Short-term memory processes and reading by deaf children

Mairéad MacSWEENEY *

* Department of Human Communication Science,
University College London.
UCL, London, UK.
E-mail : m.macsweeney@ucl.ac.uk

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Over the last 10 years our understanding of the short-term memory (STM) codes and processes used by hearing children has increased dramatically. In contrast, relatively little is known about the development of these processes in deaf children. This paper explores the development of these processes. In particular the relationship between the use of STM codes and reading ability of deaf children will be discussed.

A series of experiments are reported that test ordered recall of pictures by deaf children. Concurrent activity and recall of stimuli that are similar along different dimensions (e.g. speech, sign and visually similar) are used to tap the nature of underlying STM codes used in this task. The results show that a variety of STM codes are used in a variety of combinations. Reading ability was consistently related to overall STM performance and to some indicators of the use of a speech-based STM code. The nature of these relationships will be discussed.

Processus de mémoire à court terme et lecture chez les enfants sourds

Au cours des dix dernières années, nos connaissances des codes et des traitements utilisés par les enfants entendants en mémoire à court terme (MCT) se sont développées de façon importante. En comparaison, on sait relativement peu de choses sur le développement de ces processus chez les enfants sourds. Dans cette communication, j'explorerai le développement de ces processus. Plus particulièrement, je discuterai de la relation entre l'utilisation de codes de MCT et l'habileté de lecture des enfants sourds.

Je rapporterai une série d'expériences qui sont basées sur le rappel sériel d'images par les enfants sourds. Pour mettre en évidence la nature des codes de MCT utilisés dans ces tâches, j'ai utilisé des activités concurrentes et le rappel de stimuli présentant des similitudes selon certaines dimensions (phonologique, signée et visuelle). Les résultats montrent qu'un ensemble de codes de MCT sont utilisés dans une variété de combinaisons. Le niveau de lecture est systématiquement lié à la performance globale de MCT et à certains indicateurs de l'utilisation d'un code phonologique en MCT. La nature de cette relation sera discutée.

SHORT-TERM MEMORY PROCESSES AND READING BY DEAF CHILDREN

In hearing children, short-term memory (STM) ability is related to a range of cognitive tasks such as learning to read, reading complex text and arithmetic skills (see Gathercole & Baddeley, 1993). One of the sources of evidence for this relationship comes from research with special populations. Numerous studies have shown that developmental dyslexics have poor memory spans (e.g., Jorm, 1983; Snowling, 1991). The same relationship has also been observed in deaf children. For example Hanson, Liberman and Shankweiler (1984) showed that letter recall by poor deaf readers was poorer than that of good deaf readers matched on non-verbal IQ. The fact that both reading ability and STM ability of the average deaf child is poorer than that of their hearing peers makes the relationship between STM skill and other cognitive skills in deaf children an important area of research.

Delay in reading ability of deaf children is reflected in the finding that the average reading age of a deaf school leaver is around nine-years (Conrad, 1979). With regard to STM, deficits in immediate recall by deaf children in comparison to hearing chronological age-matched peers have been found for linguistic stimuli, such as digits (e.g., Blair, 1957; Pintner & Patterson, 1927), printed words (e.g., Hanson, 1982; Krakow & Hanson, 1985) and pictures (e.g., Campbell & Wright, 1990). In contrast, deaf and hearing children do not differ on other STM tasks, such as recall of non-linguistic (unnamable) stimuli, such as unfamiliar faces (e.g., O'Connor & Hermelin, 1973) and spatial arrays of lights (Tomlinson-Keasey & Smith-Winberry, 1990). By establishing the nature of STM functioning in children, the possibility of specifying the precise relationship between STM and other cognitive skills is enhanced. This short paper will briefly describe a study which explores the nature of STM processing by deaf teenagers.

Short-term memory refers to a system that is thought to be resource limited and required for temporary storage and processing of information (see Baddeley, 1990). The classic example of the use of STM in everyday life is that of remembering a new phone number. Most hearing people would represent this within STM using a speech-based code or 'inner voice'. Rehearsal is then used to refresh this representation, without which it would decay after about two seconds. STM is traditionally measured by testing immediate recall of a series of stimuli. The subject may be presented with a sequence of words and then asked to write down the words they saw in the correct order (serial order recall). When the stimuli to be recalled are spoken or written words hearing children from a very young age represent these items in STM using a phonological code based on speech. However namable pictures are represented pictorially or visually by hearing children until approximately seven-years when they start to verbally label these visual stimuli using internal rehearsal (for summary see Gathercole & Baddeley, 1993).

The use of this speech-based code has been identified as a possible locus of the relationship between STM ability and reading ability in hearing children, since it is thought to underlie both processes (for discussion see Goswami & Bryant, 1990). However this is just one proposal and the direction of causality between STM skill and performance on cognitive tasks is still a matter of debate. Memory span may have a direct effect on reading skill, alternatively reading may affect memory span. It is also possible that there is a reciprocal relationship between the two skills. However the explanation that this relationship is mediated by a third independent factor, such as the use of a speech-based STM code has received much support. The focus of this paper is to address whether the same explanation may apply to the reading/ STM relationship in deaf children.

Before exploring this relationship it is necessary to briefly consider the nature of a speech-based code for a deaf child. The *precise* nature of this code is unclear, although it is generally considered to be amodal, deep or 'abstract' (e.g., Leybaert, 1993). The use of such a code is not necessarily dependent on audition and can be established purely from the visual aspects of speech (Dodd, 1976). Thus a speech STM code, which is mainly based on non-auditory aspects of speech such as lip-reading, self articulation and on information derived from orthography, may function in the same way as a STM code used by hearing people where the main source of information is auditory speech. This position is supported by Dodd, Hobson, Brasher and Campbell (1983) who showed that recency in recall of lip-read digits by deaf and hearing teenagers was impaired by a phonological suffix (mouthing a number) but not a non-phonological suffix (tongue-protrusion). Therefore lip-read and heard speech appear to be processed in the same way in STM. Recent neuro-imaging data lend further support to this position. Auditory cortices are used to process seen speech alone in the absence of audition, suggesting that lip-read and heard speech is processed similarly regardless of the modality of delivery (Calvert et al, 1997; MacSweeney et al, 1999). However, it is likely that the *quality* of speech-based representations based only on the visual aspects of speech may differ from those based on audio-visual input. Lip-reading alone, in the absence of audition and cued speech, cannot convey all of the phonological aspects of speech even if this is supported by orthographic knowledge (see Leybaert, 1993, for a discussion of cued speech).

Whatever the precise nature of this speech-based code, few studies have clearly demonstrated the use of a speech-based code by deaf *children* in a STM task. Campbell and Wright (1990) showed that word recall by deaf teenagers was poorer for long words than short words. This word length effect is considered to be a signature of speech-based STM coding because it is assumed that fewer long words than short words can be rehearsed in the same amount of time. However this effect was only evident when a *spoken* response was required suggesting this may have been a function of response modality. Hanson (1982; 1990; Hanson, Liberman & Shankweiler, 1984) has been successful in identifying the use of speech-based coding by deaf college students in a number of studies. Deaf participants were poorer at recall of similar sounding words (e.g., ball, wall, tall) than dissimilar words. This is considered to be indicative of speech-based coding. As STM representations decay over time the number of distinguishing features of similar sounding stimuli is reduced, therefore the words become confused within STM and recall of temporal order is poor. However, the majority of Hanson's studies involved deaf college students, and the results may therefore be limited to this exclusive sample of the deaf population.

To explore the extent to which Hanson's findings extend to another section of the deaf population we have recently investigated the use of speech-based STM coding by deaf teenagers of normal attainment within the deaf schooling system (for full details of this study see MacSweeney, 1999). Conrad (1979) investigated the use of speech-based STM coding by deaf teenagers by testing their recall of similar sounding words. He found that around half the subjects with hearing losses greater than 85dB used a speech based code in a STM task. The majority of subjects tested by Conrad attended oral schools for the deaf. However, since Conrad's study many schools for the deaf in the UK have incorporated sign language into the education of deaf children. This resulted in what is termed *total communication* (TC), a combination of both sign and speech. Conrad (1979) proposed that an important influence on a deaf child's use of a speech-based STM code was the quality of their *external* speech. Therefore, it could be hypothesised that pupils attending a TC school are less likely to use a speech-based STM code than their peers attending an oral school because less attention is paid to the use of speech in their educational setting. To address this we compared congenitally, severely/profoundly deaf teenagers attending TC and oral schools on their use of STM codes. The use of a STM code based on sign language was also explored. The participants in the TC and oral groups were matched on chronological age, reading age, hearing loss and non-verbal IQ. Hearing chronologically age matched and reading age matched controls were also tested.

This experiment extended previous studies by Hanson and Conrad by testing recall of *pictorial* stimuli rather than printed English words. Previous studies have shown that the modality of presentation may influence the type of STM code used by deaf people: written words are likely to be recalled using a speech-based code whereas sign stimuli are likely to be recalled using a sign-based code (Hanson, 1982). We tested recall of pictorial stimuli to explore the STM representations used *spontaneously* by deaf teenagers rather than those that may be induced by the choice of stimulus modality. Subjects were required to recall a series of six pictures of concrete items on each trial. Modality of recall can also influence the use of STM codes (Campbell & Wright, 1990). Therefore in this study deaf pupil's recalled items in their preferred mode. Oral deaf subjects used a spoken response and some also signed the name of the item. Most deaf TC subjects signed their response and simultaneously produced the English mouth pattern for the word. These stimulus and response modalities were chosen so that participants would not be directed towards certain coding strategies. In addition these steps made the STM task more accessible to the deaf participants since they were not required to read stimuli or write their responses which may have placed them at a disadvantage relative to their hearing peers given their generally poorer literacy levels.A further step was taken to make the STM task more accessible to deaf teenagers. As in a traditional serial order recall task, the stimuli were all presented in the same location. However, they were then placed face down on a table to form a spatial array. This technique has often been used with young hearing children to aid ordered recall (e.g., Hitch, Halliday, Schaafstal & Schraagen, 1988; Hitch, Halliday, Schaafstal & Heffernan, 1991). The subject was then able to point to the cards to indicate order during recall. The spatial element included in this task is thought to be negligible as all items are *presented* at the same location.

The use of sign and speech-based codes by deaf teenagers was investigated in this ordered recall task using concurrent linguistic tasks. Concurrent tasks require a subject to articulate an irrelevant word or sign during the presentation of stimuli to be recalled. In terms of the working memory model (see Baddeley & Hitch 1974; Baddeley, 1990), concurrent speech is thought to recruit the part of the system responsible for subvocal rehearsal. Thus, specific disruption from concurrent speech is thought to be indicative of the use of a speech-based STM code. Similarly disruption from concurrent signing is thought to be indicative of sign-based coding. However, requiring a person to perform a secondary task during the presentation of a series of pictures to be recalled should also recruit *general* cognitive processing resources. To control for this, a non-articulatory concurrent task, foot tapping, was included in the experiment which should not disrupt any form of linguistic recoding. If a speech-based code is used, recall should be impaired by concurrent speech to a greater extent than by concurrent foot tapping. Subjects were tested on recall of pictures in the following conditions:

- Baseline (no concurrent task)
- Foot tapping - continuous tapping of each foot alternately, left then right (to control for general cognitive demands).
- Concurrent signing - repeating the British Sign Language sign BECAUSE (to disrupt sign-based STM coding)
- Concurrent speech - repeating aloud 'because, because,....' (to disrupt speech-based STM coding).

There was no difference in the pattern of recall between deaf teenagers attending oral schools and those attending TC schools. These results extend the findings of Lichtenstein (1985) who showed that deaf college students who had attended either TC or oral schools did not differ in reading ability or the use of a speech-based STM code. It appears that the communication system used in a deaf child's educational setting has little effect on their use of STM codes and overall immediate recall performance.

In contrast to many previous studies recall by deaf teenagers in the baseline condition of the current study was equivalent to that of their hearing chronological-age matched peers. Thus the changes to the design of the traditional serial order recall task that were adopted in this study appear to have been successful in making the task more accessible to deaf participants.

Recall by deaf and hearing participants did differ however across the different concurrent tasks. Recall by hearing teenagers was impaired by concurrent speech but by no other concurrent task, indicating the use of speech-based coding. In contrast, recall by the combined deaf teenage groups was poorer during all concurrent task conditions in comparison to the baseline condition. This suggests that for these subjects all concurrent tasks involved a large central executive component due to their general cognitive processing demands. These data also suggested a *specific* effect of concurrent speech on recall in comparison to the non-articulatory, foot-tapping, task [1] . This effect of concurrent speech can be considered evidence for the use of a speech-based code by these deaf teenagers. However, this effect was weak in comparison to hearing controls. This suggests that for some subjects at least this speech-based code may be underspecified. That is, the phonological representations on which they are based may not be fully defined.

The effect of concurrent signing in this study did not suggest that a sign-based STM code was used routinely by deaf subjects. Recall in the concurrent signing condition was significantly poorer than in the baseline condition but did not differ from the non-articulatory, foot tapping, control condition. There are three possible explanations for this:

- The effect of concurrent signing may be due to general cognitive interference.
- A sign-based code may be qualitatively different in nature to a speech-based STM code used by hearing people. If so, testing for the use of this code using a task that has been adapted from speech-based research may be inappropriate.
- Concurrent signing may impair sign-based STM coding, which functions in the same way as a speech-based code, but this may only have been used by a subset of subjects, or sporadically by deaf subjects on some but not other trials.

The explanation that only a subset of subjects may have used a speech-based code was supported by a further experiment with deaf *adults* (see MacSweeney, 1999). Only recall by those deaf adults who were native deaf signers was impaired by concurrent signing. Although the number of native signers in the adult group was small, this pattern of findings is supported by Wilson and Emmorey (1997; 1998; under review). The majority of the subjects tested by Wilson and Emmorey were deaf native signers. They found evidence for the extensive use of a sign-based STM code by these subjects. This suggests that early and extensive exposure to sign language may be necessary to support the use of a sign-based STM code.

With regard to overall STM ability, as with previous studies there was a positive correlation between STM ability and reading age ($r(21)=.44$, $p<.05$). The higher the subject's reading age the more items they recalled in the baseline STM condition. The relationship between speech-based coding, as measured by susceptibility to concurrent speech, and reading age also approached significance ($r(21)=.39$, $p=.07$).

[1] However, this was of borderline significance ($p=.007$) given an adjusted significance level for multiple comparisons (alpha=.005).

In summary, this study supports the proposal, presented at the beginning of this paper, that there is a relationship in deaf teenagers between reading ability, STM ability and the use of a speech-based STM code. However, establishing the direction of the relationships between these variables is more problematic and not possible from the study briefly discussed here. A further issue that remains unresolved is why some deaf subjects develop more efficient speech-based coding than others. A number of subject characteristics are known to be related to the use of a speech-based STM code, such as degree of deafness, age of onset of deafness, non-verbal IQ, speech intelligibility and family support. However, these variables do not explain the complete variance in the use of this code (see Dodd & Murphy, 1992). Further research is necessary to determine the precise conditions under which a speech-based STM code develops. Furthermore, although the use of a sign-based STM code has been identified with some deaf adults its relationship to higher level cognitive skills such as reading has not been fully explored. These may be useful areas of future research to help aid our understanding of how deaf children may successfully access written language.

References

Baddeley, A. D. (1990). Human Memory: Theory and Practice. Hove: Lawrence Erlbaum Associates.

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. Bower (Ed.), Recent advances in learning and motivation (Vol. VIII, pp. 47-90). New York: Academic Press.

Blair, F. X. A. (1957). A study of the visual memory of deaf and hearing children. American Annals of the Deaf, 102, 254-263.

Calvert, G.A., Bullmore, E.T., Brammer, M.J., Campbell, R., Williams, S.C.R, McGuire, P.K., Woodruff, P.W.R., Iversen, S.D., & David, A.S. (1997). Activation of auditory cortex during silent speechreading. Science, 276, 593-596.

Campbell, R., & Wright, H. (1990). Deafness and immediate memory for pictures: Dissociations between 'inner speech' and the 'inner ear'. Journal of Experimental Child Psychology, 50, 259-286.

Conrad, R. (1979). The Deaf Schoolchild. London: Harper and Row.

Dodd, B. (1976). The phonological systems of deaf children. Journal of Speech and Hearing Disorders, 41, 185-198.

Dodd, B., & Murphy, J. (1992). Visual thoughts. In R. Campbell (Ed.), Mental Lives (pp. 47-60). Oxford: Basil Blackwell Ltd.

Dodd, B., Hobson, P., Brasher, J., & Campbell, R. (1983). Deaf children's short-term memory for lip-read, graphic and signed stimuli. British Journal of Developmental Psychology, 1, 353-364.

Gathercole, S. E., & Baddeley, A. D. (1993). Working Memory and Language. Hove: Lawrence Erlbaum Associates.

Goswami, U. C., & Bryant, P. E. (1990). Phonological Skills and Learning to Read. Hove: Lawrence Erlbaum Associates.

Hanson, V. L. (1982). Short-term recall by deaf signers of American Sign Language: Implications of encoding strategy for order recall. Journal of Experimental Psychology: Learning, Memory and Cognition, 8, 572-583.

Hanson, V. L. (1990). Recall of order information by deaf signers: Phonetic coding in temporal order recall. Memory and Cognition, 18 (6), 604-610.

Hanson, V. L., Liberman, I. Y., & Shankweiler, D. (1984). Linguistic coding by deaf children in relation to beginning reading success. Journal of Experimental Child Psychology, 37, 378-393.

Jorm, A. F. (1983). Specific reading retardation and working memory: a review. British Journal of Psychology, 74, 311-342.

Krakow, R. A. & Hanson, V.L. (1985). Deaf signers and serial recall in the visual modality: memory of signs, fingerspelling and print. Memory and Cognition, 13, 265-272.

Leybaert, J. (1993). Reading in the deaf: The roles of phonological codes. In M. Marschark & M. D. Clark (Eds.), Phonological Perspectives on Deafness (pp. 269-309). New Jersey: Lawrence Erlbaum Associates.

Lichtenstein, E. (1985). Deaf working memory processes and English language skills. In D. S. Martin (Ed.), Cognition, Education and Deafness: Directions for Research and Instruction (pp. 111-114). Washington: Gallaudet College Press.

MacSweeney, M., Amaro, E., Calvert, G., Campbell, R., David, A.S., McGuire, P., Williams, S., Woll, B. & Brammer, M. (1999). Activation of auditory cortex by silent speechreading does not require scanner noise: an event-related fMRI study. Neuroimage, 9 (6, part 2), S1064.MacSweeney, M. (1999). The development of short-term memory in deaf children. Unpublished Ph.D. Thesis. University College London.

O'Connor, N., & Hermelin, B. M. (1973). Short-term memory for the order of pictures and syllables by deaf and hearing children. Neuropsychologica, 11, 437-442.

Pintner, R., & Patterson, D. G. (1917). A comparison of deaf and hearing children in visual memory for digits. Journal of Experimental Psychology, 2, 76-88.

Snowling, M. (1991). Developmental reading disorders. Journal of Child Psychology and Psychiatry, 32, 49-77.

Tomlinson-Keasey, C., & Smith-Winberry, C. (1990). Cognitive consequences of congenital deafness. The Journal of Genetic Psychology, 151, 103-115.

Wilson, M., & Emmorey, K. (1997). The Visuo-Spatial 'phonological loop' in Working Memory: Evidence from American Sign Language. Memory and Cognition, 25 (3), 313-320.

Wilson, M., & Emmorey, K. (1998). A 'word length effect' for sign language: Further evidence for the role of language in structuring working memory. Memory and Cognition, 26 (3), 584-590.

Wilson, M., & Emmorey, K. (Under review). An 'irrelevant sign effect' in working memory for sign language.