Effects of Age on the Temporal Organization of Working Memory in Deaf Signers

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Deaf native signers have a general working memory (WM) capacity similar to that of hearing non-signers but are less sensitive to the temporal order of stored items on retrieval. General WM capacity declines with age, but little is known of how cognitive aging affects WM function in deaf signers. We investigated WM function in elderly deaf signers (EDS) and an age-matched comparison group of hearing non-signers (EHN) using a paradigm designed to highlight differences in temporal and spatial processing of item and order information. EDS performed worse than EHN on both item and order recognition using a temporal style of presentation. Reanalysis together with earlier data showed that with the temporal style of presentation, order recognition performance for EDS was also lower than for young adult deaf signers (YDS). Older participants responded more slowly than younger participants. These findings suggest that apart from age-related slowing irrespective of sensory and language status, there is an age-related difference specific to deaf signers in the ability to retain order information in WM when temporal processing demands are high. This may be due to neural reorganisation arising from sign language use. Concurrent spatial information with the Mixed style of presentation resulted in enhanced order processing for all groups, suggesting that concurrent temporal and spatial cues may enhance learning for both deaf and hearing groups. These findings support and extend the WM model for Ease of Language Understanding (ELU).

Key words: working memory; sign language; deafness; temporal processing

Working memory (WM) is the cognitive capacity available for on-line processing and short-term storage of information (Baddeley, 2000) and shows a distinctive developmental trajectory over the life-span with increase in capacity during childhood (Davidson, Amso, Anderson & Diamond, 2006) and decline in old age (Reuter-Lorenz & Cappell, 2008). Depletion of WM capacity with advancing age is accompanied by decline in other cognitive functions such as perceptual speed, episodic memory and word fluency (Lindenberger & Ghisletta, 2009). The causal mechanisms of changing WM capacity are yet to be established.

Adequate working memory (WM) function is a prerequisite for language processing irrespective of language modality (Baddeley, 2003). However, the architecture of WM in both cognitive and neural terms may differ depending on the modality habitually used (see Rudner, Andin & Rönnberg, in press for a review). Previous work has shown that although there are striking similarities in the architecture of WM for sign-based languages and speech-based languages there are none the less intriguing differences which promise to teach us deeper truths about the nature of this fundamental cognitive function.

Sign languages are natural languages that are the preferred medium of communication of people who are born deaf (Emmorey, 2002). Rudner and Rönnberg (2008a) reported a series of studies which compared WM mechanisms in prelingually deaf signers (DS) and hearing non-signers (HN). These studies showed that when explicit processing capacity was challenged in terms of executive demands, DS were not as sensitive to the temporal order of information encoded into WM as HN. This adds to previous evidence suggesting that sign language cognition may be subject to organizational principles other than time.

In the present study we investigate whether this relative pattern remains stable in elderly people or whether effects of preferred language modality are obliterated by the general effects of aging.

Working memory

Working memory is a cognitive function that encompasses the temporary storage and processing of information from sensory sources or from other more long-term memory stores. This includes manipulation of both non-linguistic and linguistic information at all levels of language processing (Baddeley, 2003; Daneman & Carpenter, 1980). As a rule of thumb, WM may be considered to accommodate 7 items +/- 2 (Miller, 1956) but capacity may be either higher or lower according to external circumstances (Cowan et al., 2005) or individual differences (Daneman & Carpenter, 1980). Its duration is also limited and information may fade from WM or be overwritten by new information. These effects can be studied by analyzing relative recall performance for items at different serial positions in supraspan lists. Superior performance is found for the last item which has not yet faded or become overwritten, and for the first item which may have become encoded in long term memory, in contrast to earlier words in the list. The serial position effect is influenced by the sensory modality of presentation with auditory presentation of lexical and sublexical items giving superior recency performance compared to visual presentation (Rönnberg, Archer & Ohlsson, 1980; Rönnberg, 1982). This effect can also be~~en~~ understood in terms of primary and secondary language codes with auditorily presented words (primary code) giving better recency than printed words (secondary code) which require recoding to primary code in WM (Shand & Klima, 1981). This explanation is supported ~~from~~ by findings from sign language where a recency advantage in deaf native signers has been found for signs over printed words (Bellugi, Klima & Siple, 1975; Krakow & Hanson, 1985). Serial position effects are also found for visually presented items that are not verbally encoded (Hay, Smith, Hitch & Norton, 2007; Smyth, Hay, Hitch & Norton, 2005).

The obvious role of order in WM has led to proposals that separate mechanisms deal with processing of item and order information and that serial order is supported by a timing signal (Brown, Preece & Hulme, 2000; Henson, Hartley, Burgess, Hitch & Flude, 2003; Burgess & Hitch, 1999), which can also be understood in terms of the predictability of the timing of stimulus presentation (Rönnberg, 1980; 1981; 1983). It has been suggested that the inferior parietal sulcus might play a key role in maintenance of serial order (Majerus et al., 2007).

An accumulation of evidence of integration across sensory modalities in WM on the one hand (e.g. Logie, Della Sala, Wynn & Baddeley, 2000) and between WM and long-term memory on the other (Baddeley & Wilson 2002) led Baddeley (2000) to propose a fractionation from the central executive of a separate module known as the episodic buffer, to deal with these integratory functions. More recently a WM model for Ease of Language Understanding (ELU, Rönnberg, Rudner & Foo, in press; Rönnberg, Rudner, Foo & Lunner, 2008) has been proposed that focuses on the communicative function of WM. This model includes an episodic buffer known as RAMBPHO, whose function is the Rapid, Automatic, Multimodal Binding of PHOnology. Under optimum conditions, the RAMBPHO function mediates rapid access to appropriate representations in long-term memory for effortless, implicit, language understanding. Under less advantageous conditions due to a degraded signal or sensory or language impairment it is less likely that appropriate representations can be accessed without difficulty. In such a mismatch situation explicit WM capacity is needed to infer meaning (Hannon & Daneman, 2001). Accumulated evidence suggests that whereas RAMBPHO is not modality-specific (Rönnberg, 2003), the explicit component of the ELU model is (Rönnberg, Rudner & Ingvar, 2004; Rudner, Fransson, Ingvar, Nyberg & Rönnberg, 2007; Rudner & Rönnberg, 2008b).

Cognitive aging

It is well established that cognitive processes are modulated by age (Zacks, Hasher & Li, 2000) and that general processing speed decreases with age (Salthouse, 1996). WM is one of the cognitive functions that ~~is~~are affected by these changes. In particular, age-related decline in WM capacity is related to deteriorating executive functions and neural degradation of the frontal lobes which are known to support executive function (Reuter-Lorenz & Cappell, 2008), although the mismatch effect predicted by the ELU model and which involves executive function appears to remain intact with increasing age (Rönnberg et al., 2008). Further, it has been shown that where executive performance is apparently preserved in elderly people, it is associated with greater neural activity in the networks engaged during the same tasks in younger people (Cabeza et al., 2004) and less lateralization of those networks (Cabeza, 2002). This suggests that there are mechanisms at the neural level that compensate for reduced function, probably by redeploying available resources. It has been suggested that age-related sensory and cognitive deficits may share a common cause (Baltes & Lindenberger, 1997) although ~~recent work~~longitudinal analysis shows that this relationship is more tenuous than ~~once thought~~suggested by cross-sectional analysis (Lindenberger & Ghisletta, 2009). ~~One possible mechanism relating sensory and cognitive decline is the proposed notion of disuse (Rönnberg et al., submitted) whereby reduced auditory acuity leads to fewer communicative opportunities and less access to long term memory, resulting in deterioration in long-term memory function.~~

Modality specific aspects of working memory

Despite general similarities in the WM architecture for sign and speech, there do seem to be some differences in organization which are reflected at both behavioural and neural levels when explicit demands are high. These include less prominent temporal organization (Bavelier, Newport, Hall, Supalla & Boutla, 2008; Rudner & Rönnberg, 2008a; Wilson, Bettger, Niculae & Klima, 1997) and engagement of additional neural structures in the superior parietal regions, suggesting a greater reliance on spatial processing for WM for sign language compared to WM for speech (Rönnberg et al., 2004; Rudner et al., 2007), ~~possibily~~possibly related to retrieval mechanisms (Bavelier, Newman et al., 2008).

Visuospatial aspects of sign language cognition

There is evidence that indicates differences in visuospatial processing for signers and non-signers. For example, signers are better at face discrimination (McCullough & Emmorey, 1997) and more accurate in identifying emotional facial expression (Goldstein & Feldman, 1996). Furthermore, signers have an enhanced ability to generate images and detect mirror image reversals (Emmorey, Kosslyn, & Bellugi, 1993). O'Connor and Hermelin (1973) showed that whereas hearing children showed preference for temporal recall in a short-term memory task, deaf children preferred a spatial mode of recall. These results were based on an ingenious experiment where three digits were presented successively in one of three small windows arranged horizontally. Spatial and temporal order was always incongruent, i.e. the digits never appeared in left to right succession. In a later experiment (O'Connor & Hermelin, 1976) further evidence for the use of visual coding by deaf children emerged. In this study it was shown that deaf children made fewer order errors than hearing children on backward recall of visually presented letters, suggesting that they may be using a visual code that would enable them to read off a short term visual memory trace during the backward recall task in a manner not available to the hearing children who were coding verbally.

Neural aspects of sign language cognition

Sign language and speech processing are supported by the same classical language areas in the left cerebral hemisphere, which is specialised for temporal processing. The right hemisphere is specialized for discriminating the shape, size, and configuration of a visual object; its position in space; and some aspects of its movement: all of which are relevant to the analysis of sign language (Campbell, MacSweeney & Waters, 2008). Right hemisphere damage may impair some aspects of sign language processing, including maintaining topical coherence, employing spatial discourse devices (Hickok, Wilson, Clark, Klima, Kritchevsky & Bellugi, 1999), using space grammatically (Atkinson, Marshall, Woll & Thacker, 2005) and processing prosody (Atkinson, Campbell, Marshall, Thacker & Woll, 2004), and neuroimaging work has shown right hemisphere engagement in naming spatial relations in American Sign Language (Emmorey et al., 2002) and topographical processing in British Sign Language (MacSweeney et al., 2002). It is not yet clear whether right hemisphere involvement is specific to sign language processing or is related to general spatial processing mechanisms recruited during sign language processing (MacSweeney, Capek, Campbell & Woll, 2008). However, a special role for visuospatial mechanisms in sign language processing is indicated, and suggests that spatial relations may play a crucial role in sign language cognition. Thus, behavioural and neurological data suggest that the temporal and visuospatial processes engaged in cognitive tasks performed in sign language may differ from those engaged during the same cognitive tasks performed in spoken language.

Working memory for sign language

Rudner and Rönnberg (2008a) developed a WM test based on recognition of the identity and order of easily nameable pictures (Snodgrass & Vanderwart, 1980) that systematically varied temporal and spatial demands on memory. The use of easily nameable pictures placed even loads on deaf signers and hearing non-signers in terms of sensory input (visual, non-verbal), processing and storage (preferred language modality) and response (motor, non-verbal). Temporal and spatial demands were manipulated by using three different styles of presentation: Temporal, Spatial and Mixed. The results of this study showed similar levels of performance for younger adults who were either deaf signers or non-signers with normal hearing, indicating that general WM capacity is similar for sign and speech when potential sensory load differences are controlled for. However, when temporal demands were high, the deaf signers did not benefit from serial presentation of recognition cues in the same way as the hearing non-signers. These findings suggested that temporal information is less prominent in the organization of WM for sign language, although the design of the study did not rule out potential effects of deafness. Further, both groups showed a novel facilitating effect of semantic similarity, in line with the ELU model (Rönnberg et al., 2008). However, there were no differences between groups with other styles of presentation.

Present study

In the present study, the same experimental paradigm was administered to elderly deaf signers (EDS) and age-matched hearing non-signers (EHN) to investigate whether the same relative pattern would be found in older people. We predicted that the relative pattern would be preserved as language modality has previously proved to be a more potent force than age as regards organisation of the explicit component of the ELU model (Rönnberg et al., 2008), and the implicit temporal processing and semantic mechanisms involved are not primarily organised in the frontal lobes which seem to be principally affected by cognitive aging. In order to directly compare the performance of participants in the present study with the participants in the study by Rudner and Rönnberg (2008a), a further analysis was performed including data from both studies.

Method

Participants

There were two groups of participants with 14 persons in each group. The groups were elderly deaf signers (EDS) and elderly hearing non-signers (EHN). In the EDS group there were 9 women and 5 men. In the EHN group there were 10 women and 4 men. There was no significant difference in age between the groups (EDS: (X=72.5, SD=3.8; EHN: X=71.0, SD=4.2). All EDS were profoundly deaf and used sign language as their preferred mode of communication and all were prelingually deaf. They all had at least eight years of education

(X=10.1, SD = 1.5) using the oral method and were all fluent users of both SSL and Swedish. but none stated that they had used sign language before the age of seven.

All EHN reported normal hearing and either had no knowledge of sign language or only a rudimentary knowledge. All participants, although retired from working life, were healthy, active and lived in their own homes. They were all active members of pensioners' organizations; the deaf participants were members of the local society for deaf pensioners and the hearing participants were members of the local society for pensioners. All had normal, or corrected to normal, vision. All participants gave their informed consent.

Experimental paradigm

The experimental paradigm was identical to that used in Experiment 3 reported in Rudner & Rönnberg (2008a).

Main task. Stimuli were easily nameable pictures (Snodgrass & Vanderwart, 1980). These were presented in eight-item lists to participants for memorizing, and after a distracter task, cued recognition of items and their order took place separately. Three different presentation styles were used: Temporal, Spatial and Mixed. Items were presented against a white background with two concentric circles forming a circular frame divided into eight cells, see Figure 1. With the Temporal style of presentation, items were presented one at a time for one second each, at centre screen; with the Spatial style of presentation, items were presented simultaneously with one item per cell for eight seconds; and with the Mixed style of presentation, items were presented one at a time for one second each, starting in cell one and continuing to cell eight. Thus, with the Temporal style of presentation, the only organizational principle for items within a list related to temporal order; with the Spatial style of presentation, the only organizational principle for items within a list related to spatial relations and with the Mixed style of presentation, there were both temporal and spatial organizational principles.

Insert Figure 1 about here.

Eight unique lists were included for each presentation style. Thus, for each presentation style, 64 items were included, making an overall total of 192 different pictures. Two different list types were used: *distinct* lists containing items that displayed minimal semantic inter-item similarity (see Figure 1a) and *semantic* lists (see Figure 1 b) containing items that belonged to the same semantic category. Half the lists in each version were distinct and half were semantic. An additional eight-item training list of distinct items was prepared. Order of presentation style and list type was randomised.

Item recognition was cued by presenting items one by one at centre screen, surrounded by the presentation frame. For each list, a randomly selected five-item subset of the eight original list items were presented along with two novel items. Each recognition cue was visible on screen for 3 s or until the participant gave a correct response. If the cue was a target item, order recognition was then cued. In this case the target item remained visible on screen, now accompanied by a cross marking one of the cells of the presentation frame, for another 3 s, or until the participant correctly determined target order. For the spatial and mixed styles of presentation, target order was indicated when the cross marked the cell in which the target item was originally presented. For the temporal style of presentation, target order was indicated when the cross marked the cell equivalent to list position, for example, when the cross marked cell one for the first item on the list. Thus, order recall was cued for five items in each list. Overall for each condition, half of the crosses marked target cells. For half the lists in each version, recall was cued in cell number order and for the other half recall was cued in random order.

Distracter task. Between encoding and recall phases of the main task, a three-second visuospatial distracter task was administered. The purpose of this task was to prevent rehearsal during the retention phase of the main WM task. In the distracter task, a display of 20 rings (four rows of five rings each) was shown. Some of the rings (between three and seven) were formed by a solid line, whereas the others had a dotted line, see Figure 2. The task was to determine whether the number of rings with a solid line was even or not. Three seconds was allowed for the distracter task.

Insert Figure 2 about here.

Procedure

All participants performed the task with all three presentation styles in balanced order, and list presentation order within each presentation style was randomized. The stimuli were presented on a PC using Superlab software. Responses were given by pressing the “1” key for a positive response and the “0” key for a negative response. The participants were instructed to respond as accurately and as quickly as possible. A maximum of three seconds was allowed for each response. The experimenter was a native bilingual in Swedish Sign Language and Swedish and gave instructions in the appropriate language for both groups. Accuracy and latency was recorded automatically. The participants were tested singly. A self-paced training session preceded each of the three presentation styles. Participants determined rate of progress between lists individually.

Design

The design was a 3x2x2x2 split-plot design, for both item and order recognition. The within-group factors were presentation style (Temporal, Spatial, Mixed); list type (distinct, semantic) and recognition cue order (serial, random). The between-group factor was sensory and linguistic experience (EDS, EHN).

Data scoring and analysis

Responses and latency were registered automatically. Responses given outside the three seconds allowed were discounted. ANOVAs were computed for accuracy and latency for item and order recognition in the main task and accuracy in the distracter task for both groups.

Results

Main task

Item recognition. Out of the 10 items probed for the two replications of each 8-item list type, EDS recognized an average of 7.77 (s.e.m.= 0.26) and EHN recognized 8.52 (s.e.m.= 0.26). These scores were not significantly different. Item recognition performance for all three presentation styles by list type for the two groups is shown in Table 1. There was no main effect of presentation style. However there was an interaction between presentation style and group ($F(2,52) = 3.77$, $MSE = 2.28$, $p < 0.05$, *partial* $\eta^2 = 0.13$), which revealed significantly poorer performance with the temporal style of presentation ($t(52)=2.29$, $p < 0.05$) for EDS (M = 7.59, s.e.m. = 0.39) than for EHN (M = 8.89, s.e.m. = 0.39), see Figure 3, but not with either of the other two styles of presentation.

Item recognition performance was significantly greater when list items belonged to the same semantic category ($F(1,26) = 7.51$, $MSE = 1.57$ $p < 0.05$, *partial* $\eta^2 = 0.22$). This effect did not interact with presentation style or group.

EDS were significantly slower than EHN on item recognition ($F(1,26) = 9.06$, $MSE = 287273.47$, $p < 0.01$, *partial* $\eta^2 = 0.26$).

Insert Table 1 and Figure 3 about here.

Serial position effects. In order to further investigate differences in item recognition performance we computed serial position effects for the groups and different conditions in the primacy, asymptote and recency positions. To ensure comparability of the three positions primacy was based on average percentage correct for list items one and two, the asymptote on average percentage correct for list items four and five and recency on percentage correct performance for list items seven and eight. An ANOVA was computed with the within group factors Presentation style (Temporal, Mixed, Spatial), Cue order (Serial, Random), List type (Distinct, Semantic), Serial position (Primacy, Asymptote, Recency), and the between group factor Hearing and language status (EDS, EHN). This ANOVA showed a main effect of serial position ($F(2,52) = 6.28$, MSE = 0.06, $p < 0.01$, *partial* $\eta^2 = 0.20$) with significantly lower performance on the asymptote than on both primacy (MD = 0.06, $p < 0.05$) and recency (MD = 0.05, $p < 0.05$) but no significant difference between primacy and recency, see Figure 4. There was no two-way interaction between serial position and group ($F(2,52) = 0.59$, MSE = 0.06, $p = 0.56$, partial η2 = 0.02) but these two factors did interact with presentation style in a significant three-way interaction ($F(4,104) = 3.32$, MSE = 0.07, $p < 0.05$, *partial* $\eta^2 = 0.11$). Investigation of this interaction did not show any significant simple main effects relating to primacy, asymptote or recency with the Temporal style of presentation. Thus, there is no evidence of between-group differences in the primacy or recency effects relating to the Temporal style of presentation.

Insert Figure 4 about here.

Order recognition. On average, EDS recognized order correctly 3.60 (s.e.m. = 0.18) times out of the five times it was cued for the two replications of each 8-item list type, and the equivalent score for matched EHN was 4.03 (s.e.m. = 0.18). These scores were not significantly different. Order recognition performance for all three presentation styles by recognition cue order for the two groups is shown in Table 2. There was a main effect of presentation style ($F(2,52) = 15.03$, $MSE = 1.10$, $p < 0.001$, *partial* $\eta^2 = 0.37$), relating to superior performance with the Mixed style of presentation, (compared to the temporal (*Mean Difference* = 0.66, $p < 0.001$) and spatial (*Mean Difference* = 0.67, $p < 0.001$) styles of presentation (Bonferroni adjustment for multiple comparisons). A significant interaction between presentation style and group ($F(2,52) = 5.52$, $MSE = 1.10$, $p < 0.01$, *partial* $\eta^2 = 0.18$) showed worse performance with the temporal style of presentation ($t(52) = 2.34$, $p < 0.05$) for EDS (M = 3.14, s.e.m. = 0.21) than for EHN (M = 4.05, s.e.m. = 0.21), see Figure 5, but not with any of the other styles of presentation. EDS performed better with the Mixed style of presentation (M = 4.27, s.e.m. = 0.15) than with both the Temporal style of presentation (M = 3.14, s.e.m. = 0.21; $t(52) = 2.88$, $p < 0.01$) and the spatial style of presentation (M = 3.39, s.e.m. = 0.22; $t(52) = 2.24$, $p < 0.05$). HN showed no difference in performance across styles of presentation.

There was a main effect of recognition cue order ($F(1,26) = 7.22$, $MSE = 0.53$, $p < 0.05$, *partial* $\eta^2 = 0.22$) which showed that when order recognition cues were presented serially in the original order of presentation, this facilitated performance across presentation styles. This effect did not interact with group ($F(1,26) = 1.09$, $MSE = 0.53$, $p = 0.31$, *partial* $\eta 2 = 0.04$).

Insert Table 2 and Figure 5 about here.

There was no significant difference in response speed between EDS and HN on order recognition.

Distracter task

The mean response latency was 2043 ms (SD=79 ms). There was no difference in latency between groups and there was no main effect or interactions of any of the variables manipulated in the preceding main task. Mean accuracy was 1.52 (SD = 0.06) of a possible maximum score of two, and there was no difference in performance accuracy between the two groups. However, there was a main effect of list type in the preceding main task ($F(1,26) = 8.90$, $MSE = 0.34$, $p < 0.01$, *partial* $\eta^2 = 0.26$) with a greater mean accuracy when the items in the preceding lists were semantically similar (M=1.61; SD=0.06) than when they were distinct (M=1.42; SD=0.07).

Discussion

The main results of the present study were that the item and order recognition performance of EDS were inferior to that of EHN with the Temporal style of presentation, and that the order recognition performance of EDS, but not EHN, was inferior with both the Temporal and Spatial styles of presentation compared to the Mixed style of presentation. These findings suggest that temporal order processing in WM is organized differently for EDS and EHN and that style of presentation may be more crucial to WM performance in EDS than in HN.

In a previous study using the same paradigm, WM processing was investigated in a group of young adult deaf signers (Experiment 3, Rudner & Rönnberg, 2008a). That study showed that the performance of these young adult deaf signers was compromised with the Temporal style of presentation compared to that of age-matched hearing non-signers. However, the difference did not apply generally with this style of presentation to both item and order recognition, as was the case in the present study, but only under certain conditions: i.e. young adult deaf signers did not benefit to the same extent as hearing non-signers from presentation of recognition cues in the original presentation order, when it came to recognizing the order in which items were presented for memory encoding.

In the present study, we hypothesized that the relative performance pattern found for young adult deaf signers and hearing non-signers (Rudner & Rönnberg, 2008) would be maintained in elderly groups as language modality has previously proved to be a more potent force for reorganization of mechanisms in the explicit component of the ELU model (Rönnberg et al., 2008) and the neural architecture thought to support these mechanisms is not primarily organized in the frontal lobes which form part of the cerebral cortex that is particularly susceptible to age-related neural reorganization (Cabeza, 2002; Cabeza et al., 2004). However, the results of the present showed that, the pattern was reinforced with EDS showing a more extensive performance difference relating to the Temporal style of presentation applying not only to order recognition, as in the previous study (Rudner & Rönnberg, 2008a) but also to item recognition, where there was a decrement in both accuracy and latency. Order recognition is relatively independent from item recognition in the present study as feedback is given after the item recognition phase, and thus item and order recognition data reflect different underlying mnemonic mechanisms. Thus, the deficit in performance for EDS compared to EHN with the Temporal style of presentation suggests that memory encoding and not just maintenance and recall processes were affected. This is in line with recent work that has shown differential engagement of neural networks for the encoding, maintenance and recall phases of WM in deaf signers (Bavelier, Newman et al., 2008).

Further, EDS were worse at recognizing presentation order with both the Temporal and Spatial styles of presentation compared to the Mixed style of presentation, whereas EHN showed no difference in order recognition performance across styles of presentation. This finding suggests that EDS can be just as efficient in retaining temporal order information as EHN if the encoding conditions are favourable. With the Mixed style of presentation, to-be-remembered items are presented serially in a spatial array, thus both temporal and spatial information is available during encoding. With the Temporal style of presentation, only temporal information is available and with the Spatial style of presentation, only spatial information is available. Thus, it seems that if both temporal and spatial information are available at encoding, EDS can retain order information as well as EHN and better than if only temporal or only spatial information is available. This is in line with O'Connor and Hermelin (1973; 1976).

Examination of serial position curves showed classic bow-shaped serial position curves with characteristic primacy and recency effects (Murdock, 1974). There was no significant difference in the shape of the curves for the EDS and EHN. Previous work has shown that recency effects are modulated by the relationship between modality of presentation and preferred language that can be understood in terms of recoding to primary language modality (Bellugi, Klima & Siple, 1975; Hay, Smith, Hitch & Norton, 2007; Krakow & Hanson, 1985; Rönnberg, Archer & Ohlsson, 1980; Rönnberg, 1982; Shand & Klima, 1981; Smyth, Hay, Hitch & Norton, 2005). Thus, the similarity of the curves for EDS and EHN suggests that similar recoding from easily nameable pictures to primary language modality for both groups.

It has been proposed that serial order in WM is supported by a timing signal (Brown, Preece & Hulme, 2000; Henson, Hartley, Burgess, Hitch & Flude, 2003; Burgess & Hitch, 1999) and that the inferior parietal sulcus might play a key role here (Majerus et al., 2007). The inferior performance of EDS on order recognition with the Temporal style of presentation suggests that any such timing signal does not function in the same way as for EHN: specifically, temporal information has to be accompanied by spatial information for it to be used efficiently.

These findings support and extend previous behavioural findings showing that sign language users, both deaf and hearing do not process order information in WM in the same way as hearing non-signers (Bavelier, Newport et al., 2008; Boutla, Supalla, Newport & Bavelier, 2004; Geraci, Gozzi, Papagno & Cecchetto, 2008; Marschark & Mayer, 1998; O'Connor & Hermelin, 1973; 1976; Rönnberg et al., 2004; Rudner & Rönnberg, 2008a; Wilson, Bettger, Niculae & Klima, 1997; Wilson & Emmorey, 2003) The neuroimaging literature has also shown that although WM for sign language in both hearing (Rönnberg et al., 2004) and deaf (Bavelier, Newman et al., 2008; Buchsbaum et al., 2005; Pa, Wilson, Pickell, Bellugi & Hickok, 2008) signers is supported by neural networks similar to those in hearing non-signers, there is net engagement of the superior parietal cortex bilaterally for WM for sign language (Bavelier, Newman et al., 2008; Rönnberg et al., 2004) which may be related to retrieval processes (Bavelier, Newman et al., 2008).

Other findings show a certain reorganization of the left hemisphere in native signers in relation to the processing of moving objects and meaningful and non-meaningful actions (Bosworth & Dobkins, 2002; Bavelier et al., 2001; Brozinsky & Bavelier, 2004; Corina et al., 2007; Emmorey, 2008). This reorganization may conflict with neural mechanisms involved in processing the timing signal, leading to worse performance on tasks that challenge the timing mechanism.

Previous work has shown that individuals who are deaf from birth have superior attention processing abilities (Proksch & Bavelier, 2002), including faster reorientation of attention (Colmenero, Catena, Fuentes & Ramos, 2004) in the peripheral visual field but not ~~in~~ at the focus of attention. Thus, lower-level processing differences between deaf and hearing individuals may influence results of the present study relating to the Mixed and Spatial styles, where all items are presented at the periphery, but are unlikely to affect results relating to the Temporal style of presentation, where all items were presented at the focus of visual attention. This means that processing benefits relating to peripheral visual attention may play a role in order processing with the mixed style of presentation.

In the WM paradigm used in the present study, semantic similarity among list items was manipulated. Based on previous results (Rudner & Rönnberg, 2008a) we expected to find a facilitating effect of semantic similarity for item recognition for both groups, and this was exactly what we found in the present study. We argue that when WM representations based on easily nameable pictures include semantic category information, this can be used both as a cue in connection with memory retrieval and as a basis for organization of the content of WM. These findings support the notion of an episodic buffer in WM (Repovs & Baddeley, 2006) that, according to the WM model for ELU (Rönnberg et al., in press; Rönnberg et al., 2008) may function in a similar fashion irrespective of language modality.

Similarity in semantic processes between groups is further emphasized by the results of the analysis of the distracter task which showed that performance accuracy was greater for both groups when the to-be-remembered items in the preceding encoding phase of the main task were semantically similar, suggesting that facilitating effect of semantic similarity was freeing up WM capacity for the distracter task.

In order to clarify age-related similarities and differences in processing an ANOVA was performed using data from the present study and Experiment 3 in the study by Rudner & Räönnberg (2008)..

Reanalysis

Method

Participants

There were four groups of participants with 14 persons in each group. The groups consisted of the participants in the main study: elderly deaf signers (EDS) and elderly hearing non-signers (EHN); as well as the participants in Experiment 3 in the study by Rudner and Rönnberg (2008a): younger deaf signers (YDS) and younger hearing non-signers (YHN). There was a significant different in age between the older and younger groups ($t_{(54)}$ = 24.17, *p*

< 0.001). The groups were composed as follows: EDS, 9 women and 5 men; EHN, 10 women and 4 men; YDS, 9 women and 5 men; YHN, 4 women and 10 men. All deaf signers were profoundly deaf and used sign language as their preferred mode of communication and all were prelingually deaf. All hearing no~~i~~n-signers reported normal hearing and either had no knowledge of sign language or only a rudimentary knowledge.

The stimulus material, test, procedure and data analysis were as reported above.

Results

Main task

Item recognition. The general level of performance accuracy did not vary significantly with either hearing status or age. There was a main effect of presentation style ($F(2,104) = 4.29$, $MSE = 2.41$, $p < 0.05$, *partial* $\eta^2 = 0.08$), such that performance with the Spatial style of presentation was lower than with the Temporal style of presentation (*Mean Difference* = 0.42, $p < 0.05$) but not the Mixed style of presentation. However, there was no interaction with age and only a tendency towards an interaction with group ($F(2,104) = 4.29$, $MSE = 2.41$ $p = 0.08$). Investigation of this tendency did not reveal any significant different in performance between groups with any of the styles of presentation. Accuracy was superior when list items belonged to the same semantic category ($F(1,52) = 23.45$, $MSE = 1.37$ $p < 0.001$, *partial* $\eta^2 = 0.31$) and this effect was independent of hearing status and age. Deaf signers were slightly (140.71 ms), but significantly, slower than hearing non-signers on item recognition ($F(1,52) = 11.50$, $MSE = 289304.47$, $p < 0.001$, *partial* $\eta^2 = 0.18$). The difference in speed between older and younger participants was greater (437.30 ms; $F(1,52) = 111.05$, $MSE = 289304.47$, $p < 0.001$, *partial* $\eta^2 = 0.68$). These two effects did not interact with each other.

Order recognition. The level of performance did not vary significantly with hearing status or age. There was a main effect of presentation style ($F(2,104) = 19.42$, $MSE = 1.36$, $p < 0.001$, *partial* $\eta^2 = 0.27$), such that performance with the mixed style of presentation outstripped performance with both the temporal (*Mean Difference* = 0.55, $p < 0.001$) and the spatial styles of presentation (*Mean Difference* = 0.63, $p < 0.001$). However, there was no two-way interaction between this effect and either age or group. The lack of interaction between presentation style and group indicates that the generally poorer performance found in the main study for EDS on the temporal style of presentation did not generalize to YDS, and a three-way interaction between presentation style, age and group ($F(2,104) = 4.89$, MSE = 1.36, $p < 0.01$, *partial* $\eta^2 = 0.09$), confirmed that this effect was confined to EDS.

There was a main effect of recognition cue order (F(1,52) = 10.21, MSE = 0.53, p < 0.01, partial η2 = 0.16), showing better performance when recognition cues were presented in serial order. There was no two-way interaction between this effect and either age or group. However there was a three-way interaction between these factors (F(1,52) = 6.00, MSE = 0.53, p < 0.05, partial η2 = 0.10), showing that the effect of recognition cue order did not apply to YDS (serial: M = 3.61, s.e.m. = 0.20 ; random: M = 3.66, s.e.m. = 0.18) (c.f. Rudner & Rönnberg, 2008a).

There was only a tendency towards an effect of slowing for deaf signers compared to hearing non-signers ($F(1,52) = 3.42$, MSE = 680258.51, $p = 0.07$, *partial* $\eta^2 = 0.06$). However older participants were significantly slower than younger participants (238.30 ms; $F(1,52)$ = 14.02, MSE = 680258.51, $p < 0.001$, *partial* $\eta^2 = 0.21$). These two effects interacted ($F(1,52)$ = 4.02, MSE = 680258.51, $p < 0.05$, *partial* $\eta^2 = 0.07$). Although, there were no significant simple main effects in this interaction, earlier results (Rudner & Rönnberg, 2008a) showed slower performance for YDS than YHN, whereas the main analysis in the present study showed no difference in latency between EDS and EHN.

Distracter task

As in the main analysis, performance accuracy was superior when the distracter task followed a Semantic list in the main task ($F(1,52) = 5.80$, $MSE = 0.43$, $p < 0.05$, *partial* $\eta^2 = 0.10$). This effect did not interact with any other variable.

Discussion

The main result of the reanalysis was that the generally lower level of performance found for EDS with the Temporal style of presentation did not generalise to YDS. This suggests, that the ability of deaf signers to use temporal organization to support WM processing decreases with age and thus that the organization of the ELU model may change with age. Stenfelt and Rönnberg (in press) have argued that temporal order processing apart from being one of the functions of RAMBPHO, the episodic buffer in the ELU model (Rönnberg et al., 2008), may also be one of the modality-specific functions of the explicit component in the ELU model, as. P previous work has shown that modality-specific differences in WM emerge when explicit processing demands are high (Rönnberg et al., 2004; Rudner & Rönnberg, 2008a) and thus that they are related to the explicit component. Therefore, it is likely that the age-related effects revealed in the present study reflect changes in the explicit component of the ELU model.

The advantage in terms of order recognition found for EDS with the Mixed style of presentation generalized across all four groups, indicating that access to both temporal and spatial information enhances order processing for both deaf signers and hearing non-signers irrespective of age.

The reanalysis also demonstrated that the facilitating effect of semantic similarity among list items on accuracy of item recognition, and concomitant facilitation of the distracter task, is not modulated by age. This finding supports the ELU the model (Rönnberg et al., 2008) which postulates a common mechanism known as RAMBPHO for binding incoming information with information in long term memory irrespective of language modality, which is similar to the episodic buffer put forward by Baddeley (Repovs & Baddeley, 2006). It also extends the model by suggesting that this mechanism is stable over the lifespan.

Cognitive processes are modulated by age (Zacks, Hasher & Li, 2000) and processing speed decreases with age (Salthouse, 1996). Thus, it was no surprise that the older participants responded more slowly than the younger participants. However, caution should be exercised in interpreting interactions between the post-hoc age variable and the other variables manipulated in the study as the elderly deaf signers had a different educational experience from the younger deaf signers. In Sweden, and many other countries, the use of sign language by deaf people was restricted from the late nineteenth century up until the late 1970s, and during this period, deaf children were given oral training in schools (Fredäng, 2003). After 1981, when sign language was recognized as an official language in Sweden, deaf children were educated in their own native language, sign language. Thus, whereas EDS had received oral training in school, YDS had been taught in sign language. This means that although all the deaf signers included in the reanalysis used sign language as their preferred mode of communication and were prelingually deaf, there may be a confounding effect of early language experience.

Slow performance by the older groups on item recognition did not interact with hearing status, indicating that the underlying mechanisms are not affected by language modality. For order recognition, latency did interact with age showing that although elderly deaf signers are no slower than their hearing peers in responding during the order recognition phase of the task, the younger deaf signers are slower than the age-matched hearing group. This is not a floor effect, and suggests that the slower responses to the explicit task of recognizing presentation order found in YDS are not compounded by increasing age, suggesting that deaf signers may be resistant to some of the effects of cognitive slowing.

~~It has been suggested that age-related cognitive deficits may be related to deteriorating sensory function (Baltes & Lindenberger, 1997). One possible mechanism here is the proposed notion of disuse (Rönnberg et al., submitted) whereby reduced auditory acuity leads to fewer communicative opportunities and less access to long term memory, resulting in deterioration in long term memory function. Deaf individuals are not be affected by disuse in the same way, as their communication is not dependent on auditory acuity. Lack of evidence for cognitive deterioration in deaf individuals as a function of age in the present study provides indirect support for the disuse hypothesis.~~

Conclusion

We have shown that although elderly deaf signers have a similar general WM capacity to their hearing peers, they are poorer at exploiting the temporal organization of information in a WM task than both hearing non-signers and young adult deaf signers. This indicates that the neural mechanisms supporting the processing of temporal information in WM in deaf signers may become even less efficient with age, and that the ELU model may be subject to age-related change. Previous work has implicated the explicit component of the ELU model in temporal processing differences related to language modality (Rudner et al., in press; Stenfelt & Rönnberg, in press) and thus it is likely that temporal processing differences related to both age and language modality are a function of the explicit component.

The difference in temporal processing in WM for deaf signers may be related to reorganization of left-hemisphere motion processing systems as a result of early sign language experience. Temporal processing in WM has been proposed to be dependent on left-hemisphere systems (Majerus et al., 2007) which may be displaced as a result of reorganisation due to sign language use (Bosworth & Dobkins, 1999; Bosworth & Dobkins, 2002; Bavelier et al., 2001; Brozinsky & Bavelier, 2004; Corina et al., 2007; Emmorey, 2008). The results of the present study indicate that the effects of such reorganisation may be compounded by age.

The difference in temporal processing in WM shown by deaf signers was counteracted by the availability of concurrent spatial information. The enhancing effect of concurrent spatial information also applied to hearing non-signers. Thus, it may support learning in both hearing and deaf people to provide temporal and spatial cues simultaneously. Further, our investigation showed that semantic similarity among memorized items facilitated item, but not order, recognition for both deaf signers and hearing nonsigners, suggesting similar semantic binding processes in WM for signers and speakers, irrespective of age.

The findings of the present study support and extend the ELU model (Rönnberg et al., in press; Rönnberg et al, 2008) which postulates an amodal episodic buffer, RAMPHO, and an explicit component that may be organized differently for different language modalities. Specifically, results confirm the amodal nature of RAMBPHO and suggest that age as well as language modality may modulate the function of the explicit component.

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Figure and table captions

Figure 1. Stimulus configuration with examples of (a) Distinct list and (b) Semantic list.

Figure 2. Example of display used in the distracter task.

Figure 3. Item recognition performance for EDS and EHN.

Figure 4. Percentage of items correctly recognised at primacy, asymptote and recency positions.

Figure 5. Order recognition performance for EDS and EHN.

Table 1. Item recognition performance for the three presentation styles and with and without semantic similarity.

Table 2. Order recognition performance for the three presentation styles with serial and random cuing.

Figure 1.

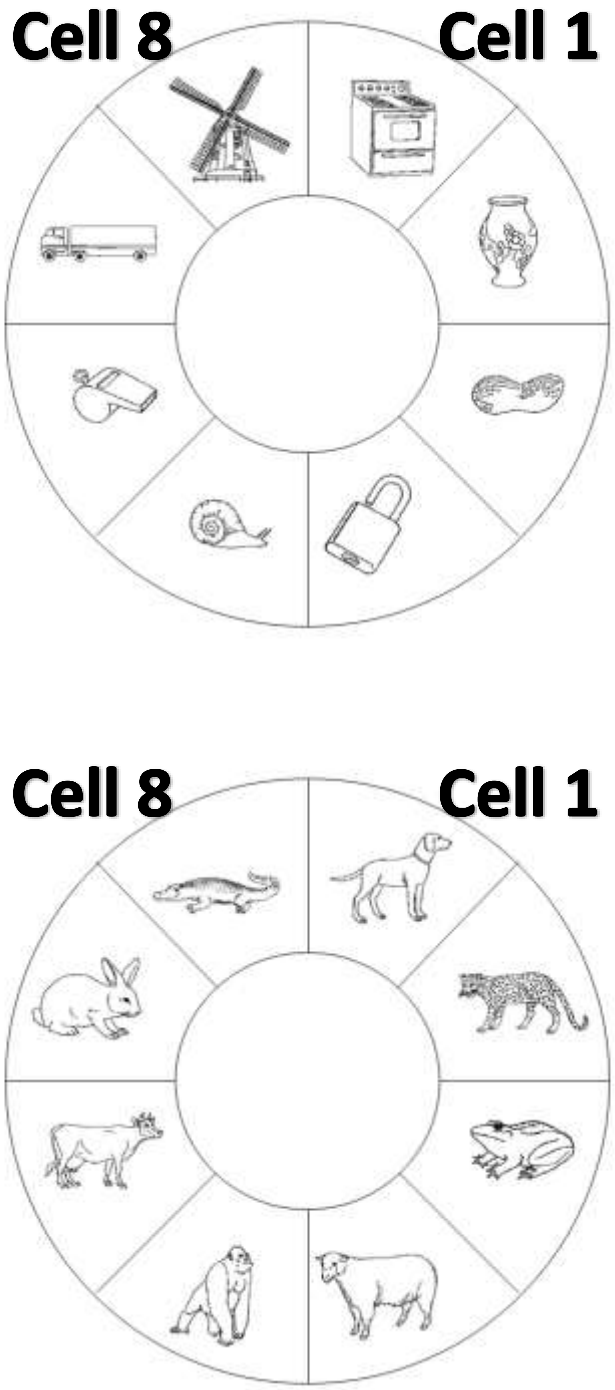

Figure 2.

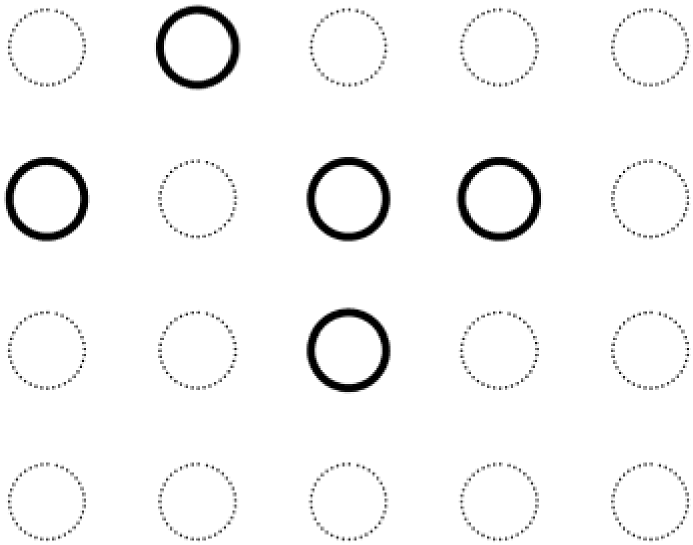

Figure 3.

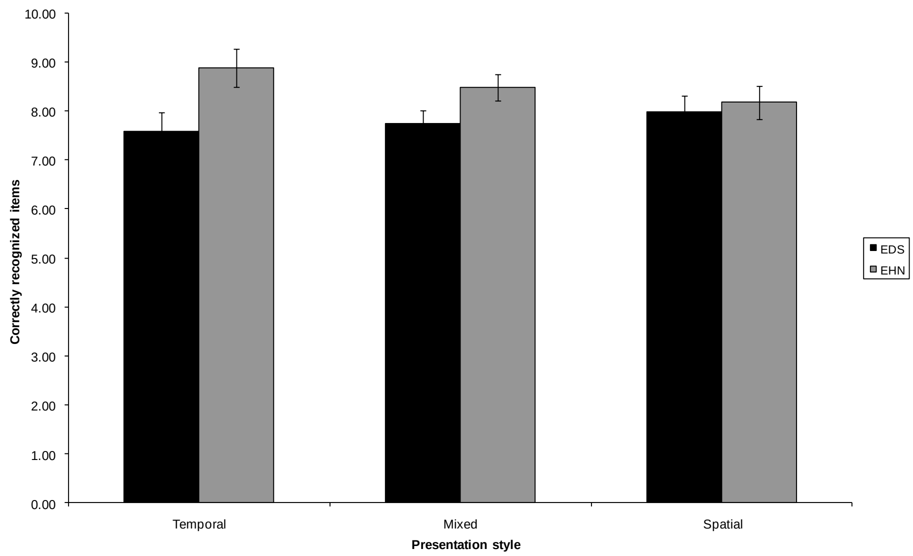

Figure 4

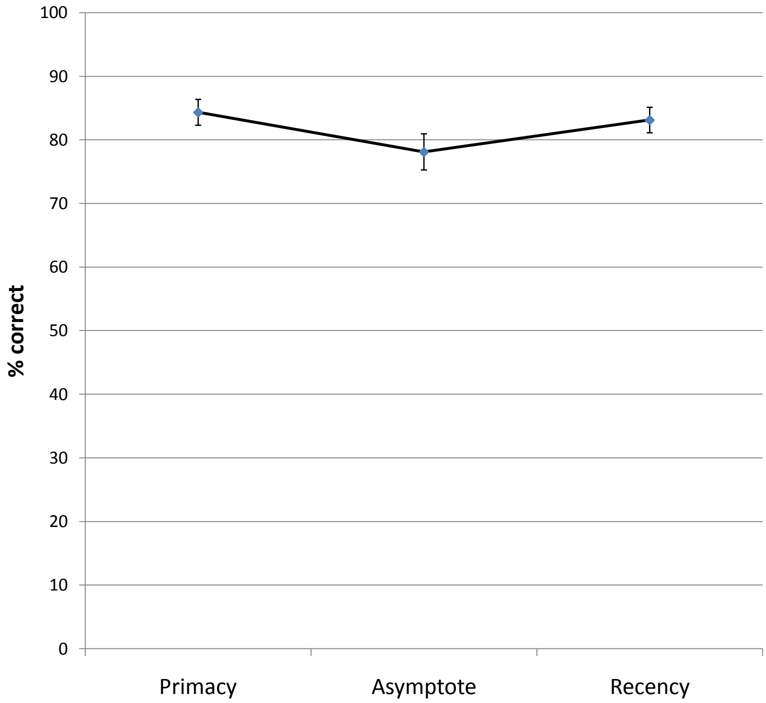

Figure 5

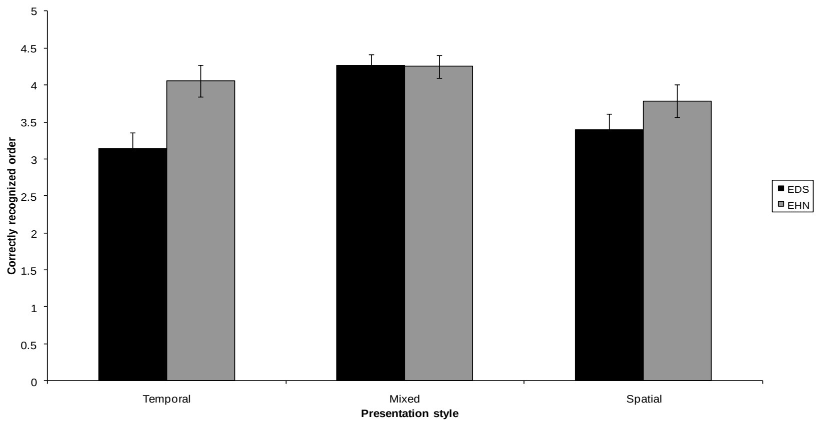

Table 1. Item recognition performance for the three presentation styles and with and without semantic similarity.

Presentation style	List type	EDS Mean (s.e.m.)	EHN Mean (s.e.m.)
Temporal	Distinct	7.50 (0.38)	8.50 (0.38)
	Semantic	7.68 (0.39)	9.29 (0.39)
Mixed	Distinct	7.64 (0.30)	8.18 (0.30)
	Semantic	7.86 (0.30)	8.79 (0.30)
Spatial	Distinct	7.89 (0.36)	8.04 (0.36)
	Semantic	8.07 (0.35)	8.32 (0.35)

Table 2. Order recognition performance for the three presentation styles with serial and random cuing.

Presentation style	Order of recognition cues	EDS Mean (s.e.m.)	EHN Mean (s.e.m.)
Temporal	Serial	3.32 (0.27)	4.04 (0.27)
	Random	2.96 (0.26)	4.07 (0.26)
Mixed	Serial	4.36 (0.21)	4.21 (0.21)
	Random	4.18 (0.24)	4.29 (0.24)
Spatial	Serial	3.57 (0.26)	4.04 (0.26)
	Random	3.21 (0.24)	3.54 (0.24)