll [6] found a non-significant difference between professional Dutch/English interpreters' Dutch WMC and their English WMC, suggesting an absence of the test language effect on professional spoken language interpreters' WMC. This result is parallel to Van Dijk et al.'s [5] finding described above.

B. Bilingual Working Memory Capacity

Two studies have investigated the language nativeness effect on bilinguals' WMC. Stafford [7] found that balanced bilinguals (who had been using both Spanish and English in daily communication since early childhood) performed similarly to unbalanced bilinguals (who were native Spanish speakers and had begun learning English at a mean age of 24 years) on a Spanish listening span task and an English listening span task. Stafford's finding suggests that balanced bilinguals are similar as unbalanced bilinguals in their bilingual WMC, and that native English speakers are comparable to non-native English speakers in their English WMC. Moreover, Sanchez et al. [8] found that native English speakers considerably outscored non-native English speakers on English WM span tasks; however, they found that another group of native English speakers performed similarly to another group of non-native English speakers on the same English WM span tasks.

C. Deaf Signers' Short-Term Memory Span

Short-term memory can be considered as a storage buffer only. Short-term memory span is often tested by immediate serial recall tasks such as the digit span task. Three studies have compared deaf native signers with deaf non-native signers in terms of their short-term memory span. Wilson, Bettger, Niculae, and Klima [9] found that deaf native signers (children) were significantly better than deaf non-native signers (children) in terms of their short-term memory span. In stark contrast, Krakow and Hanson [10], and Mayberry and Eichen [11], reported no significant differences between deaf native signers (adults) and deaf non-native signers (adults) in their short-term memory span. Taken together, these results suggest that late acquisition of signed language may affect deaf children's rote rehearsal ability, but such deficits are not observed in deaf adult signers. As short-term memory can be considered as the storage-only subset of WM, further research is needed to compare deaf native signers with deaf non-native signers in terms of their WMC.

The literature review thus far has revealed that WMC in signed language interpreters and deaf signers is a significant research gap. This paper therefore details the findings of a study that investigated WMC in professional Auslan/English interpreters (comprising hearing native signers and hearing non-native signers) and deaf signers (comprising deaf native signers and deaf non-native signers). The study had three aims: (1) compare the hearing native signers with the hearing non-native signers in terms of their WMC; (2) compare the professional interpreters' English WMC with their Auslan WMC; and (3) compare the deaf native signers with the deaf non-native signers in terms of their Auslan WMC.

III. Method

A. Participants

Thirty-one accredited professional level Auslan/English interpreters self-selected to participate in this study. They were classified into two sub-groups: 14 native signers (11 female and 3 male; mean age 40, *SD* = 14; an average of 13 years of professional interpreting experience, *SD* = 8), and 17 non-native signers (16 female and 1 male; mean age 40, *SD* = 9; an average of 8 years of professional interpreting experience, *SD* = 7). The hearing native signers acquired Auslan from birth from signing deaf parents, and still acquired English through interaction with the hearing population at the same time as Auslan. The hearing non-native signers acquired English from birth from hearing parents, and started to learn Auslan at or after age 10 by receiving formal education in Auslan and/or associating with deaf people through work or social networks.

Twenty-six deaf Auslan signers self-selected to participate in this study. They were also assigned into two sub-groups: 6 deaf native signers (3 female and 3 male; mean age 34, *SD* = 12) and 20 deaf non-native signers (15 female and 5 male; mean age 40, *SD* = 11). The deaf native signers acquired Auslan from birth from signing deaf parents. According to participant demographic information, the deaf non-native signers were born to hearing parents; used spoken English, lip reading, cued speech, and/or Signed English rather than Auslan at home before age 6; and started to learn Auslan at or after age 8 by associating with deaf people through school and/or social networks[1].

B. Materials

An English listening span task was designed to measure the professional interpreters' English WMC. An Auslan WM span task was created to measure Auslan WMC in the professional interpreters and the deaf signers. Both tasks involve information storage and processing.

English Listening Span Task. The task required participants to listen to sets of English sentences, judge whether each sentence made sense (say "yes" if it made sense or "no" if not), at the same time remember the final word of each sentence, and at the end of each set utter all sentence-final words in serial order. The goal for participants was to recall as many sentence-final words as possible in serial order.

[1] One deaf non-native signer had a deaf mother and deaf siblings, used cued speech at home before age 6, and started to learn Auslan at age 10 from deaf friends.

Participants were not allowed to say anything, write anything down, use signed language, or use gesture as memory aides. The task consisted of 4 sets each of 2, 3, 4, 5, 6, and 7 unrelated sentences, all together 108 sentences. Participants listened to 4 sets of 2 sentences, then 4 sets of 3 sentences, until 4 sets of 7 sentences (i.e., in ascending order). The time for verifying each sentence was 1 second of silent pause and the time for recalling each sentence-final word was 4 seconds of silent pause. Serial recall was prompted by a tone at the end of each set. All test sentences were recorded by a native English speaker, edited, and saved as an mp3 file inserted with all the necessary silent pauses and tones.

Take the third set of three sentences for example. Participants heard the set number "3 sentences" followed by .5 second of silent pause. They then heard "3.3" followed by .5 second of silent pause. They then heard the first sentence "She was looking across the lobby at a man in a suit" followed by 1 second of silent pause for semantic verification (say "yes"), then heard the second sentence "The man opened the door to pick up the rain" followed by 1 second of silent pause for semantic verification (say "no"), and then heard the third sentence "The student put all the articles on the same topic into a file" followed by 1 second of silent pause for semantic verification (say "yes"). They then heard a tone eliciting recall. They were then given 12 seconds of silent pause to utter the sentence-final words "suit, rain, file" in serial order.

Auslan WM span task. The Auslan WM span task followed the same structure and administration procedure as the English listening span task. This task instructed participants to watch sets of Auslan sentences on a video, verify the sensibility of each sentence (sign YES if it made sense or NO if not), at the same time memorize the last sign of each sentence, and at the end of each set reproduce all sentence-final signs in serial order. Participants were not allowed to say anything, write anything down, use signed language, or use gesture as memory aides. Participants watched 4 sets each of 2, 3, 4, 5, 6, and 7 unrelated Auslan sentences in ascending order (altogether 108 sentences). The time for verifying each sentence was 1 second and the time for recalling each sentence-final sign was 4 seconds. Serial recall was prompted by a question mark at the end of each set. All Auslan test sentences were created and articulated by a female deaf near-native signer, then filmed with an Ultra HD Flip camera, edited[2], and saved as an mp4 video inserted with all the necessary white screens and question marks.

Take the second set of three sentences for example. Participants saw THREE SENTENCES in Auslan on a computer screen followed by a white screen lasting for .5 second. They then saw "3.2" followed by a white screen lasting for .5 second. They then saw the first sentence POINT COUNTRY MANY PEOPLE WORK WITH ANIMALS followed by a white screen lasting for 1 second for semantic verification (sign YES), then saw the second sentence ME PLANE DISCUSS DECIDE GO SHOPPING TOMORROW followed by a white screen lasting for 1 second for semantic verification (sign NO), and then saw the third sentence COUPLE RECENT MARRY DETERMINE SAVE + BUY HOUSE NEW followed by a white screen lasting for 1 second for semantic verification (sign YES). They then saw a question mark staying on the computer screen for 12 seconds, prompting serial reproduction of the sentence-final signs ANIMALS, TOMORROW, and NEW.

[2] Each sentence was edited in a way that it began when the signer just lifted her hands into the air and ended when she just put her hands in her lap.

C. Procedure

Participants were tested individually. After filling out informed consent forms, the professional interpreters filled in a demographic questionnaire, completed the English listening span task, and then completed the Auslan WM span task. The deaf signers filled in a consent form and a demographic questionnaire, and then completed the Auslan WM span task. Instructions for each task were given by the person that recorded the test sentences to retain consistency. Each task started with instructions, then proceeded to a practice session, and then proceeded to the real task. Task materials were presented on a 2.7 GHz Core i7 13.3'' MacBook Pro computer. All participants were filmed during the tasks for later analysis.

D. Scoring

The English (or Auslan) WMC score was calculated as the total number of correctly recalled words (or signs) across all sets, with the maximum possible score being 108. Given the small sample in this study, all participants' data were included for statistical analyses.

IV. Results

A. The Hearing Native Signers versus the Hearing Non-native Signers in terms of their WMC

An independent-samples *t*-test yielded a marginal significant difference between the hearing native signers (M = 69.29, SD = 13.41) and the hearing non-native signers (M = 78.94, SD = 11.66) in their English WMC, $t(29) = -2.14$, p = .041, η^2 = .1364. However, when the only outlier score, namely a hearing native signer's English WMC score of 37, was removed, the results revealed a non-significant difference between the hearing native signers (M = 71.77, SD = 10.07) and the hearing non-native signers (M = 78.94, SD = 11.66) in their English WMC, $t(28) = -1.77$, p = .09. In addition, an independent-samples *t*-test revealed that the hearing native signers (M = 67.00, SD = 20.08) were comparable to the hearing non-native signers (M = 73.65, SD = 21.18) in terms of their Auslan WMC, $t(29) = -.89$, p = .38.

B. The Professional Interpreters' English WMC versus their Auslan WMC

A paired-samples *t*-test revealed no significant differences between all professional interpreters' English WMC (M = 74.58, SD = 13.21) and their Auslan WMC (M = 70.65, SD = 20.62), $t(30) = 1.58$, p = .12. There was also a non-significant difference between the hearing native signers' English WMC

(M = 69.29, SD = 13.41) and their Auslan WMC (M = 67.00, SD = 20.08), $t(13) = .52$, $p = .61$. There was also a non-significant difference between the hearing non-native signers' English WMC (M = 78.94, SD = 11.66) and their Auslan WMC (M = 73.65, SD = 21.18), $t(16) = 1.87$, $p = .08$.

C. The Deaf Native Signers versus the Deaf Non-native Signers in terms of their Auslan WMC

An independent-samples t-test yielded a non-significant difference between the deaf native signers (M = 59.17, SD = 11.34) and the deaf non-native signers (M = 54.65, SD = 18.44) in their Auslan WMC, $t(24) = .56$, $p = .58$.

V. Discussion

The study has found that the hearing native signers and the hearing non-native signers are similar in their English WMC. This finding is predominantly due to the fact that both sub-groups are native English speakers and professionally qualified interpreters. This study has also revealed that the hearing native signers and the hearing non-native signers are comparable in their Auslan WMC, suggesting a lack of Auslan nativeness effect on the professional interpreters' Auslan WMC. This result possibly arises from the fact that many professional interpreters in this study rehearsed the English translations of the to-be-remembered signs in the Auslan WM span task. In other words, both the hearing native and non-native signers could resort to English – their first and dominant language – to rehearse the to-be-remembered signs.

Both findings support the previous evidence that balanced bilinguals and unbalanced bilinguals are comparable in their WMC [7]. More importantly, the two findings replicate Van Dijk et al.'s [5] results of no significant differences between native signer interpreters and non-native signer interpreters in their WMC. In other words, there is no signed language nativeness effect on professional signed language interpreters' WMC.

Additionally, it was found that all professional interpreters' English WM is similar as their Auslan WMC. This finding lends further support to the previous evidence that professional interpreters' WMC is independent of the test language [5]-[6]. The finding probably results from the fact that a number of professional interpreters in this study adopted English subvocal rehearsal to remember the to-be-remembered words and signs.

The results revealed that the hearing native signers' English WMC is comparable to their Auslan WMC. This finding is no surprise, because the hearing native signers are balanced bilinguals of English and Auslan. It was also found that the hearing non-native signers' English WMC is similar as their Auslan WMC. This result is possibly due to the fact that many hearing non-native signers implemented English subvocal rehearsal to retain the to-be-remembered signs. The hearing non-native signers' English subvocal rehearsal strategy in both WM span tasks might lead to their qualitatively similar memory performance. Taken together, these results suggest an absence of the test language effect on professional interpreters' WMC. These results also partially support Kane et al.'s [12] claim that WMC construct is primarily determined by a domain-general (attentional) mechanism.

Furthermore, the results revealed a non-significant difference between the deaf native signers and the deaf non-native signers in their Auslan WMC. This finding is consistent with the prior evidence that deaf native signers are similar as deaf non-native signers in their short-term memory span [10]-[11]. This result is consistent with the aforementioned finding that there is a non-significant difference between the hearing native signers and the hearing non-native signers in their Auslan WMC.

It is worth attention that the small and diverse sample in this study may reduce the statistical strength of the results. However, this study highlights the need for more research on signed language WMC in hearing and deaf signers.

VI. Conclusion

This study measured English WMC and Auslan WMC in professional Auslan/English interpreters (comprising hearing native signers and hearing non-native signers). The study also evaluated Auslan WMC in deaf signers (comprising deaf native signers and deaf non-native signers). The results revealed that the hearing native signers were similar as the hearing non-native signers in their English WMC, and that the hearing native signers were similar as the hearing non-native signers in their Auslan WMC, suggesting an absence of the Auslan nativeness effect on the professional interpreters' WMC. Moreover, the results revealed that the hearing native signers' English WMC was similar as their Auslan WMC, and that the hearing non-native signers' English WMC was comparable to their Auslan WMC, indicating an absence of the test language effect on the professional interpreters' WMC. Furthermore, the deaf native signers were similar as the deaf non-native signers in their Auslan WMC, suggesting an absence of the Auslan nativeness effect on the deaf adult signers' WMC. All these findings add to our knowledge of signed language WMC in hearing and deaf signers. It would be interesting to replicate this study on hearing and deaf signers of other signed languages (e.g., American Sign Language, British Sign Language, French Sign Language). Further research is also needed to compare native signers and non-native signers on a wide range of WM measures (e.g., symmetry span task; operation span task).

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