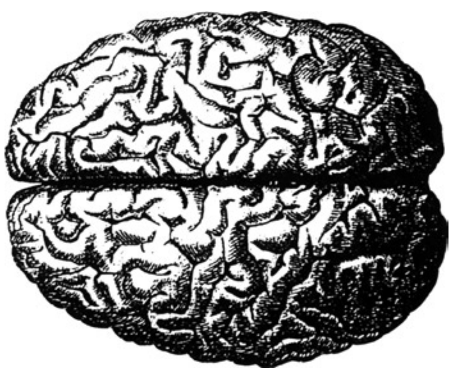

Short-Term Memory In Second Language Learners of ASL

The Competing Effects of Modality and Mother Tongue

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Mechanisms behind auditory linguistic short-term memory (STM) have been the focus of much research over the past several decades. Studies of memory span began with Miller's famous finding that for English speakers, STM has a limited capacity of about seven items.[1] That hypothesis has since been modified several times as evidence has been uncovered suggesting that memory span is limited not by the number of items to be recalled, but by the time needed to mentally rehearse these items. That is, words that take longer to mentally rehearse result in a decreased span.[2] Cross-linguistically, languages in which names for digits are shorter show longer digit spans, and opposite is true for languages with longer digit names.[3,4] When Miller's hypothesis is recast in terms of time, auditory linguistic STM is observed to hold roughly 2 seconds worth of information. Since English digits have an articulation time somewhere in the neighborhood of 310msec to 321msec, basic arithmetic explains that English digit span should be around 7 items.[3,5]

General Structure of Short-Term Memory

The current preferred model for describing STM comes from consists of a three part structure: a "visuospatial sketchpad," a "phonological loop," and a "central executive."[6,7]

The phonological loop is itself divided into a phonological storage buffer and an articulatory rehearsal loop. Evidence for this division comes from two well-established phenomena: the phonological similarity effect and the effect of articulatory suppression. The phonological similarity effect refers to the fact that STM span decreases when the items to be recalled are too phonologically similar, which suggests that the phonological information is used for encoding and rehearsal.[8] Articulatory suppression occurs when subjects are instructed to continually repeat a certain utterance during a test of STM. This also results in a lower span, suggesting that mental representation of phonological information also draws on articulatory mechanisms.[9] It is important to note, however, that these studies almost universally use linguistic stimuli, and thus it has been difficult to parse out effects that are due to the linguistic nature of the stimuli which may differ from those due to the simple auditory nature of the stimuli.

The visuospatial sketchpad is subdivided into visual and spatial STM, which each exhibit a certain degree of independence with a certain degree of interaction, the exact nature of which is not yet understood. Tests of visuospatial STM are known to show a smaller span than the phonological STM, but it has once again proven difficult to establish whether this span of only about five items is due to the visual nature of the stimuli or to the non-linguistic nature of the stimuli.[10]

Signed Languages and their Contributions to STM Research

More recently, researchers have begun to parse out the effects of modality and language on STM by studying signed languages. Most of the research to date has been conducted using American Sign Language (ASL), a natural human language which exhibits all the properties of spoken languages with comparable complexity.[11] By studying signed languages such as ASL, researchers can ask questions about how STM is affected differently by linguistic and non-linguistic stimuli, and how the modality of input (visual vs. auditory) impacts STM span, because ASL provides a way to dissociate between auditory input and linguistic input.

However, before researchers could use ASL to inform the study of STM in spoken languages, it was important to verify that analogous components of spoken language STM were present for signed languages. The earliest evidence for sign-based parallels to spoken language phenomena came from Bellugi & Siple (1974), who were the first to demonstrate a sign-based phonological similarity effect.[12] More recently, evidence has come from Wilson and Emmorey, who demonstrated an interaction between phonological similarity, manual articulatory suppression, and a word length effect as evidence for an ASL phonological loop with a phonological storage buffer and an articulatory rehearsal mechanism.[13,14] This impressive correspondence between spoken and signed language phenomena showed that visuospatial materials can be processed linguistically under certain circumstances.

However, one important difference between spoken language and signed language STM is found in span length. English span is most commonly measured by a WAIS-style digit span task in which subjects are presented with lists of numbers in increasing lengths.[15] The longest length at which they can correctly recall at least one of two lists is considered their span. For English, this number is generally in the neighborhood of 7 items.[1] When this same procedure is applied to ASL, however, span is significantly shorter, around 4-5.[16,17] These results have been replicated several times in both Deaf and hearing native signers.[18]

The usual interpretation of this finding has been that, since ASL digits take longer to "pronounce" than English digits,[19] the reduction in span is simply an instance of the well-established word length effect. However, Boutla et al. present the results of ASL span measurements that carefully manipulated stimulus duration, presentation rate, and other timing factors to see if span increased when timing was more similar to English. No alterations of the temporal processes of the stimuli resulted in an increased span, either for Deaf native signers or for hearing native signers (also called CODAs: [hearing] children of Deaf adults) who learned ASL as a first language, even though these hearing signers showed a typical English span.[18]

Therefore, it seems that ASL span for native signers has a limited capacity that is not explained by the timing constraints to which spoken languages are subject. According to Boutla et al., the most likely mechanism behind this phenomenon is a modality effect: an advantage for auditory linguistic information that ASL does not share because of its visual nature.[18]

The performance of native signers, both Deaf and hearing, was unexpected. Since ASL has demonstrated all the other phenomena associated with linguistic processing, it is surprising to witness such a strong modality effect regardless of the linguistic nature of the stimuli. A question in the present research concerns whether this only holds true for native signers; second language learners of ASL might not be subject to this modality effect. No studies of STM in second language learners of ASL have previously been conducted. Our original hypothesis predicted that ASL digit span for native English speakers who were learning ASL would resemble the English span of about 7 items, on the assumption that adult learners of ASL would likely encode these materials in English.

Research on STM Processes in Auditory Second Languages

Before studying the behavior of second language learners of ASL, we must place their performance in the context of what is known about STM processes in second language learners of spoken languages. Research on STM span in multilingual subjects is a relatively new field, and the existing research focuses almost exclusively on "bilinguals," but does not always specify whether these are native speakers of both languages. One early study claimed to establish a difference in digit span for bilingual speakers of Welsh and English, crediting timing-related factors rather than proficiency-related factors as the cause.[3] However, methodological concerns and difficulty replicating these findings cast doubt on these claims.[20,21] Researchers who followed have asked whether STM span differences observed between a bilingual speaker's two languages are due to differences in sub-vocal rehearsal rate, or to proficiency-related factors.[22] Evidence seems to support the so-called "mother-tongue superiority effect," in which subjects show a span characteristic of their mother tongue even for stimuli in which subvocal rehearsal rates or other time-related factors would predict a different span.[23] That is, subjects who are bilingual in two languages with different characteristic spans (in monolinguals) show a digit span typical of the language in which they consider themselves dominant.

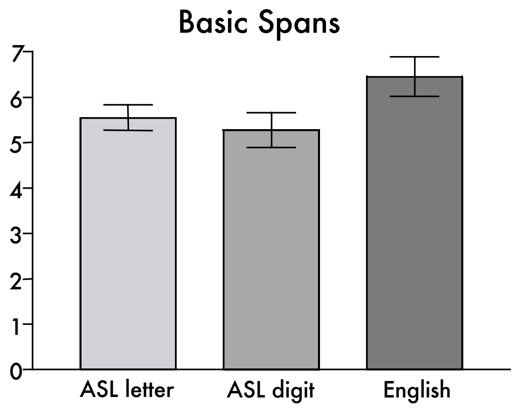
Seen in this light, the performance of CODAs (hearing children of Deaf adults) on the ASL span tasks is quite surprising! The mother-tongue superiority effect would predict that since these hearing native signers reported themselves to be English-dominant, they would show the English digit span of about 7 items. However, recent results show a span in the non-dominant language which is significantly lower than these subjects' own (dominant) English digit span of 7.05 and not significantly different from the native monolingual span of 4.91.[18]

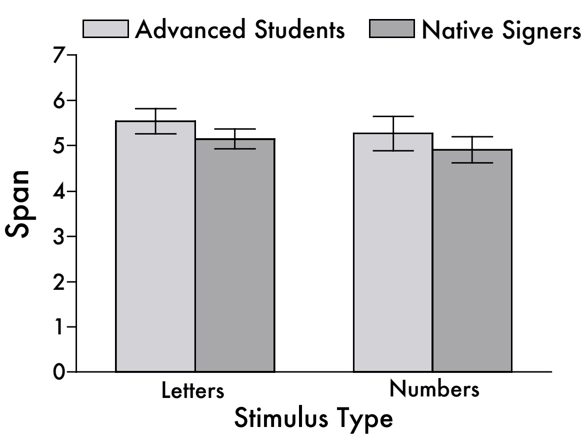
The present two experiments tested subjects of even lower proficiency than these CODAs, reasoning that the mother-tongue superiority effect would be expected to have an even more significant impact for non-native speakers. However, even if these second language learners do show a shorter (more native-like) span, it will still be necessary to rule out proficiency concerns before convincingly attributing the results to a modality effect.

The first experiment set out to measure the basic ASL spans of second language learners who were advanced students but still learning the language. If these subjects show English-like spans, it would seem that they are still mentally representing information in their native language, despite having stimulus presentation and recall in ASL, thus following the predictions of the mother-tongue superiority effect. If, on the other hand, these subjects show native-like ASL spans, we will need further analysis to determine whether the subjects are indeed showing evidence of a modality effect similar to that experienced by native signers (hearing and Deaf), or whether they are performing mental translations between ASL and English, thus occupying STM resources which might otherwise contribute to increasing span length. In addition to the determining the basic spans, a manual suppression condition was added to assess whether subjects were using a manually based mental representation system. If manual suppression is found to affect STM span, this would constitute evidence that second language learners are mentally representing information in their second language and could imply a linguistic modality effect.

Experiment 1: ASL Spans of Second Language Learners

The participants were 11 hearing undergraduate students from the University of Rochester who were advanced ASL students. These students had all finished four semesters of ASL language instruction and completed or were currently enrolled in at least one upper-level ASL course taught in sign without voice interpretation. The video-recorded stimuli for the English and ASL digit spans consisted of the digits 1-9 and were ordered randomly to form lists of increasing length, starting at 2 items and proceeding up to either 8 or 9 items. There were two lists at each length. Lists of letters were generated by arbitrarily pairing selected ASL letters to digits, and replicating the lists from the digit span. To avoid chunking, lists were modified when this process produced meaningful acronyms. The particular letters used in the ASL task were chosen to avoid phonological similarity in ASL, although no similar control for their English equivalents was made. The stimuli were produced by a native signer at a rate of one item per second, paced by a visual or auditory metronome (as appropriate), and verified by frame-by-frame analysis. The signs were produced with a neutral facial expression, and only those mouth movements that would be natural for native ASL signing.





Top, Figure 1: Mean forward serial recall span of advanced ASL students. Error bars in this and all subsequent figures represent SEM. **Bottom, Figure 2:** Comparison of mean STM spans of advanced students and native signers. Native signer data from Boutla et al. (under review).

The above process was used to create five WAIS-style tests: two of ASL letters, two of ASL numbers, and one of English numbers.[15] All subjects received all tasks. Subjects were first given the basic WAIS tests in ASL for both letters and numbers, in counterbalanced order. Then they were given these tests again using a manual suppression task (see below), also in counterbalanced order. Finally, they were given the English digit span task. Using the WAIS definition, span was defined as the longest list length at which at least one of the two lists was recalled correctly.[15]

The manual suppression task was modeled after Wilson & Emmorey (1997), and consisted of the subjects opening and closing their hands in an alternating fashion (roughly from an ASL "5" handshape to an ASL "S" handshape") throughout stimulus presentation. This particular task was chosen because it had been demonstrated to be effective in the published literature and was a good analog to the types of interference tasks used in spoken language research in terms of obeying phonological and phonotactic constraints of the language.[9,13]

Mean basic spans for ASL letters, ASL digits, and English digits are shown in Figure 1. As can be seen, the ASL span in both tasks was lower than the English span. These spans were computed using a repeated measures one-way analysis of variance (ANOVA), which showed that ASL letter and digit spans were not significantly different from one another, but they were significantly lower than English span. Figure 2 shows how the ASL spans for the advanced second language learners compare with those of the native signers tested in a separate experiment.[18] Overall then, the relatively short ASL spans for second language learners resemble those of native ASL monolinguals, while their longer English spans resemble native English monolinguals. This is the same pattern observed in CODAs.[18]

These data indicate that advanced ASL students do not behave according to the mother-tongue superiority effect, which would predict that they should show the longer, English-like span for all tasks. The reasons for this, however, are not immediately clear. The subjects may simply be having difficulty in the ASL tasks because of their lower proficiency with the language. Alternatively, they might be mentally representing the information in English, with the observed decrement due to the mental resources needed to perform a two-way translation from ASL stimuli to English mental representation and then back to ASL for recall. As a third possibility, they may be showing a modality effect, with visual ASL stimuli producing a shorter span than spoken English stimuli. This difference could be a difference between modalities for linguistic stimuli, as has been suggested for native signers, or could be a nonlinguistic modality effect characteristic of other studies of visuospatial memory.

Performance in ASL span tasks using manual suppression was examined to determine whether participants were encoding the material in ASL. It was determined that manual suppression had no impact on span. This noneffect suggests either that subjects are not mentally representing information in ASL or that the suppression task itself was not robust enough to show an effect. Unfortunately, we have reason to believe that the latter may be true. Therefore, we cannot empirically discount the possibility that advanced students show low spans because they are mentally representing information in ASL. However, anecdotal evidence including unsolicited self-reports from several participants indicates that they may have been using English-based strategies for encoding and recall. In light of these two concerns, we recommend that the above experiment be replicated with a more robust suppression task.

The results of this experiment show a shorter span for ASL materials than for comparable materials presented and recalled in English, even for second language learners of ASL. However, it is not clear from these results whether this difference is due to a modality effect, as has been seen in native users of ASL, or to other factors particular to second language learners that could produce the same patterns.

Because results from Experiment

1 could not yield conclusive answers to these questions, Experiment 2 was designed with two modifications. First, subjects of lower proficiency in ASL were used to demonstrate that the performance of the advanced students was not likely to be due to difficulty in correctly apprehending the ASL-English correspondences. Secondly, and more interestingly, Experiment 2 allowed us to investigate the hypothesis that the observed decrement in span might be due to mental translation between the two languages. These hypotheses were investigated by including conditions in which the subjects were instructed to make a one-way translation from ASL to English or vice versa.

Experiment 2: Exploring Mental Translation

The subjects were 12 hearing undergraduate students from the University of Rochester who were considered to be intermediate-level ASL students. They were recruited from the population of students currently enrolled in their fourth semester of college-level ASL language classes, and had received minimal to no ASL exposure prior to college. The apparatus and stimuli were the same as Experiment 1, with one additional WAIS-style digit task in English.

The present experiment tested basic ASL letter and digit spans and English digit span as in Experiment 1, and added three new conditions: ASL stimuli with English recall (for both letters and numbers) and English stimuli with ASL recall (numbers only). All subjects received all conditions, beginning with the basic span measures for ASL letters and numbers (in counterbalanced order), followed by English numbers. Then subjects were presented with ASL stimuli but instructed to recall them in English (with letter and numbers run with order counterbalanced), and finally were presented with English numbers and instructed to recall them in ASL. The nature of the trials was the same as in Experiment 1, but run without manual suppression.

Mean basic spans for ASL letters, ASL numbers, and English numbers for these intermediate ASL students are shown in Figure 4. ASL spans were significantly lower than English, but there was no significant difference between the two ASL conditions. This finding parallels the trends observed in CODAs and in the advanced students from Experiment 1.

Figure 5 shows the basic spans of the intermediate students compared with those of advanced students. An unexpected trend seemed to emerge in which intermediate students consistently outperformed advanced students. Although there was no main effect of proficiency level, the trend observed on the graph indicates that it might be worth controlling for basic memory span when comparing span between groups. If a difference in basic memory span were observed using English digit span as a baseline, we might suspect that the subject pools simply differed in their basic STM capacity. For the present data, this control was performed by an analysis of difference scores. Since we were most interested in the difference between the subject's native language (English) and their second language (ASL), difference scores for each condition were computed (English digits minus ASL digits; English digits minus ASL letters), and a two-way ANOVA was computed as before. This analysis indicates that there are no significant differences in basic ASL or English spans between intermediate and advanced ASL students.

Most importantly, as previously noted, the intermediate ASL students show lower ASL spans than English spans, as do advanced ASL students.

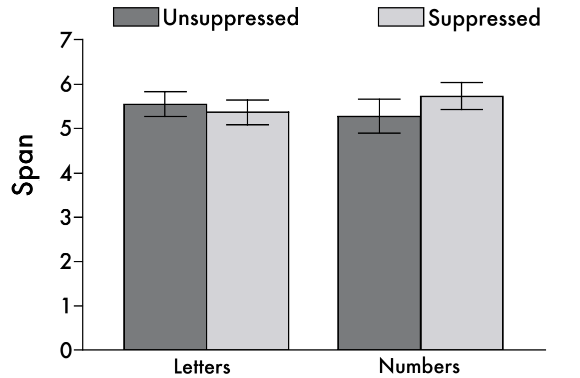
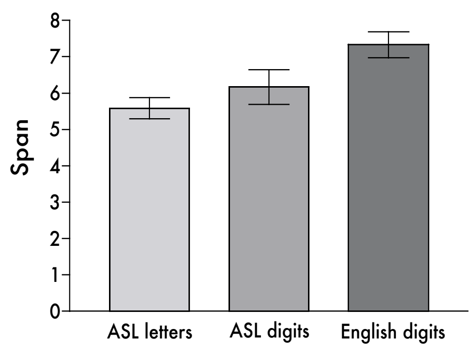
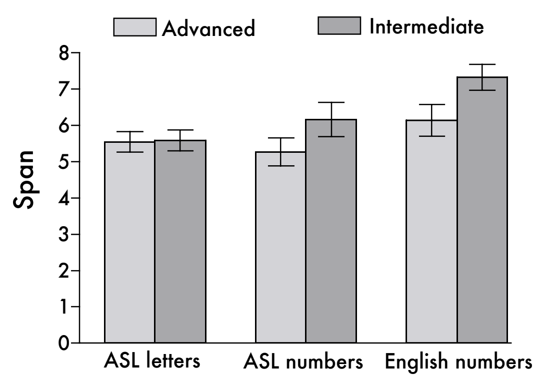


Figure 3: The effect of manual suppression on mean STM span for advanced ASL students.

Although this could suggest that the subjects are mentally representing the materials in ASL, two other explanations remain. First, it is possible that both groups of subjects simply have difficulty with the ASL–to-English correspondences because of their lower proficiency in ASL. Second, they may be making mental translations that deplete STM resources. To test this first explanation, span measurements from the one-way translation conditions were examined under the reasoning that if subjects show a longer span in these conditions, we can be sure that they have sufficient knowledge of the ASL-English correspondences. Data from these translation conditions also allow us to test our predictions about mental translation by comparing subjects' performance on the basic ASL conditions against the translation conditions. If subjects are already performing a two-way translation in the basic ASL conditions, we would





Above Left, Figure 4: Mean forward serial recall span for intermediate ASL students. **Above right, Figure 5:** Comparison of mean span for advanced and intermediate ASL students. Note unexpected superior (although non-significant) performance of intermediate students on both ASL numbers and English numbers.

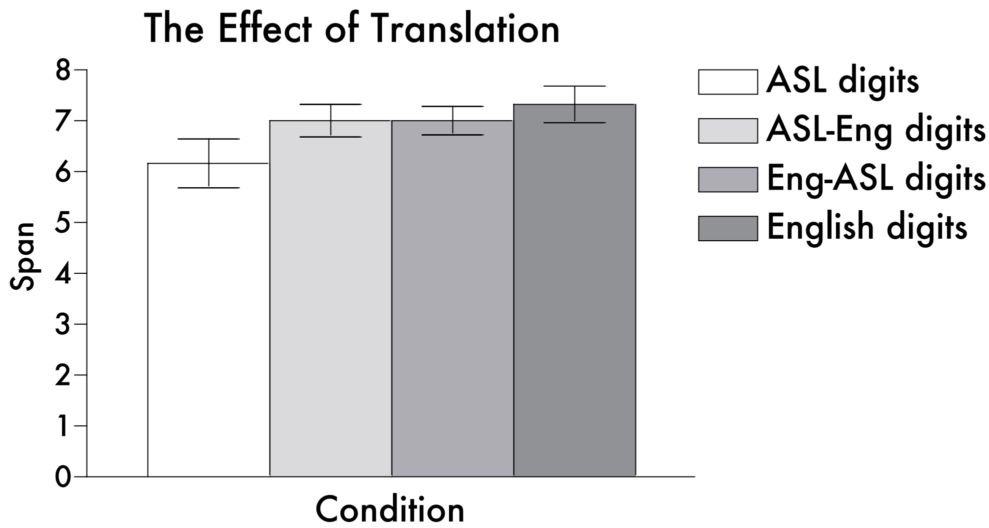


Figure 6: Mean forward serial recall digit spans for intermediate students for the basic ASL, basic English, and the one-way translation conditions

not expect the one-way translation conditions to be very different.

In comparing the ASL-to-ASL letters condition with the ASL-to-English letters condition in order to determine the effect of a one-way translation for letters, it was determined that the spans are not significantly different. This finding ran contrary to our expectations and likely results from the uncontrolled variable of phonological similarity. Although the letter stimuli were controlled for phonological similarity in ASL, many of the letters were phonologically similar in English (B, C, D, G, S, F), which is known to reduce English letter span.[8] For a more informative perspective, we turned to the data from the digit span tasks, where these concerns did not play a role.

Figure 6 presents the spans of intermediate students for the ASL-to-ASL, ASL-to-English, English-to-ASL, and English-to-English conditions. It is clear that the only span that is lower than the basic English condition is the ASL-ASL digit span. Two conclusions emerge from this set of data. First, it is clear that the intermediate students do not have problems making the correct ASL-English correspondences under one-way translation. Therefore, it is reasonable that the smaller span of the advanced students for the basic ASL conditions was also not due to difficulty understanding the input or correctly expressing the material in recall. Second, and more importantly, it appears that when subjects perform a mental translation where English is involved either as input or output, they show an English-like span, even in response to ASL stimuli. Since mental translation was an option available to the subjects in the basic conditions (and perhaps encouraged under manual suppression), the fact that they made no apparent use of it suggests that the observed difference between basic English and ASL spans is due to the modality effect rather than translation. However, it is possible that although a one-way translation for either encoding or recall may not have produced a significant decrement in span on its own, the aggregate effect of both translations might.

Therefore, we further investigated the hypothesis that the subjects were showing a low span in the pure ASL conditions because they were performing two mental translations: once from ASL stimuli to an English mental representation, and then back to ASL again for recall. According to this hypothesis, ASL span should be able to be predicted from the basic English span, minus the sum of the decrements for encoding and recall translations. We therefore compared the subjects' actual ASL digit span against the span predicted by the translation decrement hypothesis. This predicted value was determined by taking the mean basic English digit span, subtracting the difference between that and the ASL-to-English condition (the "encoding" translation) and then further subtracting the decrement between the basic English span and the mean from the English-to-ASL condition (the "recall" translation). This resulted in a predicted ASL span of 6.67, which was not significantly different from their observed ASL span of 6.167. For the sake of completeness, we then performed the analogous operations to compare observed English span against the English span predicted by the translation decrement hypothesis, given ASL span. The resulting prediction of 7.833 was not significantly different from the observed span of 7.33. Therefore, we cannot rule out the possibility that for second language learners, the observed decrement in span may not be due to a modality effect, but to two-way mental translation.

Finally, the intermediate subjects' ASL spans were then compared with those of native signers from Boutla et al. (under review).[18] It was discovered that the intermediate students show a longer span than native signers. This difference is primarily due to the intermediate students' high digit span.

Initially, this result seems to suggest that the intermediate students are behaving according to the mother tongue superiority effect, at least for digits. In other words, they are showing a longer digit span than native signers, which some might argue could be due to mental representation in English. However, it is important to remember that no control of basic STM capacity was made between these two groups. When controlling for basic STM capacity, no differences were found between advanced and intermediate students. If it were possible to control for basic STM capacity between intermediate students and native signers, we might not find any significant difference. (For a side by side comparison of all three proficiency levels, see Figure 7.) While this is far from a definite conclusion, it is helpful to consider this possibility, especially since we have no direct evidence that subjects are mentally representing the materials in English unless instructed to do so. Conversely, it is also important to remember that it has not yet been empirically demonstrated that any of the non-native subjects are mentally representing information in ASL even when their span is native-like in length.

Conclusions

Two hypotheses can accurately account for the pattern of data described in Experiments 1 and 2. One of these is the modality effect hypothesis, which postulates that STM for any visual information, even if it is linguistic in nature, is limited to a capacity of 3-5 items.[10,18] Support for this idea from the present experiment includes the observation that STM span for second language learners fails to obey the mother-tongue superiority effect that has been observed for spoken language bilinguals who are dominant in one of their languages.[23] Since the only significant difference between those studies and the present experiment is the modality in which the second language operates, modality is the clearest cause of the results. However, one puzzling piece of evidence is that monolingual English speakers perform equally well on a digit span task when stimuli were presented in the auditory and visual modality, suggesting that the mechanism behind the present result is more complicated than a simple modality effect. [24] Further research manipulating the nature of the visual stimuli for second language learners (signs vs. digit words vs. Arabic numerals) should help to disambiguate these results. If second language learners show a shortened span only for ASL conditions, the modality effect would appear to be linked specifically to ASL as a visuospatial language, and not to the purely visual or purely linguistic nature of the stimuli.

The second viable hypothesis is the translation decrement hypothesis, which postulates that subjects are mentally representing everything in their first language. According to this hypothesis, the observed decrement for ASL spans is claimed to be due to the mental translations necessary between encoding and recall. Our experimental manipulations reveal that this explanation has not been discounted. Note that this prediction runs counter to the mother-tongue superiority effect, but this effect was found in studies of "bilinguals," many or most of whom may have been native speakers of both languages. It is possible that the mother tongue superiority effect does not appear so directly in adult learners, who may show greater decrements when mentally translating to or from the non-dominant language. There is good reason to suspect that language processes used by second languages learners may differ significantly from those used by native speakers.[25] Research on second language learners (i.e. non-native bilinguals) of spoken languages with differing characteristic STM spans should provide useful insights into the mental behavior of second language learners.

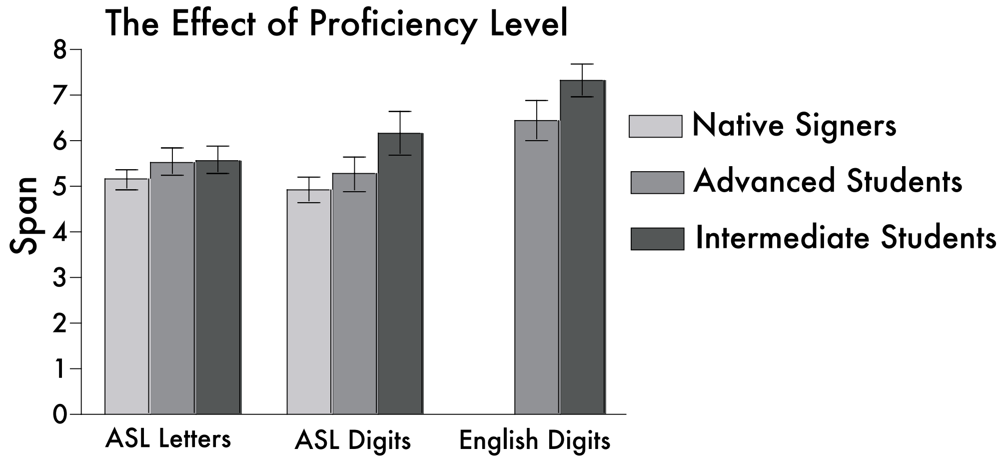


Figure 7: Comparison of mean basic spans for all proficiency levels. Native signer data from Boutla et al. (under review). Note the intermediate students' consistently higher performance on both ASL and English digits.

Matt Hall was a magna cum laude graduate of the University in May 2003 with a Bachelor of Arts in Brain and Cognitive Sciences (Highest Distinction and Honors in Research) and a Bachelor of Arts in American Sign Language (High Distinction). This article is the result of the independent research conducted throughout his senior year which earned him Honors in Research for BCS. Matt is still at the University as a research assistant to Daphne Bavelier in the department of Brain & Cognitive Sciences, where he continues to study the organization of spoken and signed languages in the brain through behavioral and functional magnetic resonance imaging techniques.