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The puzzle of working memory for sign language

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Why is immediate-serial-recall (short-term memory) span consistently shorter for sign language than it is for speech? A new study by Boutla *et al.* shows that neither the length of signs, nor the formational similarity of signed digits, can account for the difference. Their results suggest instead that the answer lies in differences between the auditory and visual systems. At the same time, however, their results show that sign language and spoken language yield equivalent processing spans, suggesting that reliance on immediate-serial-recall measures in clinical and educational testing is misplaced.

One might expect that working memory for sign language would parallel working memory for visual-spatial materials, rather than for speech. Instead, the evidence indicates that working memory for speech and sign are strikingly similar (for reviews see [1,2]). For both language types, information is maintained in a phonological rather than a semantic code, and both speakers and signers use an articulatory mechanism to rehearse subvocally or submanually [2]. For sign language, phonological coding is based on manual rather than oral features (e.g. hand configuration, place of articulation on the body, movement, and hand/arm orientation) [3].

Despite these intriguing parallels, storage capacity has been found to differ significantly for speech and sign, with speakers consistently exhibiting a longer span than signers. The recent study by Boutla, Supalla, Newport and Bavelier [4] attempts to identify the factors that explain this discrepancy. One possible explanation is that – at least when a standard digit-span task is used – the visually similar number signs in American Sign Language (ASL) give rise to a phonological similarity effect and thus poorer memory for signers. However, the difference in span is not just limited to digits. Another frequently proposed explanation builds on the fact that signs take longer to articulate on average than words do [5]. On this theory, the longer articulation time creates the equivalent of a word-length effect, thus reducing span [6]. A third possibility is that deaf people simply have a smaller short term memory capacity than hearing people, and thus the difference is unrelated to language modality.

The persistence of the span difference

The study by Boutla *et al.* [4] shows that none of these explanations is sufficient. The sign stimuli in their

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experiments were letter signs from the manual alphabet, which have two advantages: first, these signs are phonologically distinct, and second, they are quick to articulate. Indeed, signers and speakers did not differ in the rate of production during recall or on another production rate task (letters for signers and digits for speakers). Despite this, deaf signers still exhibited a mean span of 4.4, in contrast to 7.2 for the matched hearing English speakers. Furthermore, when hearing ASL/English bilinguals were tested in both languages, they had a mean ASL span of 5.2 and an English span of 7.05.

These results are groundbreaking for two reasons. First, they demonstrate for the first time that the span difference persists even when tested within the same person using the two different language modalities (cf. [7,8]). This shows decisively that it is not deafness *per se* that somehow affects working memory capacity. Second, these results indicate that the previously most plausible explanation – that articulation time is responsible for the difference – cannot be the whole story. Even when articulation time is equated, the sensory modality of language makes a difference.

How modality affects working memory

What explains the difference in span between speech and sign? The most likely possibility lies in the different relative strengths of the auditory and visual systems, coupled with the peculiar demands of immediate serial recall. Boutla *et al.* cite the longer persistence of sensory traces in the auditory system than in the visual system, as well as superior coding of serial order within audition. Both of these seem to be outgrowths of the auditory system's stronger specialization for temporal information. By contrast, the visual system is relatively poor with temporal coding, but superior with spatial coding.

This line of argument accords well with other results that suggest modality-dependent effects on working memory for sign versus speech. For example, working memory for ASL appears to involve a less-temporally ordered, spatial coding that is unavailable for spoken language [9,10]. In addition, serial recall for ASL is disrupted by irrelevant visual input (signs and other structured visual stimuli), in a manner parallel to the effects of irrelevant auditory input for speech [6]. These findings and those of Boutla *et al.* [4] support models of working memory that hypothesize sensorimotor representations, as opposed to amodal representations (e.g. [11]). Sensorimotor coding in working memory has potentially broad theoretical implications, as it bolsters a more general account of human cognition in which sensory and motoric mechanisms are important explanatory factors.

We should note that articulation length might still be an aspect of language modality that affects span, when comparing lexical words versus signs (i.e. items not equated for length). The point that these new data make, though, is that even when length is controlled for, a difference in span persists between sign and speech.

Are numbers special?

A shadow of doubt, however, remains over these conclusions. The reason is that, in the Boutla *et al.* study, the sign language and spoken language stimuli differed in one trivial but possibly crucial respect – the former were letters and the latter were digits. This would seem unimportant were it not for recent results suggesting that digits have a special status in human cognitive processing. Patients with semantic dementia show a surprisingly preserved digit span, relative to their disrupted word span. Jeffries *et al.* [12] propose that this is the result of a category-specific advantage for numbers. Most interesting for the present purposes, Jefferies *et al.* found that even in the healthy normal controls, digit span is substantially better than word span. This is true even when the two sets of stimuli are equated for articulatory length, phonological similarity, word frequency, imagability, and set size.

What does this mean for the sign language results? Previous investigations report mean ASL digit spans ranging from 4.6 to 4.7 [13,14], and unpublished data from the Bavelier laboratory also indicate no significant difference between digit span and letter span for deaf ASL signers. However, given the phonological similarity of ASL number signs, memory span for digits should actually be shorter than for phonologically dissimilar letters. The category-specific advantage for numbers might cancel out the phonological similarity effect. Thus, a crucial unanswered question remains: if both signers and speakers were tested with letter stimuli, would the difference in span persist, and would it be as large? For the moment, it appears that Boutla *et al.* have identified the major source of the speech/sign span difference, but further testing is needed to eliminate this last doubt.

Why doesn't span matter for processing?

In a final twist, Boutla *et al.* also demonstrate that the sizable, persistent difference in immediate serial recall span nevertheless has no effect on a more complex measure of working memory processing capacity (a speaking/signing task involving both immediate memory and sentence generation). Unlike the straightforward demands of immediate serial recall, processing span tasks require subjects to process, maintain, and update multiple competing representations in working memory. When signers and speakers were tested on such a task, performance was identical for the two groups.

Given that immediate serial recall capacity could easily be an important variable in accomplishing the more complex span task, it is striking that no difference at all was found between signers and speakers. The probable explanation is that ASL (like other signed languages) exhibits linguistic structuring that exploits spatial mechanisms and avoids reliance on temporally encoded distinctions [15]. For example, phonological distinctions tend to be simultaneously rather than sequentially encoded; non-concatenative morphology is preferred over linear affixation; many syntactic markers are conveyed by facial expressions produced simultaneously with manual signs; and certain grammatical functions make use of spatial simultaneity rather than linear sequencing of elements. This tendency towards spatial rather than temporal strategies might come into play when the constraints of serial recall are lifted.

With respect to real-world functions, immediate serial recall is a relatively artificial task that is stacked in favor of auditory processing. Therefore, the difference in immediate-serial-recall span might have little impact on the everyday lives of signers. However, as Boutla *et al.* point out, clinical evaluation and educational testing of deaf individuals commonly use a digit span task, which their results suggest might be inappropriate without normative adjustments. In this respect, the work of Boutla *et al.* represents an important step forward not only in theoretical understanding of the phenomenon but also in practical implications for the deaf population.

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Attention and awareness in synchrony

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Interactions between functional areas are often considered to account for subtle aspects of cognitive functions, although direct experimental evidence is scarce. A recent study by Gross *et al.* relates the strength of synchrony between human parietal, frontal and occipital regions to the availability of attentional resources. These results support the current view that attention and awareness emerge from dynamic interactions in distributed networks.

Attention increases the efficiency of information processing, leading to faster and better performance in many tasks. However, only a limited part of the incoming visual flux benefits from such resources. How and where the 'atten-attentional bottleneck' occurs is only beginning to be understood. The attentional blink (AB) paradigm has proved useful to probe attentional capacity limitations [1,2]. In this paradigm, subjects view a rapid sequence of visual stimuli and must identify targets embedded in this stream. If a second target falls within 500 ms of a first target, it often cannot be consciously reported (as if 'blinked'), although its processing can reach high-level stages such as semantic analysis [3]. The attentional bottleneck has been localized in the right intraparietal sulcus and the frontal cortex [4], but the neural mechanisms responsible for attentional limitation remain largely unknown. Recent findings [5] using the AB paradigm suggests that capacity limitations are related to neural communication within this network in humans. Gross and colleagues found that

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