The development of short-term memory in deaf children

Mairéad Finola MacSweeney

Department of Psychology, University College London

Submitted for the degree of Doctor of Philosophy, October 1998.
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Abstract

Deaf people do not have full access to the auditory component of spoken language. This thesis tackled the question 'what impact does this have on their STM representations and overall STM performance?' Also, how does impoverished exposure to auditory spoken language affect the development of STM coding and STM ability? To answer these questions deaf subjects of different ages were tested on immediate recall of pictures in a variety of paradigms.

Recall by deaf teenagers, but not deaf adults, was impaired by non-articulatory concurrent tasks. It is argued that this indicates a delay in the development of central executive processes in deaf people. There was evidence for the use of multiple STM codes. Young deaf children (eight-year-olds), like their hearing RA controls, used a visual STM code. This code was also used by deaf teenagers but was supplemented by the use of a speech-based code, which was also used by deaf adults. However, there was no evidence for the widespread use of sign-based coding in these studies. The use of a speech-based STM code and overall STM ability were closely related to reading age, both at the individual level (correlational analyses) and at the group level (in comparison to RA controls). Speech rate and sign rate were also related to these skills. Deaf people did not use this code as efficiently as hearing people. Nevertheless, speech-based coding was widely used by deaf readers, even when the task demands did not necessitate its use.

Finally deaf, but not hearing, children were better at recall of still pictures of 'dynamic' concrete items than static items. It is argued that variation in early experiences of deaf and hearing children leads to subtle differences in semantic organisation, which are reflected in STM performance.
Acknowledgements

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Extended abstract

The dominant form of representation used in short-term memory (STM) by hearing people is a code based on the phonological and/or phonetic aspects of speech. Deaf people do not have full access to the auditory component of spoken language. This thesis tackled the question - what impact does this have on their STM representations and overall STM performance? Also, how does impoverished exposure to auditory spoken language affect the development of STM coding and STM ability?

Chapter 1 describes some factors that affect the early life experiences of deaf children. These include audiological and aetiological factors and language experience at home and at school. Exposure to the auditory component of spoken language can vary greatly between deaf children depending on the aetiology, type, age at onset, degree and quality of the deafness. These factors were controlled as far as possible in this thesis by only selecting subjects with congenital or prelingual sensori-neural deafness and who were severely or profoundly deaf. The language experience of deaf children can also vary greatly depending on age at diagnosis, parental hearing status and the language approach used in the home and at school. A consideration of these factors indicates that the majority of deaf children do not experience adequate language exposure to sign or speech in the early years critical to language development. This is likely to have a substantial impact on subsequent development of linguistic cognitive skills, including linguistic STM.

Chapter 2 outlines linguistic STM processing by hearing people. The working memory model (Baddeley & Hitch, 1974; Baddeley, 1986) is described in some detail since this is used as the theoretical framework for the experiments reported in this thesis. The development of STM coding in hearing children is also described. There is now substantial evidence indicating that hearing children initially represent pictorial stimuli in a visual STM code and only start to use a speech-based STM code to represent these stimuli at around seven-years-old. Consideration of the
pattern of STM code use by hearing children allows predictions to be made regarding the use of these codes by deaf children which is the main concern of this thesis.

Chapter 3 reviews studies that have explored the use of STM codes by deaf people. In particular the use of visual, speech and sign-based STM codes are considered. In summary, there appears to be evidence for the use of all these types of STM codes. Which type of code is used can depend on subject characteristics and task demands. For example, a speech-based code is more likely to be used to recall printed English stimuli than a sign-based code. Similarly, the only evidence for the use of a sign-based STM code has come from studies that have used sign stimuli. A number of questions are raised by this consideration of the literature, which are addressed in this thesis.

Whether deaf children have a general deficit in the immediate recall of linguistic stimuli or a specific deficit in serial ordered recall is unclear. Experiment 1 in Chapter 4 addresses this question. Here deaf teenagers and hearing RA and CA controls are tested on serial ordered recall and free recall of pictures. The results suggest that deaf people do have a specific deficit in recall of ordered linguistic stimuli. When recall of order was not required performance by deaf teenagers fell between that of hearing RA and CA controls, but did not differ significantly from either group.

Chapters 5 and 6 test deaf subjects’ STM coding for pictorial stimuli under two paradigms. Subjects were first requested to perform concurrent linguistic and non-linguistic tasks during presentation of the stimuli. Pilot studies are reported in the first part of Chapter 5 that establish the level of difficulty for the non-articulatory concurrent task, included to control for the central executive demands of the linguistic concurrent tasks. There was substantial use of speech-based STM coding, as indicated by the disruptive effect of concurrent speech on recall, by deaf teenagers (Experiment 2) and deaf adults (Experiment 3). Evidence for the use of sign-based STM coding was scarce. It is possible that a small subgroup of deaf adults used a sign-based STM code in this task to supplement a weak speech-based STM code. Experiment 2b explored the characteristics of deaf subjects that were related to overall STM ability and the use of different STM codes. The strongest correlates of STM performance
were reading ability and speech rate and sign rate. These factors were also related to the use of a speech-based code, though to a lesser extent than STM ability.

In Experiment 5 (Chapter 6) the use of speech and sign based codes was explored using a different methodology. Subjects were required to recall pictorial stimuli, which could vary in visual, sign name or spoken name similarity. The main aim of this experiment was to establish the nature of the developmental progression in the type of codes used in STM by deaf children. Therefore different age groups of deaf children (eight- and fourteen-year-olds) and appropriate hearing control groups were tested. Again performance by deaf groups was similar to that of their hearing RA controls. The data suggested that deaf eight-year-olds used a visual code alone whereas deaf teenagers used both visual and speech-based codes. Again there was no evidence for the use of a sign-based code by these subjects.

Despite similarities between deaf subjects and their RA controls in Experiments 1, 2 and 4, Experiment 5 (Chapter 6) tested one aspect of STM performance in which differences were predicted. Given differences in the early environments of deaf children it was predicted that the special semantic salience of perceived object movement in a deaf child's world would lead to richer LTM representations for items that had dynamic properties. Young deaf children and hearing CA and RA controls were tested on recall of pictures of objects that were rated as having high or low dynamic potential. Recall of 'dynamic' stimuli by deaf children was better than their recall of 'static' stimuli. In contrast, hearing controls showed no difference between their recall as a function of this variable. This finding underlines the importance of considering the impact of long-term semantic knowledge on immediate recall and that subtle differences in semantic organisation between deaf and hearing children may be reflected in their STM performance.

Chapter 7 summarises the findings of this thesis. A speech-based phonological code was widely used by deaf teenagers and adults in the STM tasks reported here. Furthermore, the use of this code and overall STM ability were related to reading ability. Speech rate and sign rate also correlated with STM ability. It was proposed that these relationships indicate the importance of long-term phonological representations to STM performance. In addition the finding that semantic knowledge
can influence STM performance also supports the consideration of long-term knowledge when considering STM performance of deaf children, as has recently become more fully realised in research with hearing children. The important consideration therefore is how deaf and hearing children may differ in their long-term semantic and phonological representations.

The final part of Chapter 7 discusses possibilities for future studies that address the limitations of those reported here. In addition, the necessity of developing appropriate tools to assess the long-term phonological knowledge of deaf children (both sign and speech-based) is discussed.
Chapter 1

1.1 Introduction

Over the last ten years our understanding of the development of short-term memory (STM) processes in hearing children has increased substantially (see Gathercole, 1998). It is now realised that there is a strong relationship between STM skills and aspects of language processing such as learning to read (Gathercole & Baddeley, 1993). This relationship has also been identified in deaf children (Conrad, 1979). However, deaf children’s proficiency in language processing domains is typically poor. Compared with hearing peers deaf children have poor memory spans for linguistic stimuli (e.g., Blair, 1957; Campbell & Wright, 1990; Hanson, 1982; Krakow & Hanson, 1985; Pintner & Paterson, 1917; Waters & Doehring, 1990). They are also delayed in vocabulary development (e.g., Griswold & Commings, 1974) and reading development (e.g., Harris & Beech, 1995; Harris & Beech, 1998), demonstrated by the finding that the majority of deaf children leave school with a reading age of around nine-years-old (e.g., Conrad, 1979). The link between STM and fundamental language processing skills makes the study of STM processing by deaf children an important area of research. The aim of this thesis is to develop a richer understanding of STM processing by deaf children. A particular area of focus is how deaf children represent information within STM.

This chapter outlines the factors that affect the early life experiences of deaf children. A consideration of these factors allows some insight into the world of a deaf child and the immense impact that deafness can have on all aspects of life, including parent-child interaction, family dynamics, early socialisation and cognitive, social and emotional development. In particular, factors likely to affect their preferred way of representing information in STM are discussed. Those I will consider are:
Chapter 1

- audiological and aetiological factors
- early language experience at home and at school

1.2 Audiological and aetiological factors

It is estimated that 6.6 percent of the UK population under 60-years-old have some degree of hearing loss (RNID, 1997). This thesis is concerned only with a small sub-sample of this group. All deaf participants had a congenital/prelingual, severe/profound, sensorineural hearing loss. In addition, no deaf participant had any additional disability and all had hearing parents. Each of the following audiological and aetiological factors will now be discussed in detail:

- type of deafness
- aetiology of sensori-neural deafness
- age of onset of deafness
- quality and degree of deafness

1.2.1 Type of deafness

Deafness can result from damage to different parts of the auditory apparatus and its consequences are different depending on the site of impairment. Conductive deafness refers to any condition in which the transfer of sound from the outer and middle ear to the inner ear is impaired. This can be caused by structural damage to the outer or middle ear and also by middle ear disease or otitis media. Otitis media prevents the eardrum and ossicles in the middle ear from vibrating freely and therefore impairs the transfer of sound. Conductive losses are usually ameliorated either by amplification or surgery. In contrast, sensori-neural deafness is due to damage of the inner ear, specifically the nerves of the cochlea or the auditory nerve. This form of deafness has more serious implications. Amplification can be delivered via hearing aids but this
does not provide a clear signal and the sound is often distorted.

Conductive deafness is often transient, particularly if caused by middle ear disease (otitis media). Therefore, the amount of auditory speech experienced by children with conductive hearing losses can vary over time. **For this reason, only children with sensori-neural, permanent, hearing impairment participated in the experiments in this thesis.**

1.2.ii Aetiology of sensori-neural deafness

Sensori-neural deafness can occur before, during or after birth. Table 1.1 shows the aetiological classification of children with permanent hearing impairment (> 40dB) born in the Trent region from 1985-1993 (Davis, Bamford, Wilson, Ramkalawan, Forshaw & Wright, 1997). This table also gives examples of the main causes of deafness within each classification.

<table>
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<tr>
<th>Aetiology</th>
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<td>Genetic</td>
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<tr>
<td>Prenatal (e.g., rubella - accounting for 1/3 of cases)</td>
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</tr>
<tr>
<td>Perinatal (e.g., prematurity, lack of oxygen at birth)</td>
<td>6.7</td>
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<tr>
<td>Postnatal (e.g., meningitis, measles)</td>
<td>6.1</td>
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<tr>
<td>Cranio-Facial Abnormalities</td>
<td>1.2</td>
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<tr>
<td>Other (e.g., chemotherapy)</td>
<td>1.7</td>
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<td>Unknown</td>
<td>40.9</td>
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</table>

In the Davis et al. study around 40% of cases of permanent hearing impairment were genetically based, approximately half of whom had a family history of hearing
impairment (20% of total). This is defined as permanent hearing impairment in at least one of the following family members: parent, sibling, grandparent, great-grandparent, aunt, uncle, nephew, niece or cousin (Davis et al., 1997). Davis et al. do not report what proportion of these deaf children were born to one or two deaf parents, though a common estimate is that approximately 10% of deaf children fall into this category (e.g., Marschark, 1993a). Since deaf children of deaf parents have been shown to differ in linguistic, cognitive, social and emotional development from deaf children of hearing parents (e.g., Padden & Humphries, 1988; see section 1.3.ii), only deaf children of hearing parents participated in experiments reported here.

According to the Davis et al. study the aetiology of deafness is unknown for a considerable proportion of deaf children. This makes experimental control of this variable difficult. It is known that children who are deaf through non-genetic influences often have additional disabilities or sensory problems. In an attempt to control for the influence of aetiology of deafness, deaf children were only selected to participate in the experiments reported here if there were no additional disabilities identified in their school records or by their class teacher.

1.2.iii Age at onset of deafness

The age at which a child becomes deaf affects early auditory speech experience. Although the age of mastering a language varies from child to child, the age of three years is generally accepted as the cut-off for distinguishing those who become deaf prelingually (before learning a spoken language) and postlingually (after learning a spoken language) (e.g., Conrad, 1979). Only children whose deafness was reliably diagnosed as occurring before the age of three years participated in the experiments reported here.
Quality and degree of deafness

Quality of deafness is measured by testing the child’s responses to tones at different frequencies (125 – 8,000 Hz). These tones are played through headphones to each ear separately. Each tone is first played at a high decibel (dB) level and gradually decreased until the child fails to respond. The final dB level at which the child responds to each frequency is then plotted on an audiogram (see Figure 1.1). Information on such pure-tone sensitivity is essential to ensure that the child is provided with the hearing aid that enhances sounds at appropriate frequencies. Since every child’s audiogram is different, it is difficult to control for hearing loss at specific frequencies in group studies therefore degree of deafness across frequencies is used as one of the selection criteria in this thesis.

Figure 1.1: Audiogram example

Degree of deafness is determined for the left and right ear separately by calculating the mean hearing loss across all frequencies tested. For example, Figure 1.1 shows a
hearing loss of 100dB in the right ear and 80dB in the left ear. A person’s overall degree of hearing loss is then usually described as the level of hearing loss in the better ear. In Figure 1.1 the child has a hearing loss of 80dB in the better ear. This degree of hearing loss is then used to categorise a person’s deafness according to a classification system that ranges from normal hearing to profound deafness. Boundaries of this classification system can vary. The system used by the RNID (1997) is adopted in this thesis. This is shown in Table 1.2.

Table 1.2: Classification labels of levels of deafness (RNID, 1997)

<table>
<thead>
<tr>
<th>Range of hearing loss</th>
<th>Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>up to 25 dB</td>
<td>normal</td>
</tr>
<tr>
<td>26-40 dB</td>
<td>mild</td>
</tr>
<tr>
<td>41-70 dB</td>
<td>moderate</td>
</tr>
<tr>
<td>71-95 dB</td>
<td>severe</td>
</tr>
<tr>
<td>95 dB +</td>
<td>profound</td>
</tr>
</tbody>
</table>

Speech requires mean intensities of around 45-55 dBs to be heard clearly over the tested frequency range, although sensitivity to different speech sound contrasts differs over this range. Since this thesis is concerned with those deaf children who are least likely to have useful auditory speech experience, only severely or profoundly deaf children were tested.

1.3 Early language experience at home and at school

From an audiological perspective, deaf children are not a homogeneous group. The amount and quality of speech input differs greatly between deaf children due to the type of deafness (sensori-neural or conductive), the age at onset and the degree of deafness at specific frequencies. Another factor to affect heterogeneity of the deaf population is differences in early language experience. Early researchers regarded
deaf people as a homogeneous experimental group who were ‘without language’ (e.g., Furth, 1966). However, consideration of the factors that affect the early language experience of deaf children demonstrates that they are not ‘without language’. Rather the early language experience of a deaf child, in the home and at school, is dramatically different to that of a hearing child.

Most deaf children are not brought up in a fluent sign language environment. Therefore they miss out on incidental language that a hearing child can overhear or a deaf child in a fluent sign language environment can oversee. The importance of such incidental language exposure in the first three years of life, regardless of modality, cannot be overestimated. This is precisely the crucial window of opportunity for learning language (Newport, 1990). A child exposed to language after this sensitive period may not achieve fully proficient language skills. Such poor language development in early childhood will affect social, emotional and cognitive development and will also have knock on effects for subsequent language development when the child reaches school age. Since the first systematic language exposure many deaf children encounter is when they enter school, at around four-years-old, the language approach used at school is also likely to influence their cognitive development.

The factors important to a deaf child’s early linguistic experience considered here are:

- age at diagnosis of deafness
- parent’s hearing status and choice of communication method
- language modality used at school

1.3.1 Age at diagnosis of deafness

Recent technological advances mean that universal neo-natal screening for hearing impairment may soon be widely available (Davis et al., 1997). However, the current
situation is that most infants are first tested for hearing at eight months. This test is administered by a health visitor and determines whether the child turns to locate low-level sounds made out of the child’s field of vision. Davis et al. (1997) found that around fifty percent of children with a hearing loss greater than 40dB would not be diagnosed by eighteen months using this method of screening. Furthermore, half of these children would not be diagnosed by the age of three and a half. Therefore, at school entry age, around twenty-five percent of children with a permanent hearing loss have not been diagnosed.

Failure to diagnose deafness until a child is two- or three-years-old means that:

- The child will not have had the benefit of wearing hearing aids and therefore will have missed out on important early auditory experience.
- Parents will not have adapted their communication behaviour accordingly to accommodate their child’s deafness.
- Parental and family adjustment is more likely to be problematic (Bamford & McSporran, 1993).

Late diagnosis of deafness can thus lead to impoverished early language experience. This can impair subsequent language development, placing major obstacles in the way of the child’s development of cognitive, social and emotional skills.

1.3.11 Parents’ hearing status and choice of communication method

*Deaf children of hearing parents*

Ninety percent of deaf children are born to hearing parents who are unlikely to have previous experience of deaf people. Their knowledge of the audiological condition of deafness is likely to be limited, as will be their knowledge of the community in which many deaf people participate. This is usually termed ‘Deaf’ culture. As a result of this lack of knowledge, the dynamics of a hearing family are drastically changed by the
arrival of a deaf child (see Gregory, 1976; Gregory, Bishop & Sheldon, 1995). Adjustment to having a deaf child in the family will depend on a range of factors such as marital stability, social support, socio-economic status and mother’s educational level (see Musselman & Kircaali-Iftar, 1996; Calderon, 1988 - cited in Calderon & Greenberg, 1993).

One of the most difficult decisions faced by parents is choosing the language approach to use with their deaf child. The main options available are spoken language and sign language. Although these are not necessarily used independently of each other, they can be defined as follows:

- **Spoken language**: There are a number of approaches with the shared goal of achieving good spoken language skills by deaf children. All these approaches involve maximising the child’s use of their residual hearing by paying particular attention to the appropriate use of hearing aids. The *natural aural approach* assumes that natural speech reading with aided hearing will suffice to develop spoken language ‘normally’. A more traditional *oral approach* would also include some specific speech-training techniques, both visual and aural. Finally, *cued speech* (Cornett, 1967) incorporates taught cues to aid lip-reading. Handshapes, positioned around the mouth, are used to disambiguate patterns that are difficult to lip-read. However, cued speech is not used in formal education in the UK and therefore is not widely accessible.

- **Sign Language (in the UK, British Sign Language - BSL)**: Sign languages are natural languages used by Deaf communities around the world. Sign languages are now recognised as full languages in the same sense as spoken languages (see Sutton-Spence & Woll, in press). The grammatical structure of BSL is very different to that of the spoken language that surrounds it, English. BSL is conveyed in space using movement of the hands, face and body. In addition to using signs to represent lexical items, fingerspelling is also used in BSL. This
uses 26 different handshapes to represent the letters of the alphabet. Therefore, any English word can be spelt on the hands. In BSL fingerspelling is mainly restricted to representing proper names.

One of main factors influencing whether a deaf child will develop good language skills, regardless of the approach chosen, is the degree of parental commitment and motivation to the language development of their child (see Musselman & Kircaali-Iftar, 1996). In particular this may be the case for hearing parents who choose sign language as their mode of communication with their child, since they are unlikely to have previous useful experience of sign language.

Only a small proportion of hearing parents of deaf children uses sign language. Of those that do, few achieve proficiency in its use (Young, 1997) as they are late learners of a second language. Hearing parents learning sign language are likely to face a number of additional difficulties. Young (1997) suggests they must try to balance the “...quest for Sign Language proficiency, ....acknowledging the overriding importance of communication .....and confirming the visual quality and child appropriateness of the signing” (1997, pg. 264). Therefore, in practice, hearing parents often use single signs to support spoken English. This is termed Sign Supported English (SSE) as English word order is retained and single signs are used to represent the main terms. SSE can be considered to be an inter-language: - a form combining elements both of English and BSL, although relative dominance of each language will vary between individuals (see Woll, 1998). This means that deaf children are often exposed to language models that are ill-formed in terms of BSL. Also, spoken language may be slowed and more disjointed when used in conjunction with signs. Therefore, although sign language is conveyed wholly in the visual medium and is fully accessible to a deaf child on a sensory basis, good models from which to learn the language are not widely available.
Deaf children of deaf parents

So far, only deaf children of hearing parents have been considered. Deaf children of deaf parents (10% of total) are likely to have very different language exposure for a number of reasons.

- Deaf children of deaf parents (DoD) are likely to be diagnosed earlier than deaf children of hearing parents (DoH) as they are considered to be at risk.
- The first language in most deaf households is BSL, therefore DoDs are able to oversee signed conversations in the same way a hearing child can overhear spoken conversations at a very early age.
- Regardless of whether the first language in the home is sign or speech, DoDs are likely to experience a more effective language environment than DoHs as deaf parents are usually more aware of their deaf child’s needs and adapt their behaviour accordingly. For example, a hearing child can look at an object while simultaneously attending to an auditory label given by the caregiver. In contrast, a deaf child must switch attention from the object to the caregiver to see the label, whether it is spoken or signed. Deaf mothers often make this learning process easier for their deaf child by performing the sign next to the corresponding object, rather than in normal signing space, so that visual input is maximised (Harris, Clibbens, Chasin & Tibbetts, 1989; Harris & Mohay, 1997).

The finding that DoDs often outperform DoHs on different aspects of cognitive ability such as IQ (Braden, 1994) and reading (Kusche, Greenberg & Garfield, 1983) has often been attributed to their rich early language exposure, usually presumed to be sign language. However, isolating one factor as the cause of the enhanced cognitive development of DoDs may be too simple. DoDs are also likely to have experienced better family dynamics, parental support and general early socialisation than DoHs. Although these could be considered secondary factors of language experience, they may make independent contributions to the development of the deaf child that should not be ignored.
Language modality used at school

Language experience at school may influence cognitive processing of deaf children tested in this thesis to an even greater extent than language experience at home for two reasons:

1. Approximately twenty-five percent of deaf children are not diagnosed until the age of three and a half (Davis et al., 1997). For these children, the language environment they encounter at school is likely to be their first systematic exposure to language and is critical to their subsequent language development.

2. The majority of deaf children who participated in this thesis attended residential schools for the deaf where the communication policy employed in the classroom is extended to out of school hours. Thus, the effect of language modality used at school may be extensive.

The issue of which language approach should be used to educate deaf children has been debated since the beginning of modern deaf education. This is a politically sensitive issue as it can be argued that the choices made on behalf of the child ultimately determine how the child will later fit into society as a deaf adult. That is, whether they will integrate into the hearing world, the Deaf world or feel comfortable in both. Any researcher working in the field of deafness needs to be aware of these issues, which are difficult to avoid. Therefore the educational placements available to deaf children, in terms of language approach, will be reviewed briefly.

**Oral approach**

The oral approach uses only spoken language and particular attention is paid to maximising residual hearing using hearing aids. The main premise of this approach is that spoken language is dominant in mainstream society and a child should not be excluded from this simply because s/he is deaf. Oralism was the main form of education of deaf children in the UK until the 1980s. It then became apparent that an oral approach did not provide all deaf children with the cognitive tools to reach the
same levels of academic achievement as their hearing peers. For example, Conrad (1979) showed that the average reading age of the deaf school leaver was nine-years-old. He concluded that “Oral education leaves too many deaf children close to illiterate” (1979, pg. 175). This led many education authorities in the UK to incorporate sign language into the education of deaf children.

**Total Communication**

Schools that adopt a sign language approach do not use pure BSL. This is due to a lack of deaf teachers and a lack of hearing teachers of the deaf with appropriate levels of sign proficiency. The most widely used ‘manual’ approach is Total Communication (TC) which involves a combination of BSL signs and spoken English. As spoken English and BSL have different grammatical structures it is not possible to use both languages simultaneously. Instead, English word order is usually retained and either Signed English (SE) or Sign Supported English (SSE) is used. In SE signs are used to represent all terms in the spoken sentence including morphological aspects of spoken language for example, plurals and tenses. This makes communication very slow and therefore SE is restricted to use in educational situations. SSE is a more widely used system. Here, the English word order is retained and only the key parts of the sentence, such as nouns and verbs, are signed.

Recently, proponents of oralism have argued that the educational achievements of deaf children under a TC approach have not increased substantially since the time of Conrad’s study and that this approach has failed deaf children (Lewis, 1996; Lynas, 1994a; 1994b). They claim that more efficient hearing aids and earlier diagnosis of deafness mean that oral education can now provide deaf children with greater access to spoken language leading to higher academic achievement. They argue it is time for a return to the oral education of deaf children (Lewis, 1996).

The response to this challenge from proponents of sign language is that a sign approach has not failed deaf children: it simply has not been given the opportunity to
succeed (Kyle, 1994). They argue that since the majority of teachers of the deaf are hearing, with variable levels of sign skill, deaf children are often not exposed to ‘true’ sign language. In school they are usually exposed to an artificial use of sign language in the form of SSE, whose syntax and morphology come from spoken English.

**Bilingualism**

A new approach to the education of deaf children is that of ‘Bilingualism’. Some regard this as a resolution of the conflict between the inadequacies of oral and TC approaches. Ideally bilingualism involves using BSL to establish good language skills and a good knowledge base, while English is taught as a second language to facilitate access to literacy.

However, this approach does not satisfy all parties and many argue that Bilingualism has been embraced too readily in the absence of empirical support, as perhaps TC was twenty years ago. Lynas (1994a) goes further in her condemnation and argues that the enthusiasm for bilingualism:

"...has been given momentum by the weight of an ‘evangelical’ movement of, doubtlessly well intentioned but politicised, militant deaf activists claiming rights to cultural hegemony of deaf individuals” (Lynas, 1994a, pg. 150).

This statement captures something of the heat of the debate within deaf education today. Although deaf children attending schools employing different language approaches are compared in this thesis, the aim is not to present evidence for or against different types of language approach. Rather the goal is to explore the effect that educational background may have on the use of STM coding strategies.
1.4 Chapter 1: Implications

This chapter has outlined some of the factors that affect the early life experiences of deaf children. A consideration of these factors allows some insight into the world of a deaf child and the immense impact that deafness can have on all aspects of early socialisation and cognitive, social and emotional development. Perhaps surprisingly, the atypical language experience of so many deaf children does not appear to result in a general cognitive deficit. Deaf children have been shown to perform as well as their hearing peers on tests of non-verbal IQ (Braden, 1994). However, the combined influence of the factors discussed in this chapter can have a devastating effect on some aspects of a deaf child’s cognition, in particular those tapping linguistic ability. Deaf children usually perform below their hearing peers in tests of reading ability (e.g., Conrad, 1979), verbal IQ (Braden, 1994) and vocabulary development (e.g., Griswold & Commings, 1974). Since language-based STM skills are related to important cognitive skills such as learning to read, the focus of this thesis is STM for linguistic stimuli.

The subject characteristics discussed in this chapter are likely to influence the linguistic STM abilities of deaf children. By only selecting participants who were congenitally/ prelingually and severely/ profoundly deaf, the number of individual differences in the experimental studies reported in this thesis were limited to those of particular theoretical interest.
Chapter 2 - Short-term memory in hearing adults and children

2.1. Introduction

Short-term memory (STM), as measured by immediate recall or recognition of previously presented items, 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. For example, numerous studies have shown that developmental dyslexics have poor memory spans (e.g., Jorm, 1983; Snowling, 1991). However, the direction of causality between STM skill and performance on cognitive tasks is not yet clear. 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 or that this relationship is mediated by a third independent factor, such as phonological awareness (see Goswami & Bryant, 1990). Moreover, the inter-relationships may differ at different ages and different levels of skill. Despite the debate in this area, the fact that a relationship does exist between STM and a range of cognitive skills makes the study of STM an important area of research. By establishing the nature of STM functioning in children, the possibility of specifying the precise relationship between STM and other cognitive skills is enhanced.

The purpose of this chapter is to review the literature regarding STM processing and coding by hearing people. In particular, the development of these processes in hearing children will be discussed. This chapter is divided into four main sections:

- First, models of STM will be discussed. The working memory model (Baddeley & Hitch, 1974) will then be discussed in detail as this model is the basis for several of the experiments reported in this thesis.
• The second part of the chapter explores characteristic effects of verbal STM which have informed the development of models of STM over the past thirty years. The use of a speech-based code in STM will be discussed, along with the effect of irrelevant speech, word length, speech similarity and concurrent speech on immediate serial ordered recall (SOR). Some of these effects, and their possible sign language analogues, are explored with the deaf participants in this thesis.

• The third part of the chapter reviews the emergence of these characteristic aspects of verbal STM in hearing children. How this informs our understanding of the development of STM coding and processes in hearing children will be discussed.

• Finally, the use of concurrent tasks to investigate STM processes will be considered in more detail. Concurrent tasks are used in two experiments reported in this thesis. Therefore, it is necessary to explore the principles and assumptions that underlie the use of this approach with hearing people.

2.2. Models of memory

There has been much debate regarding the structure of memory. Some argue that memory is a unitary system made up of one store (Melton, 1963). Others argue that memory comprises functionally separable systems: one termed short-term memory (STM), which is resource-limited and required for temporary storage and processing of information, and another, termed long-term memory (LTM), which is potentially unlimited in size and required for permanent storage and knowledge (e.g., Waugh & Norman, 1965). The debate regarding the structure of memory continues today. However, there is now substantial neuropsychological and behavioural data to support a dissociation between STM and LTM (e.g., Milner, Corkin & Teuber, 1968; Shallice & Warrington, 1970).
Evidence supporting a dissociation between STM and LTM led to the proposal of a number of information processing models of memory. Atkinson and Shiffrin (1968) proposed the modal model, which was a development of Broadbent's (1958) model of selective attention. According to the modal model, information enters the processing system via modality dependent sensory stores. This information is then passed into a short-term store and finally into a long-term store. The short-term store was assumed to be an active part of the system involved in processing information en route to the long-term store and incorporating a number of control processes, such as rehearsal, coding and retrieval. Atkinson and Shiffrin also proposed that the short-term store was involved in many aspects of human cognition and should therefore be regarded as a 'working memory'.

However, Atkinson and Shiffrin’s model could not readily account for some aspects of the neuropsychological data. Shallice and Warrington (1970) identified a patient K.F. whose STM skills were impaired, yet his long-term learning was normal. Furthermore, K.F.’s STM impairment did not affect his performance of everyday activities. Until this time it had been assumed that any STM system was a unitary storage system of limited capacity. It was also assumed that STM played a fundamental role in a number of cognitive processes such as reasoning and comprehension. That is, all sensory information must be processed via STM. However, KF had impaired digit span yet his general cognitive processing was intact. Baddeley and Hitch (1974) explored this discrepancy by attempting to create, an analogue of KF’s performance in normal subjects by ‘filling STM’ with a demanding task (dual task paradigm).

The digit span task had traditionally been regarded as an index of STM ability. This task requires immediate recall of digits in the order presented. If performance on a cognitive task, such as reasoning, relies entirely on STM processes, then requiring subjects to retain digits and perform a reasoning task simultaneously should impair reasoning performance. When subjects were required to recall a small digit load (three
digits) there was little or no effect on reasoning. When the load was increased to six
digits performance on the reasoning task, although impaired, was still functional. This
suggested that there was a "...considerable component of working memory which is
not taken up by the digit span task" (Baddeley & Hitch, 1974, pg. 75). That is, STM
may comprise of multiple systems, each related to a specific domain. Support for this
interpretation came from STM patients such as PV whose memory impairment
differed across different aspects of STM. PV's recall of auditory stimuli was
substantially poorer than her recall of visually presented stimuli (Basso, Spinnler,
Vallar & Zanobio, 1982).

To account for these data Baddeley and Hitch (1974) proposed the 'Working
Memory' model. In this model STM was fractionated into a number of subsystems: a
control system, termed the central executive, and a number of modality-specific slave
systems (verbal and spatial). According to this model, patients such as PV and KF
were able to perform everyday activities because they had only suffered damage to
the part of the STM system that dealt with verbal material, yet the rest of their STM
system was intact. The working memory model was also able to account for the
differential effects of memory loads of three and six digits on reasoning ability. When
verbal memory load exceeds the capacity of the verbal slave system, central executive
processes are recruited to help retain the sequence. These processes were thought to
be employed in cognitive tasks such as reasoning. Therefore when a large memory
load was imposed performance on the cognitive task was impaired.

In the UK, the term 'working memory' has become synonymous with the model of
STM proposed by Baddeley and Hitch (1974), later revised to account for new
findings (Baddeley, 1986). However, the term is used elsewhere to refer to rather
different concepts (for a review of the use of the term see Richardson, 1996). In North
America 'working memory' is often used to refer to a general processing resource that
co-ordinates the functions of STM and LTM in relation to a specific task such as text
comprehension. Although it is necessary to be aware of these different uses of the
term working memory, in this thesis the term working memory is only used to refer to the model proposed by Baddeley and Hitch (1974; Baddeley, 1986).

The working memory model has remained particularly influential, especially in the UK. It has generated much research, which has led to refinements in the model itself (Baddeley, 1986). It has also inspired the development of new models, particularly of phonological STM (see Gathercole, 1996; 1997; Chapter 7 in this thesis), which have their roots in the working memory model (e.g., Burgess & Hitch, 1992).

2.3. The working memory model (Baddeley & Hitch, 1974; Baddeley, 1986)

The original working memory model, proposed by Baddeley and Hitch (1974), consisted of a control system, termed the central executive and two slave systems: the visual spatial-sketch pad, specialised for visuo-spatial material and the articulatory loop for speech material. The basic structure of the model has not changed materially, although the slave systems have become more fully specified over this time. Each of the components of the working memory model will now be discussed in turn.

2.3.i. The Central Executive

The central executive is thought of as a limited capacity processor involved in the planning and control of actions. It is also thought to play a role in visual imagery (Logie, 1995) and the combination of information from the visuo-spatial sketchpad, the phonological loop and other cognitive systems, including LTM (Baddeley, 1996). Although many high level cognitive processes have been attributed to the central executive it remains “…the most complex and least understood component of the working memory model” (Baddeley, 1996, pg. 12). The theoretical development of this part of the model was advanced substantially by Baddeley’s (1986) adoption of
supervisory attentional system (SAS) proposed by Norman and Shallice (1980). This model accounts for a subject’s strategic control of action when necessary. For example, allowing a subject to cope when an automated task, such as driving, is interrupted.

A task used to explore the function of the central executive, which demonstrates the possible role of the SAS, is the random generation of numbers, letters or spatial sequences. Numbers and letters are often cited in a well-known order, for example ‘1, 2, 3’ or ‘A, B, C’. The requirement to produce these stimuli in random order places demands on the central executive to override the automated route of ordered production (Baddeley, 1966a). Increasing task demands further, by requiring a fast generation rate, leads to greater impairment of performance and responses become less random (Baddeley, 1966a; Towse, 1998). This suggests that the random generation task taps central executive resources and can, in turn, be used in a dual task paradigm to determine which cognitive processes are dependent upon the central executive (see Baddeley, 1986).

Further use of random number generation and other tasks may further illuminate the structure of this part of the working memory model. At present it is unclear whether the central executive is a unitary system or made up of a separate subsystems (e.g., Barnard, 1985) that form an “executive committee” (Baddeley, 1996, pg. 26).

2.3.ii. Visuo-Spatial Sketchpad

The visuo-spatial sketchpad is thought to be responsible for the processing and storage of visual and spatial information within STM. Until recently the visuo-spatial sketchpad has been a poorly developed part of the working memory model. In a review of this area, Logie (1995) proposed that the visuo-spatial sketchpad might have two components. First, the visual cache, that acts as a store for visual
information. Second, an *inner scribe* that is thought to rehearse information in the visual store and be involved in planning movement.

Temporary storage of information in the visual cache in the form of a visual representation has been inferred from a number of sources. First, irrelevant visual material appears to interfere specifically with retention of visual stimuli (Quinn & McConnell, 1996). Second, confusions for items that are visually (pictorially) similar can be made in STM. However, this only occurs under some conditions:

- In young children who do not yet use a speech-based STM code for visual stimuli (e.g., Hayes & Schulze, 1977).
- In children in late childhood when concurrent speech precludes verbal recoding of the item (Hitch, Woodin & Baker, 1989).
- In adults, in conditions of concurrent speech when stimuli are presented simultaneously rather than sequentially (Frick, 1985).
- When stimuli are presented at a fast rate so that verbal labelling of items is not possible (Wolford & Hollingsworth, 1974).
- When stimuli are unnamable, such as unfamiliar Chinese characters (Hue & Ericsson, 1988).

Evidence supporting the existence of an *inner scribe* has come mainly from studies involving performance of irrelevant tasks. A series of studies by Smyth and colleagues have shown that memory for movement sequences can be disrupted by irrelevant movement in the retention interval (e.g., Smyth & Pelky, 1992; Smyth & Pendleton, 1990). Similarly, a concurrent spatial tracking task interferes specifically with recall of spatial stimuli (Baddeley & Lieberman, 1980) and with spatial reasoning (Farmer, Berman & Fletcher, 1986).
2.3.iii. The Phonological Loop

The phonological loop is the most thoroughly explored part of the working memory model. It is thought to be responsible for processing and maintaining phonological information. Originally this component was termed the 'articulatory loop'. This was thought to be linked to underlying speech mechanisms and have the primary function of refreshing articulatory programs stored in the loop (Baddeley & Hitch, 1974). It was also thought to be a time-based system, with a linear relationship between the number of words recalled in serial order and the time taken to articulate the words (Baddeley, Thomson & Buchanan, 1975; Hulme, Thomson, Muir & Lawrence, 1984).

This simple model of phonological STM was later revised to account for new experimental data. It was renamed the 'phonological loop' to account for the fact that the loop was not purely articulatorily based (Baddeley, 1990). One of the main lines of evidence for this came from teenagers unable to speak since birth, anarthrics. These subjects showed similar characteristics of phonological STM as normally articulating people (Bishop & Robson, 1989). The major revision to the structure of the model was to divide the loop into two components that dealt with phonologically structured material: a phonological store and a control process involving subvocal rehearsal under strategic control of the individual (Baddeley, 1986; Salamé & Baddeley, 1982) (see Figure 2.1). Support for the functional and possible structural dissociation between a phonological store and a subvocal control process comes from recent imaging studies which suggest the phonological store to be localised in the left supramarginal gyrus, and the subvocal rehearsal process in Broca’s area (Paulesu, Frith & Frackowiak, 1993).
The phonological store temporarily holds information in the form of a phonological memory trace. The memory trace of the stimuli to be recalled is thought to decay after approximately one and a half to two seconds unless it is refreshed via the subvocal rehearsal process (Hulme, Thomson, Muir & Lawrence, 1984). This rehearsal is thought to be cumulative. That is, after the presentation of each new stimulus the whole set is rehearsed from the beginning.

The phonological loop is thought to deal with stimuli in different ways according to modality. Spoken stimuli have direct access to the phonological store, whether they are auditory or simply lip-read (Campbell & Dodd, 1980). In contrast, since the store only processes phonologically structured material visual stimuli, such as pictures or text, must first be recoded into a phonological code to gain entry to the store. The subvocal control process is responsible for this recoding. Thus, the subvocal control process is thought to be responsible for recoding visual stimuli into a speech-based code to gain access to the phonological store and subvocal rehearsal of these speech-based memory traces within the store (Baddeley, 1986). The subvocal control process is also thought to act as an output buffer for speech production.
2.3.iv. Summary of Section 2.3

Over the last twenty-four years the working memory model has proved to be an influential model of STM, particularly in the UK. By making only few assumptions about its structure, the model can account for a wide range of experimental data. It has also generated a wealth of new research and raised new empirical questions. An indication of the fruitful nature of the working memory model is its continued development over time rather than simply being replaced by an alternative model.

Very recent developments in the proposed structure of the working memory model have attempted to account for the data indicating the strong influence of long-term knowledge on STM processes which the earlier model did not address (see Baddeley, Gathercole & Papagno, 1998; Gathercole, 1997; Logie, 1995; 1996). These developments and alternative models of STM will be considered further in the Discussion chapter of this thesis and in Experiment 5 (Chapter 6) which explores the influence of long-term semantic knowledge on immediate recall by deaf children.

At this point it is worth considering how coding systems used by deaf people may be accommodated in the working memory model. One possibility may be that deaf signers use a code based on the phonological parameters of sign language within the visuo-spatial sketchpad. However, the visuo-spatial sketchpad is specifically non-linguistic (see Logie, 1995) and BSL is, above all, a structured language (Sutton-Spence & Woll, in press). So the phonological loop may be a more appropriate framework in which to consider STM for linguistic stimuli by deaf people.

2.4. Characteristic effects of phonological STM in hearing people

The task most widely used to investigate the nature of the phonological loop is the immediate recall of lists of stimuli that can be represented verbally. The lists can
either be recalled in the order in which they were presented (serial order recall - SOR), or in any order regardless of serial position (free recall - FR). Rehearsal in the loop is cumulative and is therefore based on temporal order. SOR is therefore a sensitive measure of phonological loop function. The two most commonly used ways of testing SOR are:

- Memory span - The number of items presented for recall is increased until the subject fails to reach a certain criterion, such as accurate recall of two out of three lists at a particular list length. Memory span is then the largest number of items recalled before errors occur.
- Recall of stimuli of fixed list lengths - In this procedure all subjects are presented with a fixed number of stimuli. To avoid ceiling effects the number of stimuli presented is usually set at above the average memory span for the subject group tested. Since memory span increases with age, in developmental research different age groups are usually presented with different list lengths of stimuli. The dependent variable (memory accuracy) is then the mean number of items correctly recalled across trials.

Manipulations of these SOR tasks have led to the identification of characteristic effects of phonological STM. The following effects will be discussed in detail:

- speech-based coding
- irrelevant speech effect
- word length effect
- speech similarity effect
- concurrent speech effect
2.4.i. The nature of speech-based coding

Items to be recalled in a test of STM must be stored *internally* until output is required. This requires some form of inner representation. This representation is usually referred to as a STM *code* or *memory trace*. The importance of considering the nature of the STM code used in a given situation is summarised by Cowan (1996) who says “It is not the stimuli or the responses *per se* that primarily govern the nature of immediate recall performance. Instead it is the nature of the internal memory codes that is critical” (1996, pg. 35). For hearing people the code predominantly used in STM is based on features of speech. Hence the STM code used by hearing people is often referred to as ‘inner speech’ (e.g., Conrad, 1979; Sokolov, 1972).

To investigate the nature of inner speech used by hearing people, Baddeley (1966b) tested the recall of words which were either ‘acoustically’ similar (e.g., cad, cat, can) or acoustically dissimilar (e.g., cow, day, bar). Subjects were also tested on recall of stimuli that were semantically similar (e.g., big, long, broad) or semantically dissimilar (e.g., old, deep, foul). Recall of ‘acoustically’ similar stimuli was much poorer than that of dissimilar control stimuli. In contrast, the effect of semantic similarity, while significant, was small. This pattern of results held for spoken and written words. Baddeley (1966b) therefore argued that STM used speech *sounds* rather than word meanings as the basis for coding.

However, subsequent evidence indicated that memory span was also related to articulatory factors such as spoken word duration (Baddeley, Thompson & Buchanan, 1975). This led Baddeley (1986) to propose that inner speech develops from overt articulation and was likely to be based on articulatory features. It has already been noted that Bishop and Robson’s (1989) findings with congenital anarthrics argued against this position. These youngsters showed characteristics of supposedly
'articulatory' coding, such as effects of spoken word duration (a word length effect). Therefore they argued that the code used in phonological STM "...is an abstract phonological representation" (Bishop & Robson, 1989, pg. 139).

The precise nature of this 'abstract' phonological code is not yet fully understood, though it is likely to be amodal. It has been argued that these amodal phonological representations consist of activation patterns across a network of phonological knowledge stored in LTM (e.g., Gathercole & Martin, 1996; Logie, 1996). This phonological knowledge may have been acquired from accumulated speech experience. Alternatively, it has been proposed that humans have an innate, gesturally-based, sensitivity to 'acoustic' changes in languages and are able to map heard sound via phonetic analysis onto existing phonological structures (Liberman & Mattingley, 1985).

Both notions suggest that a child with impaired auditory speech perception may have difficulty establishing a STM code based on speech. However, both auditory and lip-read speech input lead to similar effects in phonological STM (e.g., Campbell & Dodd, 1980). That is, phonology is not necessarily dependent on an acoustic mode of delivery, other modalities such as vision (lip-reading) and touch (Fowler & Dekle, 1991) may provide the same information. Since deaf people have access to lip-reading they may map lip-read speech onto innate phonological structures in the same way as hearing people map auditory speech. This would allow a phonological code based on speech to be established despite lack of hearing. These issues will be considered in more detail in Chapter 3 of this thesis.

Deaf people may be able to establish a STM code based on speech. It is also possible that deaf people recode information into a STM code based on the parameters of sign

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1 However Raine, Hulme, Chadderton and Bailey (1991) report data which do not fully support this position. Furthermore Bishop, Brown and Robson (1990) found that anarthrics were poorer than cerebral palsied children of the same age on phoneme discrimination tasks such as lexical decision.
language. Given that both signed and spoken languages have a phonological structure (Coulter & Anderson, 1993) the term 'phonological code' can be ambiguous. To avoid confusion the term 'speech-based code' is used throughout this thesis to refer to the use of a phonological code based on features of speech. This terminology is in line with Baddeley's (1996) use of the term phonological which he uses in a purely "neutral sense as meaning speech-based" (1996, pg. 75).

2.4.ii. Irrelevant speech effect

One characteristic of phonological STM that is dependent on the use of a speech-based code is the disruption of recall when irrelevant speech is played during stimulus presentation (Colle & Welsh, 1976). This effect was thought to be specific to irrelevant speech stimuli, as white noise did not disrupt performance. According to the working memory model this occurs because speech input, whether attended or unattended, has direct access to the phonological store. Within the phonological store, speech-based traces of the irrelevant speech become confused with the memory traces of items to be recalled, thus recall is impaired. Furthermore, since speech similarity influences STM performance, similarity between the stimuli to be recalled and the irrelevant speech that is heard should influence recall accuracy. Salamé and Baddeley (1982) tested this hypothesis. Subjects were asked to recall a series of digits while irrelevant speech was played. The irrelevant speech was either digit words (e.g., one, two); words made up of the digit phonemes (e.g., tun, woo); or words dissimilar to the stimuli to be recalled (e.g., jelly, tipple). All three types of irrelevant speech disrupted recall. However, interference was greatest from irrelevant speech that was phonologically similar to the stimuli to be recalled, that is digits and words constructed from digit phonemes. Thus, similarity of phonological structure appears to influence the level of disruption from irrelevant speech.
However, this interpretation has been challenged over the last seven/eight years by Jones and colleagues (e.g., Jones, 1994; Jones, Beaman & Macken, 1996; Jones & Macken, 1993). Jones and Macken (1995) argue that Salamé and Baddeley's (1982) experiment was flawed because the similar and dissimilar irrelevant stimuli were of different spoken lengths. Therefore, subjects heard *more* speech-similar irrelevant words, which were short, than dissimilar words, which were long. This in itself could have led to different levels of disruption. When Jones and Macken (1995 - Experiment 1) controlled for this confound, they showed that speech similarity played a small role in the effect of irrelevant speech. In further studies Jones and colleagues also demonstrated that the ‘irrelevant speech effect’ was not necessarily dependent upon *speech* as originally thought. Rather, they argued it may be due to the *changing nature* of the irrelevant stimuli. For example, irrelevant tones that change in pitch also disrupt SOR of words (Jones & Macken, 1993). They accounted for this in terms of the object-oriented episodic record model of STM (for a summary, see Jones, Beaman & Macken, 1996). This model assumes that changing-state irrelevant stimuli (e.g., 1, 2, 3, 4,) are more disruptive than steady state stimuli (e.g., 1, 1, 1, 1,) because they contain more potentially conflicting cues to serial order. The precise implication of this series of studies for the working memory model is not yet clear and is undergoing further investigation.

2.4.iii. Word length effect

Another robust characteristic of verbal STM is the effect of word length on recall. Span for short words (e.g., wit, sum) is greater than that for long words (e.g., aluminium, university) whether presented auditorily or visually (Baddeley, Thompson & Buchanan, 1975). Baddeley et al. also showed that recall of two-syllable words that take longer to speak (e.g., harpoon) is poorer than recall of two-syllable words with short articulation times (e.g., wicket). Therefore, the word length effect was attributed to articulatory properties of words rather than phonological properties, such as
number of syllables. The working memory model accounts for this effect in terms of subvocal rehearsal. Rehearsal is assumed to take place in ‘real time’ - words that take a long time to articulate overtly are assumed to take a long time to rehearse subvocally. Since more short than long words can be rehearsed in the same amount of time, fewer short words are lost from the phonological store as a consequence of decay. This results in greater span for short than long words.

However, it is now apparent that the word length effect may not be wholly attributable to rehearsal. Other factors may also contribute. This possibility was raised fifteen years ago by Hitch and Halliday (1983) who pointed out that although very young children showed word length effects it was unlikely that they were using subvocal rehearsal. They argued this may indicate that “the nature of the auditory word length effect needs to be revised” (1983, pg. 93). Recent studies have confirmed this speculation and a number of alternative explanations of the word length effect have now been proposed (see e.g., Caplan, Rochon & Waters, 1992; Caplan & Waters, 1994; Baddeley & Andrade, 1994).

The alternative position that has received most empirical support suggests an additional locus of this effect at response output (Henry, 1991; Henry & Millar, 1991; Cowan, 1992). Since preparation and response time is greater for long than short words more short words can be produced in a given time. Therefore, fewer short words are lost from the phonological store as a consequence of decay during recall, resulting in the traditional word length effect. Cowan, Day, Saults, Keller, Johnson and Flores (1992) tested this hypothesis using lists in which either the first half was long words and the second half short words or vice versa. Recall of items was not affected by word length specifically, but by how long it had taken to recall earlier items in the list. When long items were presented first, overall recall was poor because subsequent items had suffered greater decay in the phonological store. Further support for an output rather than rehearsal based explanation of the word length effect came from Avons, Wright and Pammer (1994). They tested subjects on
probed recall, which eliminates the need to report all the items in the list. Subjects were cued with a probe to which they had to respond with the item which had followed it at presentation. This led to a dramatic drop in the size of the word length effect, supporting the hypothesis that output time plays an important role in the word length effect.

2.4.iv. Speech similarity effect

An extremely robust characteristic of phonological STM is that SOR of similar sounding items (e.g., B, T, C, D) is poorer than recall of dissimilar items (e.g., Y, J, S, O) (e.g., Conrad & Hull, 1964). It could be argued that this effect is due to perceptual confusion of auditorily presented stimuli at the time of encoding (Baddeley, 1966b). However, it also occurs when stimuli are presented visually (Baddeley, 1966b - Experiment 3; Conrad & Hull, 1964).

According to the working memory model the ‘acoustic’ similarity effect occurs in the phonological store. The number of distinguishing features between memory traces of similar items decreases over time due to decay. Therefore the memory traces become less easily identifiable, resulting in poorer recall. This effect is usually referred to as the ‘phonological similarity effect’. However, this term can lead to confusion, as it is also possible to talk of phonological similarity of sign stimuli. This effect of similar sounding items will be termed the ‘speech similarity effect’ throughout this thesis.

2.4.v. Concurrent speech effect

The final characteristic of phonological STM to be discussed here is the disruption of recall when a subject is required to repeat an irrelevant word or phrase, such as ‘the, the, the’, during presentation of stimuli to be recalled (Murray, 1968). This effect is
not simply an irrelevant speech effect from the spoken input, as the disruption still occurs when the subject is asked to *mouth* rather than voice the irrelevant material (Macken & Jones, 1995; see also Gupta & MacWhinney, 1995). According to the working memory model concurrent speech impairs recall because preparation for speech output occupies the subvocal rehearsal process. This is thought to have knock-on effects for both encoding and rehearsal stages of STM processing:

- recoding of visual stimuli into a speech-based code is impaired
- memory traces cannot be rehearsed

If this account is correct, the working memory model predicts that concurrent speech should interact in specific ways with the effects of speech similarity and word length.

- The speech similarity effect - This is thought to occur in the phonological store which stores information in a speech-based code. If concurrent speech impairs the recoding of visual stimuli into a speech-based code then it should reduce the speech similarity effect for visual stimuli. Since auditory stimuli have direct access to the phonological store they should be unaffected. Baddeley, Lewis and Vallar (1984) report data that support these predictions.

- The word length effect - This has traditionally been accounted for in terms of the subvocal rehearsal process. Since concurrent speech utilises this process the word length effect should be abolished regardless of whether the stimuli are auditory or visual. These predictions have been supported, however for auditory stimuli subjects must continue the concurrent speech throughout presentation *and* recall to eliminate the word length effect completely, otherwise, rehearsal may occur in the recall period (Baddeley, Lewis & Vallar, 1984).

Concurrent speech does not reduce recall to floor level. Subjects are still able to recall a small number of items under concurrent speech conditions. Here memory for linguistic stimuli is thought to be supported by the limited storage capacity of the central executive.
Since concurrent speech is thought to occupy the subvocal rehearsal process this task is often referred to as ‘articulatory suppression’. This term assumes that the task will *suppress* a speech-based STM code. However, this may not always be the case (see section 2.6). Even if it could be assumed that concurrent speech disrupts a speech-based code, the term *articulatory suppression* further assumes that this code is essentially *articulatory*. Since Bishop and Robson (1989) found a word length effect in subjects who could not articulate, this may be an unwarranted assumption. Therefore, the task often referred to as ‘articulatory suppression’ is termed *concurrent speech* throughout this thesis.

Concurrent tasks have rarely been used to investigate the use of STM codes by deaf people. Therefore, concurrent tasks are used in two experiments reported in this thesis to explore the use of speech and sign-based STM codes by deaf teenagers and adults. The performance requirements of concurrent tasks and the interpretation of the effect of concurrent speech will be considered in detail later in this chapter.

### 2.5. Developmental changes in phonological STM

One of the main reasons for interest in the area of STM development is that numerous studies have shown STM ability to be related to the development of important cognitive functions such as learning to read, language acquisition and development (see Gathercole & Baddeley, 1993). The most fundamental finding in this area is that memory span increases with age (e.g., Chi, 1976). Some researchers explain this in terms of ‘operational efficiency’ (e.g., Case, Kurland & Goldberg, 1982). This position assumes that STM consists of a limited capacity that must be divided between storage and processing systems. Since processing is assumed to be less automated for young children than older children it is argued that young children require more processing resources to complete operations. For example, item identification is a necessary operation in a standard STM task. Young children may
require more general processing resources than older children to complete this operation, leaving less available for rehearsal and thus leading to a lower level of recall (for a critique, see Towse & Hitch, 1995; Towse, Hitch & Hutton, 1998).

The operational efficiency explanation is based on the assumption that STM is a limited capacity unitary system. However, the acceptance that a larger proportion of the adult data could be accounted for by representing STM as a set of co-ordinated components (e.g., Baddeley & Hitch, 1974; Barnard, 1985) led a change in the way that development of memory span was studied, particularly in the UK. Hitch and Halliday argue that studying children of different ages can help separate-out the components of the adult cognitive STM system. They term this process ‘developmental fractionation’ (e.g., Halliday & Hitch, 1988; Hitch, 1990; Hitch & Halliday, 1983). This approach suggests that different components of phonological STM develop at different rates. This evidence will now be reviewed.

2.5.i. Word length effect

Hulme, Thomson, Muir and Lawrence (1984 - Experiment 1) found that four-year-olds show a word length effect when tested on spoken recall of auditory stimuli. This result was later replicated with six, eight and ten-year-olds (Hitch, Halliday, Dodd & Littler, 1989). According to the traditional working memory account of the word length effect these data indicate the use of subvocal rehearsal by these children. However, Hitch et al. (1989) showed that with pictorial stimuli only recall by ten-year-olds was affected by word length. The authors claimed that young children did not automatically recode picture stimuli into a speech-based code to gain access to the phonological store and thus such stimuli could not be rehearsed. In contrast, since *auditory* stimuli have direct access to the phonological store, these stimuli were thought to be rehearsed by children as young as four, resulting in a word length effect.
However, previous studies had judged that rehearsal emerged in children at a later age. For example, Flavell, Beach and Chinsky (1966) observed children during a test of picture recall. Lip movements were thought to be indicative of subvocal rehearsal and from this it was estimated that children start to rehearse at around seven-years-old. If this is the case, the word length effect in the recall of auditory stimuli by children as young as four could be due to factors other than rehearsal.

A number of adult studies support this proposal. As already discussed (section 2.4.iii), articulation speed at output has also been identified as a contributor to the word length effect (Avons, Wight & Pammer, 1994; Cowan, Day, Saults, Keller, Johnson & Flores, 1992; Cowan, Keller, Hulme, Roodenrys, McDougall & Rack, 1994; Henry & Millar, 1991). Gathercole and Hitch (1993) further specified the cause of this output effect in a process they called phonological readout. They argue that at output, stored phonological forms are mapped onto ‘abstract articulatory gestures’, which may be based on the processes developed for speech perception. Longer words take longer to prepare for output via this mapping and therefore recall is impaired. Thus, although the word length effect for heard words can be found in young children, a number of factors may contribute to the effect.

2.5.ii. Speech similarity effect

As with the word length effect, the effect of speech similarity on recall by hearing children is influenced by stimulus modality. Four- and five-years-olds are affected by speech similarity of auditorily presented stimuli (e.g., Halliday, Hitch, Lennon & Pettipher, 1990; Hayes & Schulze, 1977; Hulme, 1987). However, Hitch, Halliday, Schaafstal and Heffernan (1991) showed that recall by five-year-olds was not sensitive to speech similarity for labels of pictorial stimuli. Thus, young children probably do not spontaneously recode pictorial stimuli into a speech-based code. This supports conclusions drawn from studies of the word length effect.
Hitch et al. also clarified a previous discrepancy in the literature. Hulme (1987) had shown that four-year-olds were sensitive to speech similarity of pictures. However, in this study the experimenter overtly labeled the pictures at presentation. Hitch et al. confirmed that when young children were themselves allowed to overtly label pictorial stimuli they show a speech similarity effect (see also Ford & Silber, 1994; Johnston & Conning, 1990). Since verbally generated labels are essentially auditory stimuli they gain direct access to the phonological store and lead to a speech similarity effect.

2.5.iii. Concurrent speech effect

Concurrent speech has been shown to impair recall of pictorial stimuli in eight-year-olds (Hitch, Halliday & Littler, 1989). This may be due to disruption of the recoding process or disruption of subvocal rehearsal. In contrast, if recall of auditory stimuli is impaired by concurrent speech, this could only be due to disruption of subvocal rehearsal as auditory stimuli do not require recoding.

Henry (1991 - Experiment 2) tested five- and eight-year-olds on memory span for spoken stimuli. Subjects were tested under three conditions: concurrent speech (saying ‘blah’); irrelevant speech (hearing ‘blah’) and both irrelevant and concurrent speech combined. Neither age group was affected by the concurrent tasks. These results suggest that cumulative subvocal rehearsal is not used by the age of eight. The results also suggest that the effect of concurrent speech on recall of visual stimuli by eight-year-olds in the Hitch et al. study was due to disruption of verbal recoding of the stimuli, not rehearsal. These data support the conclusions drawn from studies of the word length effect, which suggest that the important STM process of cumulative subvocal rehearsal is not used for either spoken or pictorial stimuli until late childhood.
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Since concurrent tasks are used in two experiments in this thesis, studies of STM that have used these tasks with hearing children will be discussed further in section 2.6.iii.

2.5.iv. Use of STM codes by hearing children

Consideration of the characteristic effects of phonological STM in young children illustrates that a speech-based code is not an obligatory code that is used from a very early age for all stimuli. Studies of the effects of word length, speech similarity and concurrent speech suggest that from the earliest age tested, around four/five-years-old, children represent auditory stimuli in a speech-based STM code. In contrast, pictorial stimuli do not appear to be represented in a speech-based code until around seven-years-old when children start to use the subvocal control process to recode these stimuli. This pattern of use of speech-based coding is supported by a study of children's awareness of inner speech, which found that six/seven-year-olds, but not four/five-year-old, could infer that others may use a strategy such as 'inner speech' (Flavell, Green, Flavell & Grossman, 1997).

Thus, the use of a speech-based STM code develops and there are likely to be individual differences between children in their ability to use this code (Cowan, 1996). Children who find the recoding process difficult may require more processing resources to complete the recoding task. In addition, a more able subject may have the foresight to recode stimuli at more appropriate points in the trial than a less able subject.

Young children may not use a speech-based STM code to represent pictured stimuli, however the fact that recall of visual stimuli is not at floor level suggests that some form of STM code can be used. A number of studies have demonstrated that this alternative code is likely to be visually based (Hayes & Schulze, 1977; Hitch, Woodin
& Baker, 1989; Longoni & Scalisi, 1994; Walker, Hitch, Doyle & Porter, 1994). For example, Hitch, Halliday, Schaafstal and Schraagen (1988) tested five- and ten-year-olds on SOR of pictures that were either similar in visual features (e.g., pen, fork) or visually dissimilar (e.g., pig, cake). Five year-olds were poorer at recall of visually similar pictures than dissimilar pictures. In contrast, recall by ten-year-olds was not affected by visual similarity. Hitch, Woodin and Baker (1989) extended this conclusion. They showed that eleven-year-olds were affected by visual similarity when the use of a speech-based code was disrupted by concurrent speech. That is, when the dominant speech-based code was unavailable, children in late childhood could still utilise a visual code.

In summary, greater awareness of the importance of stimulus modality in tests of immediate recall has demonstrated that children go through a developmental progression in their use of STM codes (see Hitch, 1990; Hitch & Halliday, 1983). Very young children can use a speech-based code to represent auditory stimuli. However, a visual code is used to represent pictorial stimuli until mid-childhood when children begin to use verbal labels.

The studies reviewed above only tested four/five-years-old and ten/eleven-years-olds. Children in mid-childhood have yet to be tested on recall of visually similar stimuli. Therefore, it is unclear whether the existence of a speech similarity effect indicates a simple switch from the use of a visual code to a speech-based code or whether children go through a transitional period in which both visual and speech-based codes are used. This possibility is addressed in Experiment 4 in this thesis by testing this age group on recall of visually similar and speech similar pictures.
2.5.v. Development of subvocal cumulative rehearsal

The ability to represent pictorial stimuli in a speech-based STM code develops with age. Once represented in a speech-based code, auditory and pictorial stimuli must be refreshed to achieve efficient immediate recall. According to the working memory model, the subvocal rehearsal process is responsible for this function. However, the fact that the subvocal rehearsal process is used at around seven-years-old for verbal recoding of pictured stimuli does not necessarily mean that this process is also used for rehearsal at the same age. On the basis of the effects of concurrent speech, Henry (1991 – see section 2.5.iii) argues that rehearsal is unlikely to be used until the age of nine or ten. However, others have argued that this is likely to take place slightly earlier at around seven-years-old (Gathercole & Hitch, 1993). Gathercole and Hitch (1993) point out that the use of rehearsal is unlikely to be switched on at a particular point in development. Rather, the strategic use of rehearsal is more likely to develop in stages. First, there may be overt repetition of items to be recalled. Then this repetition ‘reflex’ becomes covert. Eventually this reflex would come under the control of the child, resulting in adultlike cumulative subvocal rehearsal.

The conclusion that children do not use subvocal cumulative rehearsal until mid- to late childhood provided evidence against a rehearsal-based explanation of the increase of memory span with age (e.g., Hulme, Thomson, Muir & Lawrence, 1984). Hulme et al. (1984) showed that the time taken to repeat a word, word pairs or triads increased linearly with memory span for the same words. The same linear function held for subjects from four-years-old to adulthood (see also Nicholson, 1981). At that time, speech rate was thought to be an indirect measure of rehearsal speed so these data were viewed as supporting the idea that children as young as four used adultlike rehearsal and that the increase in memory span with age was due to increased rehearsal efficiency. It is now clear from studies of the word length effect and concurrent speech (e.g., Henry, 1991) that children are unlikely to use cumulative subvocal rehearsal until around nine-years-old. Rather the relationship between
articulation rate and STM ability in young children is likely to reflect an output effect. That is, as children get older they can output words more quickly, so that they may be less vulnerable to decay in storage (Cowan & Kail, 1996; Henry, 1991).

Rehearsal therefore cannot provide a full account of increases in memory span in young children. Other age-related factors must also be involved (Henry, 1994; Henry & Millar, 1991). Recent studies have shown that these factors include: output preparation time (Henry, 1991); stimulus familiarity (Henry & Millar, 1991); identification time (Hitch, Halliday & Littler, 1989); vocabulary knowledge (see Gathercole, 1998); phonological skill (Kail, 1997); memory search rate (Cowan, 1996) and general processing speed (see Cowan & Kail, 1996).

2.5.vi. Insights from development: conclusions

In summary, the phonological store component of the phonological loop is present from an early age in hearing children and may be used only to store auditory stimuli. Visual stimuli only gain access to the phonological store once recoded into a speech-based form via the subvocal control process. This process can start to be evident at around seven-years-old (Gathercole & Hitch, 1993). However, it may not be used routinely to rehearse visual and auditory stimuli until around nine-years-old.

This developmental fractionation of working memory (Hitch, 1990) has furthered our understanding of the increase in memory span with age. It has also helped to validate the proposed dissociation between components of the phonological loop in the working memory model.
2.6. Further consideration of concurrent speech

Two experiments in this thesis use concurrent tasks to investigate speech and sign-based STM coding by deaf people. This approach has rarely been used with deaf people. Therefore, it is essential to ensure that any effects of concurrent linguistic tasks on recall are interpreted correctly. Since both the central executive and the phonological loop are involved in performing linguistic STM tasks and linguistic concurrent tasks, it is possible that the deleterious effect of concurrent speech is due to disruption of either of these components of the working memory system. If the locus of the concurrent speech effect is the central executive, this is indicative of general cognitive interference from the requirement to initiate and maintain the irrelevant concurrent task (see e.g., Parkin, 1993). However, the effect of concurrent speech is generally accepted as indicating specific disruption of the phonological loop. Baddeley (1990) cites evidence from patients and normals to support this position. However, in situations where the effect of concurrent speech is unclear, for example with special subject groups such as deaf people, it is necessary to be cautious. It would be unwise to interpret any effect of concurrent speech as solely indicative of disruption of the phonological loop when it is equally likely that the locus of the effect is the central executive.

This issue has often been addressed using a concurrent task as a control task. Ideally, such tasks should involve the same degree of central executive processing as concurrent speech, but not load specifically on the phonological loop (i.e., not speech-based). In addition to these tasks being non-verbal they should also be non-articulatory. Wilding and White (1985) showed that chewing, which is non-verbal yet articulatory, impaired performance on a rhyme judgement task to the same extent as mouthing a word, which is a verbal articulatory movement. In this thesis, I apply Wilding and White’s findings to immediate recall and use a non-articulatory task to control for some of the motor demands of concurrent speech and sign. Studies that have used this approach with hearing people will now be reviewed in detail.
2.6.1. Non-articulatory control tasks in tests of immediate recall by adults

Parkin (1993) argues that a non-articulatory task is only useful as a control task if it has "the same general distracting qualities" (1993, pg. 130) as concurrent speech. However, at present there is no reliable measure of the comparative distraction levels of concurrent tasks. Therefore, subjective judgments have to be made regarding the choice of appropriate tasks. For example, Baddeley (1986) suggests that tapping a single finger is equivalent to repeating a single utterance and that it is "always wise in studies of articulatory suppression to include a tapping condition to control for any general attentional effects on performance" (1986, pg. 58). However, the majority of studies of immediate recall have not followed this advice. Rather, many have simply cited one of a handful of earlier studies that did include a non-articulatory concurrent task. There does not appear to be a published report that tests hearing adults on SOR, under conditions of concurrent speech and concurrent non-articulatory tasks within the same study. Some studies have used non-articulatory concurrent tasks in conjunction with the Peterson forgetting paradigm, which involves recall of consonant trigrams following filled or unfilled retention intervals of different lengths. These studies will now be reviewed.

Vallar and Baddeley (1982)

Vallar and Baddeley (1982 - Experiment 1) tested subjects on the Peterson forgetting task (Peterson & Peterson, 1959). Recall on this task is typically poorer when subjects are required to count backwards in threes in the retention interval than when they are not given a secondary task. This effect was traditionally explained in terms of disruption of rehearsal by the secondary task (Peterson & Peterson, 1959). Vallar and Baddeley argued that if this interpretation was correct then repeating 'the, the' aloud in the retention interval should also disrupt rehearsal in the Peterson task and have the same effect as backwards counting. A non-articulatory control task was also included. This involved tapping a single hand at the same rate as concurrent speech.
Recall was affected by counting backwards in threes but not by repeating 'the' or hand tapping. Vallar and Baddeley argue that counting backwards does not interfere with subvocal cumulative rehearsal as originally thought, rather it involves "greater general processing demands" (1982, pg. 58) than concurrent speech.

Many authors have cited this study as support for the argument that tapping a single hand is an adequate control task for concurrent speech in tests of SOR. However, there are a number of problems with this interpretation:

- The Peterson task only requires recall of three consonants, which is an easier task than standard SOR of six to eight items. Since the difficulty of the primary task is likely to interact with the difficulty of the secondary task, generalising from the Peterson task to a SOR task may not be valid.
- Subjects only performed the secondary task in the retention interval and not during presentation of stimuli. As the working memory model predicts that continuous speech has differential effects in these two phases of the task, the effect of hand tapping may also vary according to the stage at which it is performed.
- Recall in the continuous speech and tapping conditions was close to ceiling. Therefore it is possible that differences between conditions were masked.

These criticisms do not detract from Vallar and Baddeley's main findings and their implications for the use of the Peterson paradigm. However, the issue of whether tapping a single hand is an adequate control for the general cognitive requirements of concurrent speech remains. A study by Morris (1986) raises similar doubts.

*Morris (1986)*

Morris (1986 - Experiment 2) also used the Peterson paradigm to investigate the use of central executive resources by Alzheimer's Disease (AD) patients. In agreement with Vallar and Baddeley (1982), recall of trigrams by age-matched controls was not
affected by continuous speech or tapping a single hand during the retention interval. However, recall by AD patients was affected by continuous speech and tapping, with continuous speech having the greater effect.

The hypothesis that concurrent speech and tapping a single hand are of an equal level of difficulty cannot account for this finding. Vallar and Baddeley had shown that trigram recall in normal adults did not use subvocal rehearsal, yet in these AD patients concurrent speech led to a greater effect on recall than did hand tapping. Morris proposed that, unlike age-matched controls, AD patients may rely on subvocal rehearsal to complete the Peterson task, thereby leading to a greater effect of concurrent speech. However, this hypothesis has no independent support. An equally likely explanation is that continuous speech and tapping disrupted recall by AD patients because they suffer from impaired control of central executive processes. Furthermore, the fact that continuous speech impaired recall to a greater extent than continuous tapping suggests that the central executive component involved in continuous speech is greater than that involved in tapping a single hand.

### 2.6.ii. Non-articulatory concurrent activity in tasks other than immediate recall

Although not widely used in tests of immediate recall, non-articulatory control tasks have been used in tests of word learning and reading. Some of these studies will be discussed here as they are relevant to the issue of what is the appropriate level of difficulty for non-articulatory concurrent tasks as control tasks for concurrent speech.

**Word learning - Papagno, Valentine and Baddeley (1991)**

A study regularly cited as support for the use of finger tapping as a non-articulatory task, which has similar processing requirements as concurrent speech, is an investigation of word learning by Papagno, Valentine and Baddeley (1991). They tested subjects on paired associate recall of 'word - word' pairs and 'word - foreign
word' pairs. Subjects were either required to repeat 'bla' or tap a finger as stimuli were presented. Italian subjects were not affected by either concurrent speech or tapping when learning 'word-word' pairs. In contrast, learning of 'word - foreign word (Russian)' pairs was impaired by concurrent speech but not finger tapping. English subjects showed the same interaction between concurrent task and word type when presented with Finnish words as the novel stimuli (Experiment 6). Papagno et al. argue that this indicates the importance of the phonological loop to the learning of new vocabulary (see also Baddeley, Gathercole & Papagno, 1998).

Of relevance to the present discussion is one experiment in this series in which English subjects were tested on learning spoken 'English – Russian' word pairs. Here subjects did not appear to use the phonological loop as they did not show the predicted interaction between word type and concurrent task (Experiment 4). Rather, it is likely that a semantic code was used as English speakers were able to generate a large number of semantic associates to the Russian stimuli (Experiment 5). If English subjects did not use speech-based coding in Experiment 4, this study may give additional insight into whether concurrent finger tapping is a valid control task for concurrent speech. Concurrent speech led to poorer performance than concurrent finger tapping. Therefore, in a task in which “phonological coding may not have played a particularly important role” (Papagno et al., 1991, pg. 339), concurrent speech led to significantly poorer performance than tapping a single finger at the same rate. This finding does not support the hypothesis that tapping a single finger employs the same amount of central executive resources as concurrent speech.

Reading
Many studies of reading have used non-articulatory concurrent tasks to control for the general cognitive effects of concurrent speech since the role of phonology in skilled reading is not yet fully understood (see Besner 1987). Two such studies are worthy of consideration here as they are relevant to the issue of the appropriate choice of a non-articulatory concurrent task.
Levy (1981)

Levy (1981) tested subject's ability to tell whether a target sentence was one of three they had just seen or heard. During presentation of sentences subjects were either required to continuously repeat '1, 2, 3, 1, 2,' or tap a hand at the same rhythm as the concurrent speech. With auditory stimuli subjects were affected by both tasks to a similar degree. When stimuli were visual, subjects were again affected by both tasks but concurrent speech had a significantly greater effect than concurrent tapping. Levy argues that the increase in task demands from reading, in comparison to listening to sentences, caused subjects to recruit phonological processes. Thus, leading to greater interference from concurrent speech than concurrent tapping.

Margolin, Griebel and Wolford (1982)

Margolin, Griebel and Wolford (1982) agree with Levy (1981) that reading increases task demands in comparison to listening but they disagree that subjects are likely to recruit phonological processing in this situation. Rather they favour a general resource limitation hypothesis. They argue that concurrent speech leads to greater disruption because it is a more difficult task than concurrent tapping and that this difference in level of difficulty only becomes apparent when the tasks are combined with a more difficult primary task, in this case reading. Margolin et al. (1982) also argue that the use of hand tapping as a control task was problematic, saying:

"it is crucial that tasks used as a comparison with articulatory suppression be roughly similar in difficulty. Although difficulty level is not easy to evaluate in the abstract, tapping seems to us to be an easier task than articulatory suppression" (1982, pg. 614).

To explore this issue further Margolin et al. replicated the Levy (1981) study using a concurrent task in which subjects had to press a button in response to a low-level electric shock applied to a finger. In the concurrent speech condition subjects counted aloud from 1 to 10 continuously during presentation of sentences. For auditory
stimuli the results were consistent with those of Levy (1981) as there was no
difference between the effects of the two concurrent tasks. With visual stimuli
Margolin et al. found that both concurrent speech and reaction to shock impaired
recall to the same extent, whereas Levy had found that recall was disrupted to a
greater extent by concurrent speech than tapping. Therefore, Margolin et al. argued
that the effect of concurrent speech in this task was due to ‘general interference’
rather than specific disruption of speech coding as argued by Levy.

However, a potentially important component of the shock task that was overlooked by
Margolin et al. was that shocks were administered randomly over presentation of the
sentences, whereas concurrent speech was self-regulated by the subject. As central
executive resources are employed to override automated tasks (see section 2.3.i) it is
possible that in this situation concurrent speech actually made fewer demands on
executive resources than the unpredictable shock task.

Despite this, Margolin et al.’s results highlight the need to be cautious when drawing
inferences from the effects of concurrent speech. They conclude that their findings do
not imply that concurrent speech is not useful in all paradigms, rather that:

‘...the effect of articulatory suppression is based on two components: one a
disruption of articulatory processes and the other general disruption of
cognitive processing. In short-term memory tasks, the former component
appears dominant. In tasks using sentences or text, the general deficit appears
dominant’ (Margolin et al., 1982, pg. 617).

Considering concurrent speech in this way may be particularly relevant when working
with children. It is possible that a general interference component of concurrent
speech is greater for children than for adults for whom processes may become more
quickly automated. This possibility will now be considered.
2.6.iii Use of non-articulatory control tasks with children

Halliday, Hitch, Lennon and Pettipher (1990)

The most detailed investigation of the use of concurrent speech and other concurrent tasks with young children was by Halliday, Hitch, Lennon and Pettipher (1990). They conducted a series of experiments to determine whether concurrent speech interacts with speech similarity and word length effects in recall by children in the same way as in recall by adults. The non-articulatory task included to control for the 'general attentional effects' of concurrent speech was tapping a pen on the table.

In Experiment 1 five and eleven-year-olds were tested on memory span for pictures with short or long spoken names. Subjects were tested in three conditions: no concurrent task; concurrent pen tapping; concurrent speech (repeating 'teddybear'). Recall by five-year-olds was impaired by both concurrent tasks to the same extent, but they showed no effect of word length. This suggests that the disruption from both concurrent tasks was due to general cognitive interference. The same conclusion appeared to apply to eleven-year-olds whose recall was also affected to the same extent by both concurrent tasks. Furthermore, although eleven-year-olds showed a word length effect in the control condition and this was eliminated in the concurrent speech condition, concurrent tapping also eliminated the effect. Therefore, the results do not provide any evidence for a specific effect of concurrent speech on phonological STM in these eleven-year-olds.

In Experiment 2, five and ten-year-olds were tested on recall of speech similar and dissimilar pictures under three conditions: no concurrent task; concurrent pen tapping and concurrent speech. Ten-year-olds were affected by both concurrent tasks, but in contrast to Experiment 1, the disruptive effect of concurrent speech was greater than that of concurrent tapping. Furthermore, a speech similarity effect was present in both the hand tapping and control conditions but was abolished by concurrent speech. These findings suggest that concurrent speech had a specific effect on phonological
processing by ten-year-olds in this experiment.

In contrast to Experiment 1, five-year-olds in Experiment 2 were not affected by concurrent speech, concurrent tapping or speech similarity. The lack of an effect of concurrent tasks could be due to a floor effect on the memory span task. In this task the number of pictures to be recalled is gradually increased from two to three and so on. Children recalled approximately two items correctly in the control condition. This was slightly lower than in Experiment 1. To test this possibility, in a third experiment only five-year-olds were tested on recall of three pictures, as opposed to testing memory span. The effects of speech similarity and word length were tested under the concurrent task conditions used in Experiments 1 and 2. The results confirmed conclusions from Experiments 1 and 2 as five-year-olds did not show effects of either speech similarity or word length. Furthermore, recall was affected by concurrent speech and concurrent tapping, however there was no difference between the two tasks. This suggests that when task demands are increased by testing recall of supra span lists, more central executive resources are recruited and therefore disruptive effects of concurrent tasks become more apparent.

The Halliday et al. study highlights some important considerations. Both five- and ten-year-olds were affected by concurrent speech. If a non-articulatory concurrent task had not been included this effect may have mistakenly been interpreted as indicating the disruption of speech-based recoding or rehearsal. A study cited by Hitch (1990) demonstrates this problem of interpretation. Hitch, Halliday and Littler (unpublished) compared recall by five and eleven-year-olds during concurrent speech and no concurrent task conditions. Recall by both age groups was affected by concurrent speech. This was interpreted as indicating that five-year-olds engage in "active rehearsal of spoken materials" (1990, pg. 234). However, Hitch (1990) did

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2 It is possible that this also explains the lack of effect of concurrent tasks on memory span of 5- and 8-year-olds in Henry's (1991) experiment (see section 2.5.iii).
accept that this interpretation should be considered cautiously as concurrent speech may disrupt recall by “dividing attention” rather than disrupting rehearsal. Thus, the data can only be interpreted accurately by comparing the effect of concurrent speech to a non-articulatory concurrent task. To indicate a specific effect on speech-based coding, the disruptive effect of concurrent speech must be greater than that of the non-articulatory task.

Data from the Halliday et al. studies also support Margolin et al’s (1982) account of the effect of concurrent speech, at least for children. The fact that concurrent tapping significantly impaired recall in comparison to a control condition for both five and eleven-year-olds indicates that for these age groups performance of any concurrent task involves some degree of general executive processing.

2.6.iv. Summary of studies using concurrent speech

There are few studies of immediate recall relevant to the issue of whether concurrent speech leads to general cognitive interference. Studies of word learning and reading generally support the position that there are distinct effects of concurrent speech. First, there is a general cognitive interference effect and second, specific disruption of a speech-based STM code. In terms of the working memory model these effects are due to disruption of the central executive and phonological loop respectively. The effects of these two aspects of concurrent speech may be more or less prominent in different types of tasks and on different subject groups, such as adults, children and special subject groups. Finally, it is still unclear what is the appropriate level of difficulty for a non-articulatory concurrent task to control for the central executive demands of concurrent speech. Margolin, Griebel and Wolford (1982) suggest that tapping a single hand is too simple. However, their ‘response-to-shock task’ may be too difficult given its unpredictability.
2.7. Chapter 2: Conclusion

The development of STM coding and processes is now reasonably well understood in terms of the working memory model (Baddeley, 1986). Hearing children go through a developmental progression in their use of STM codes. Young children use a speech-based STM code to represent auditory stimuli from a very early age, but pictorial stimuli are represented using a visual code until around seven-years. Then a speech-based code becomes dominant for all stimuli. This code is only used subvocal rehearsal at around the age of nine- or ten.

Knowledge of the development of STM coding and processing in hearing children can now be used as a working model from which to explore the development of these skills in deaf children throughout the rest of this thesis.
Chapter 3 - Short-term memory coding by deaf people

3.1. Introduction

In comparison to hearing chronological age-matched peers, deaf children have repeatedly been shown to have poor immediate memory spans 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). This deficit even extends to sign stimuli when recall by deaf and hearing signers is compared (Krakow & Hanson, 1985). In contrast, deaf and hearing subjects do not differ in recall of non-linguistic stimuli, that is stimuli that are unnamable, such as unfamiliar faces (e.g., O'Connor & Hermelin, 1973a), spatial arrays of lights (Tomlinson-Keasey & Smith-Winberry, 1990), geometric designs (McDaniel, 1980) and locations (Sterne, 1996). Proficiency in the use of linguistic recoding strategies is likely to play an important role in this distinction between recall of linguistic and non-linguistic stimuli by deaf people.

Early researchers often regarded deaf people as a ‘without language’ group who consequently could not establish a speech-based STM code. As theories of STM were predominantly speech-based this posed a challenge to memory researchers and led them to ask how deaf people represent information within STM. “Can we be sure teachers and [deaf] pupils are thinking in the same stuff?” (Conrad, 1970, pg. 181). Chapter Two described the language-based STM codes and STM processes used by hearing people. Less is known about STM coding and processing by deaf people, and even less about the development of these codes and processes in deaf children, which is the main focus of this thesis.

This aim of this chapter is to review the literature relevant to this issue. The chapter is divided into the following sections:
First, three different STM coding options that may be available to deaf children are outlined. These are visual coding, speech-based coding and sign-based coding.

Second, evidence for the use of these STM codes will be discussed by considering variations of effects known to be characteristic of verbal STM in hearing people. These are effects on recall of stimulus similarity, irrelevant stimuli, stimulus length and concurrent activity.

Third, whether there is sufficient evidence to suggest the existence of a sign-based working memory system will be considered.

Fourth, aspects of speech-based STM coding by deaf people will be discussed, including the subject characteristics that relate to the use of a speech-based code and the possible nature of such a STM code in deaf people.

Finally, how the use of STM codes may affect overall STM performance will be considered by comparing deaf subjects’ performance on tests of free and serial order recall tasks.

3.2. STM coding options available to deaf people

First reactions to the question of what do deaf people ‘think in’ (e.g., Furth, 1966) were that deaf people must use visual or spatial information in STM (e.g., Blair, 1957; Pintner & Paterson, 1917). Then, in the 1970s, following the recognition of sign languages as ‘true’ languages, there was much interest in whether deaf signers could use a STM code based on the formational parameters of signs (e.g., Bellugi & Siple, 1974). It was also realised that hearing loss did not necessarily preclude access to all aspects of speech phonology, but that it may be possible to establish speech-based representations purely on the visual aspects of speech (Dodd, 1976). Each of these coding possibilities will now be discussed.
3.2.i. Visual coding

There are two main reasons for proposing that deaf people may use a visual STM code to a greater extent than hearing people. First, deaf people may be able to compensate for their hearing loss by developing highly sophisticated visual systems (Blair, 1957). Although this proposal seems intuitively attractive, it appears that sufficient and appropriate visual stimulation is needed for this neural compensation to occur (Mayberry, 1993). One such form of visual stimulation is exposure to a visuo-spatial language, sign language. It has been argued that early exposure to sign language can enhance specific visuo-spatial cognitive processes which are linked to sign language such as detecting mirror reversals (Emmorey, Kosslyn & Bellugi, 1993) and face discrimination (Bettger, Emmorey, McCullough & Bellugi, 1997). It is also possible that such exposure could lead to enhanced ability to use a visual STM code.

The second reason why deaf people may use a visual STM code more than hearing people is based on research with hearing children. Use of visual STM code by young hearing children gradually decreases through childhood as they start to use a speech-based code. By around ten-years-old this STM code is used to the virtual exclusion of others. Many deaf children may not establish an efficient speech-based STM code. Therefore, it is possible that a visual code remains a useful STM code for deaf children beyond late childhood.

3.2.ii. Speech–based coding

The vast majority of research in the area of STM coding by deaf people has focused on the use of speech-based coding (e.g., Campbell & Wright, 1989; Conrad, 1979; Hanson, 1982; 1990). The reason for this is that hearing people are largely dependent upon the use of a speech-based STM code to facilitate STM, which in turn appears to be related to a number of cognitive skills. Therefore, the use of a speech-based code
has often also been regarded as fundamental to the cognitive development of deaf children.

The quality of a speech-based code established in the absence of auditory input may be fundamentally different to that of a speech-based code as used by hearing people. In such situations, much knowledge of speech phonology must come from lip-reading, self-articulation and from reading text (Dodd, 1976). The precise nature of a speech-based code as used by deaf people and the individual differences related to its use will be discussed in detail later in this chapter.

3.2.iii. Sign-based coding

Since hearing people use a STM based on the phonological properties of spoken language, some cognitive psychologists have assumed that deaf signers will also recode information into the phonological properties of their first language, sign language. This hypothesis has been termed the Primary Language Coding Hypothesis (Shand, 1982).

To investigate the form that such a sign-based STM code may take the phonological structure of signs need to be considered. Just as the constituent units of spoken words are characterised as phonemes, signs can be described in terms of their component parts, termed ‘cheremes’ by Stokoe (1960). Stokoe described three basic parameters of signs - handshape, location and movement. Friedman (1977) later added ‘orientation’ of the hands to this list of parameters. Figures 3.1a – 3.4b show pairs of BSL signs which differ on just one of these parameters while the remaining three parameters remain constant. Various terms have been used to describe a STM code based on these parameters of sign language, such as cheremic, formational or phonological. In this thesis the code is simply referred to as a sign-based code in contrast to the use of the term speech-based code.
Chapter 3

Figure 3.1a: LIKE

Handshape minimal pair: same location, orientation and movement

Figure 3.1b: MY

Figure 3.2a: NAME

Location minimal pair: same handshape, orientation and movement

Figure 3.2b: AFTERNOON

Figure 3.3a: ARRIVE

Movement minimal pair: same handshape, orientation and location

Figure 3.3b: JAM

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1 Figures reproduced with permission from Sutton-Spence and Woll (in press). Arrows represent the direction of the movement.

2 BSL glosses for English words are referred to in capital letters.
If a sign-based STM code is used by some deaf people it does not necessarily follow that this would function in the same way as a speech-based STM code. There are differences in brain specialisation for signed and spoken languages. For example, the special skills of the right hemisphere in parsing spatial relations (and possibly visual movement) suggest that it is more closely involved in sign language processing than auditory spoken language processing (Neville, Bavelier, Corina, Rauschecker, Karni, Lalwani, Braun, Clark, Jezzard & Turner, 1998; Poizner, Battison & Lane, 1979; Poizner, Klima & Bellugi, 1987). Furthermore, for a deaf child to successfully establish the use of a sign-based STM code, extensive exposure to a good sign language model is required. Chapter One described how few deaf children have early extensive exposure to such a model. Therefore, the extent to which young children are able to establish the efficient use of such a representation is variable.

Many studies that have investigated the use of STM codes by deaf people have adapted techniques used to explore linguistic STM in hearing people. These studies will now be reviewed in terms of the effect explored. These are effects of:

- similarity of stimuli
- irrelevant stimuli
- stimulus length
- concurrent activity
3.3. Similarity of stimuli

Recall of similar sounding stimuli (e.g., B, T, V) by hearing people is poorer than recall of dissimilar stimuli (e.g., L, J, Y) (Conrad & Hull, 1964). According to the working memory model this is explained in terms of confusion of similar memory traces in the phonological store. This methodology has also been adapted to investigate the use of visual coding by hearing children by testing their recall of visually similar pictures (e.g., Hayes & Schulze, 1977). The similarity technique has also been adapted to look at the use of a sign-based STM code by deaf people.

3.3.1. Visual confusion errors in letter recall

Wallace and Corballis (1973) explored visual STM coding by deaf people using a task which could be considered a precursor to the direct test of the effect of stimulus similarity on recall. They tested deaf teenagers on SOR of sequences of printed letters. Two sets of stimuli were used. Both were made up of the same letters, however one set was uppercase (e.g., B, H, N) and the other lowercase (e.g., b, h, n). Since both sets of stimuli were made up of the same letters, the acoustic, articulatory and fngerspelling properties of the stimuli were identical. The authors argued that any errors made with one set of stimuli but not the other must be due to visual coding. The results were analysed by establishing subjects’ error matrices indicating which items were substituted for others. The authors then inferred, for each substitution, whether it was visual or speech-based. Deaf subjects made predominantly visual errors, whereas hearing subjects made mainly speech-based errors.

Using a procedure similar to Wallace and Corballis, MacDougall (1979) explored visual coding developmentally. Subjects were tested on recall of the same letters printed in two different fonts, one leading to more similarity between letters than the other. Analysis of subjects’ error matrices showed that deaf eight- to ten-year-olds and older teenagers relied heavily on a visual code to complete the task.
The Wallace & Corballis and McDougall studies suggest that deaf children are more likely to use a visual code to represent linguistic stimuli than hearing subjects. However, in neither study were the stimuli directly manipulated so that they were similar in specific ways. Manipulating the visual similarity of pictorial stimuli has been widely used as a test of visual STM coding with hearing children (e.g., Hayes & Schulze, 1977; Hitch, Halliday, Schaafstal & Schraagen, 1988; Hitch, Woodin & Baker, 1989). This approach has not yet been used with deaf children to investigate the use of a visual STM code for stimuli for which the linguistic labels are known. This is addressed in Experiment 4 in this thesis.

### 3.3.ii. The importance of stimulus modality on speech and sign similarity effects

A number of studies have investigated speech- and sign-based STM coding by deaf people by testing recall of speech and sign similar stimuli within one experiment. In one such study Shand (1982) argued that deaf signers recode stimuli into their first language, sign language. Importantly, Shand argued that both signed stimuli and printed English stimuli are recoded into a sign-based STM code. To explore this position Shand tested deaf college students on written SOR of stimuli which were either presented as printed English words or American Sign Language (ASL) signs. Three sets of stimuli were tested:

- speech-similar items (e.g., shoe, through, new)
- sign-similar items - (e.g., candy, apple, onion - similar in terms of movement and location).
- dissimilar items - this consisted of four items from both the speech-similar and sign-similar sets, so that a subset of the experimental stimuli sets acted as their own controls.
The effect of speech-similarity on recall was not significant. In contrast, recall of sign-similar items was poorer than dissimilar items for both ASL signs and printed English stimuli. Shand claimed deaf subjects recoded printed English words into a sign-based STM code, thus supporting his Primary Language Coding hypothesis.

However, Shand's stimuli were not controlled for word length, distinctiveness or semantic relations. Hanson and Lichenstein (1990) repeated Shand's experiment with non-signing hearing subjects. These subjects were also poor at recalling printed words for which the equivalent ASL glosses were similar in sign-phonological structure. While Shand's (1982) study is often cited as offering evidence for the use of a sign-based STM code by deaf people, the effect is more likely to be one of word length, distinctiveness or semantic relations than actual use of sign-based coding.

Hanson (1982)

Hanson (1982- Experiment 1) investigated the importance of stimulus modality on the use of speech and sign-based STM coding directly. Deaf college students were tested on probed recall of three sets of stimuli which were similar in different ways. Each of these stimulus sets had its own control set of dissimilar stimuli, matched on frequency to the experimental set. The three experimental stimuli sets were:

- speech-similar items (e.g., two, blue, who)
- sign-similar items (e.g., knife, egg, name – similar in ASL in terms of handshape and all were articulated in neutral signing space in front of the signer)
- orthographically similar but speech dissimilar (e.g., meat, head, peace). These stimuli were included to control for the possibility that poor recall of speech similar stimuli may be due to orthographic similarity between words rather than speech-similarity per se.
The following groups were tested on recall of these stimuli presented in the following modalities:

- Deaf group 1 - presented with sign stimuli
- Deaf group 2 - presented with printed word stimuli
- Hearing group - presented with printed word stimuli

Since all deaf subjects were native signers, it was predicted that, of all deaf people, this subgroup of the deaf population would be most likely to recode printed English stimuli into a sign-based STM code.

The deaf sign stimulus group showed poor recall of sign-similar and speech-similar signs but not orthographically similar signs. In contrast, recall by the deaf and hearing groups presented with printed words was affected by speech similarity but not by sign or orthographic similarity. Therefore, a STM code based on the parameters of ASL was only used when sign stimuli were to be recalled.

A possibility that Hanson does not discuss is that differences in response modality may have also contributed to differences between groups. Subjects presented with sign stimuli recalled in sign, whereas subjects presented with words used a key press response. Campbell and Wright (1990) showed that deaf children appeared to use a speech-based STM code when a spoken response was required but not when a non-verbal response was required (see section 3.5.i). Therefore, it is likely that both stimulus modality and response modality play an important role in determining STM coding by deaf signers in any particular STM task.

3.3.iii. Speech similarity effects on recall by deaf teenagers (Conrad, 1979)

A large study that investigated deaf children’s use of speech-based STM coding to recall printed English stimuli was that of Conrad (1979). In earlier studies Conrad and
colleagues had used the analysis of substitution error matrices to investigate speech-based coding by deaf people (e.g., Conrad & Rush, 1965; Conrad, 1970; Conrad, 1972). Results from these studies indicated that some deaf children made speech errors, as did hearing children. This led Conrad to explore the use of a speech-based code directly, by testing subjects' recall of similar sounding words. This work was published in Conrad's seminal work 'The Deaf School Child' (1979).

In 'The Deaf School Child' Conrad set out systematically to assess the 'language for thought' used by deaf school-leavers, in particular their use of 'internal speech' or speech-based coding. The study involved 468 prelingually deaf fifteen/sixteen-year-olds from England and Wales, the majority of whom were educated orally, following the dominant mode of deaf education at that time. The sample covered the full range of hearing loss. The selection criterion was that pupils were receiving special education in either a school for the deaf or a partially hearing unit and English was used as the first language in the home. Subjects were tested on written recall of sequences of five printed words taken from a speech similar set (do, few, who, zoo, blue, true, screw, through) or control set (bare, bean, door, furs, have, home, farm, lane).

Subject's errors in the recall of each set of stimuli were then used to establish their Internal Speech Ratio (IS-R). This was the percentage of all errors that were speech-based. For example, a subject who made three errors in the speech similar condition and a total of four errors across both conditions had an IS-R of 75. The size of the IS-R was regarded as an indicator of the extent to which the subject used a speech-based code. Conrad excluded all subjects with an IS-R between 48 and 52 whose coding was ambivalent. Subjects with scores greater than 52 were classed as speech-based code users and those with scores below 48 as using a non-speech-based code.

The results showed that 94% of hearing controls were classed as using a speech-based code. In comparison around 45% of children with hearing losses greater than 85 dB
were classed as using a speech based code. Thus, over half of the severely and profoundly deaf children tested showed no evidence at all for the use of a speech-based STM code.

One problem with this study relates to those subjects who fell in the ambiguous coding (48<IS-R>52) category (n=46, approx. 10% of total). By definition these subjects made a similar number of errors on both stimulus sets. Conrad argued that these subjects may have used a manual code rather than a speech-based code. Alternatively, he proposed that these subjects may have “unusually weak preference for any coding system to a point where - perhaps haphazardly - they shift from one to the other” (1979, pg. 105). However, this method of calculating an IS-R does not distinguish between a subject making few errors and a subject making many errors with both stimulus sets. This difference in error rate should distinguish between subjects that fit the two explanations proposed by Conrad. Experiment 4 in this thesis investigates this possibility, using a different coding classification system.

Despite these problems, twenty years on, the results of Conrad’s study represent a benchmark of deaf children’s cognitive ability to which researchers still refer. It remains the only large-scale experimental study of language and memory in British deaf children. In addition, the work stimulated a new wave of research into cognition and deafness and imposed rigorous methodologies for subsequent researchers to follow. Some implications of Conrad’s findings on the education of deaf children were discussed in Chapter One. The theoretical implications of this study with regard to the nature of a speech-based code as used by deaf people and the subject characteristics Conrad identified as related to the use of this code will be discussed later in the chapter.

In summary, studies that have used the stimulus similarity technique to investigate speech- and sign-based STM coding support the position that stimulus modality is of fundamental importance to what type of STM code is used by deaf people. Deaf
people appear more likely to encode stimuli in a speech-based code when presented with English printed stimuli (e.g., Conrad, 1979; Hanson, 1982). However, if presented with sign stimuli, deaf signers are more likely to use a sign-based STM code (Hanson, 1982; Wilson & Emmorey, 1997a – see section 3.6.iv).

Using word and sign stimuli can be problematic. With word stimuli deaf people may automatically be placed at a disadvantage, given their generally lower reading levels. When sign stimuli are used, fluently signing hearing controls must be recruited, which can be difficult. Pictures have not been widely used to test the influence of speech and sign-similarity on recall by deaf people. This approach avoids the problems of word and sign stimuli and has the benefit of not steering subjects towards the use of one type of linguistic STM code over another. Rather subjects are able to use their preferred STM representation. Pictorial stimuli are used in all the experiments reported in this thesis.

3.4. Irrelevant Stimuli

Another characteristic effect of phonological STM in hearing people is the disruptive effect of irrelevant speech. Irrelevant speech played during the presentation of stimuli to be recalled impairs recall of spoken and written words by hearing subjects (Salamé & Baddeley, 1982). Since this effect is dependent upon auditory input this manipulation is not suited to investigating the use of a speech-based code by deaf people. However, a variation of this task can be used to investigate sign-based coding.

The sign analogue of the irrelevant speech task requires presentation of the irrelevant stimuli at the same time and in the same location as the sign stimuli to be recalled. As both the target and irrelevant are visual this is likely to cause attentional interference. One can, however, present the irrelevant material in a retention interval following the
presentation of stimuli since this method has been shown to produce an irrelevant speech effect with hearing subjects (Miles, Jones & Madden, 1991).

3.4.i. Visual and manual irrelevant tasks (Siple & Brewer, 1985)

Siple and Brewer (1985) investigated deaf college students’ use of sign-based STM coding. Their aim was to determine whether such a code was visually or manually (kinesthetically) based. Subjects were tested on SOR of signs. In the retention interval subjects either performed a visuo-spatial task (following lines in mazes to indicate where they ended) or a manual task (tying bows in shoelaces). The visuo-spatial activity, but not the manual task impaired recall. The authors therefore concluded that a sign-based STM code was more likely to be visually-based than kinesthetically-based.

However, methodological problems make interpretation difficult. The manual task of tying a shoelace may be easier and more automated than maze tracking. If so, the manual task may cause less general cognitive interference than the visual task, leading to better recall. Had hearing non-signers been tested on recall of words under the same task conditions this would have provided a direct test of whether the two tasks were of the same level of difficulty, as recall by hearing subjects should not be affected differentially by these tasks.

3.4.ii. Irrelevant pseudo-signs (Wilson & Emmorey, under review)

A better controlled study than that of Siple and Brewer (1985) has recently addressed the issue of interference from irrelevant stimuli on recall by deaf people. Wilson and Emmorey (under review) tested deaf college students on SOR of signs, while hearing subjects were tested on recall of the same items as printed words. Both groups were exposed to three types of irrelevant material in a retention interval of twelve seconds.
All conditions involved the same onset and inter stimulus interval (ISI) timings. The three types of irrelevant material were as follows:

- In the control condition a uniform light grey field was presented with a darker grey field in the ISI.
- In a ‘shape’ condition meaningless shapes were shown moving across the screen.
- Finally, pseudo-signs were presented that were formed by re-combining elements of the ASL sign stimuli.

Irrelevant shapes and pseudo-signs impaired recall by deaf subjects. Furthermore, the effect of pseudo-signs in comparison to shapes was of borderline significance ($p=.056$). A suffix effect does not appear to account for this effect since recency was not affected in any condition. These results would seem to suggest an irrelevant visual input effect, analogous to the irrelevant speech effect. However, recall by hearing subjects was also impaired by irrelevant pseudo-signs in comparison to the control condition, though this was of borderline significance ($p=.08$). Wilson and Emmorey argue that this borderline effect may be due to ‘attentional capture’ either because subjects automatically attend to human stimuli or because hearing non-signers were interested in watching sign language. Therefore, the authors conclude that there is a specific effect of irrelevant visual stimuli on the encoded memory for signs in deaf people, whether or not the irrelevant input is linguistic.

The implications from these studies of sign-based STM coding using irrelevant stimuli are not yet clear. Wilson and Emmorey’s ‘attentional capture’ explanation of the effect of irrelevant pseudo-signs on recall by hearing non-signers needs further support. In addition, the precise locus of the irrelevant stimuli effect on deaf signers in this study is unclear. It is possible that visual movement of the irrelevant stimuli made a substantial contribution to the disruptive effect since visual movement is an important parameter of sign phonology. This could be explored in the future by comparing the effects of static and dynamic irrelevant stimuli on recall of sign stimuli.
3.5. Length of stimuli

The next characteristic effect of phonological STM to be explored here is the effect of stimulus length. Immediate memory span for long words by hearing people is usually smaller than that for short words (Baddeley, Thompson & Buchanan, 1975). The working memory model has traditionally accounted for this in terms of the duration of the phonological loop being fixed. Therefore, fewer long than short words can be rehearsed in a given time leading to greater opportunity for decay of long items within the phonological store. However, an explanation of the word length effect that has been favoured more recently is that long words take longer to produce (Avons, Wight & Pammer, 1994; Cowan, Day, Saults, Keller, Johnson & Flores, 1992; Cowan, Keller, Hulme, Roodenrys, McDougall & Rack, 1994; Henry, 1991). Whether the effects is located at storage or at output, both explanations agree that at some stage of recall subjects use a speech-based representation of the item to be recalled. The handful of studies that have explored the effects of word and sign-length on recall by deaf people will now be discussed.

3.5.i. Word length effects and response modality (Campbell & Wright, 1990)

Campbell and Wright (1990 - Experiment 2) investigated speech-based coding by deaf oral teenagers by exploring the effect of word length on immediate recall. Subjects were tested on recall of pictures with one-, two- or three-syllable labels. Recall by deaf subjects and hearing reading-age matched children (nine-year-olds) was sensitive to word length when a naming response was required but not when tested using a picture selection response. In contrast, hearing teenagers showed a word length effect in both the naming and picture construction conditions. Kyle (1986) also showed that using a non-verbal response did not elicit a word length
effect in deaf adults. In the same paper Campbell and Wright (1990 - Experiment 1) showed that deaf teenagers, unlike hearing teenagers, did not use rhyme cues spontaneously in a paired association task. In accord with recent studies of the word length effect in hearing children, Campbell and Wright propose that the observed word length effect in these deaf subjects is indicative of "speech output preparation" (1990, pg. 281) rather than subvocal rehearsal.

This study highlights the importance of response modality when working with deaf people. It was only when speech-based knowledge was actually required in the form of spoken recall that the deaf teenagers were affected by word length. Spoken recall can be difficult for many deaf people and a written response may place many at a disadvantage given their generally lower level of literacy. Using a picture grid (e.g., Kyle, 1986) or picture selection response (Campbell & Wright, 1989) alters the nature of the task as this then becomes a test of recognition and memory for order, rather than a test of memory for item and order information. Therefore, in all experiments in this thesis subjects were allowed to recall in their preferred language mode, sign or speech, or in a combination of the two modalities. This has the benefit of not steering subjects towards the use of one code over another.

3.5.ii.  Sign length effects (Wilson & Emmorey, 1998)

The effect of sign length on recall by deaf people has not been well explored. One of the reasons for this is the difficulty in defining what constitutes sign length (see Kyle 1986, for discussion). However, one published study has tested the hypothesis that signs that take a long time to articulate are less well recalled than signs with a short articulation time. Wilson and Emmorey (1998) tested deaf college students on probed recall of long ASL signs, involving a large movement and short signs, which involved short movements without a change of location of the hands. Consistent with the effect of word length on recall by hearing people, recall was poorer for long than short
signs. This study also tested the effect of concurrent signing on recall and is described in more detail in section 3.6.iv.

3.6. Concurrent tasks

The final characteristic of phonological STM to be discussed in this chapter in relation to STM coding by deaf people is the effect of concurrent tasks on recall. When hearing people articulate an irrelevant word or phrase during the presentation of stimuli, their recall performance is impaired (Murray, 1968). This is thought to be due to the disruption of the subvocal rehearsal process. The effect of concurrent speech persists when auditory feedback is prevented (e.g., Macken & Jones, 1995) therefore it is not related to audition. Thus, it is surprising that there are only two reports in the literature of this task being used to investigate speech-based coding by deaf people. Similarly, only a handful of studies have adapted this method to use concurrent signing to investigate the use of sign-based coding.

3.6.i. The effect of concurrent speech and finger tapping (Chincotta & Chincotta, 1996)

Chincotta and Chincotta (1996) used concurrent tasks to investigate the use of a speech-based code by Hong Kong Chinese ten- to sixteen-year-olds who were profoundly deaf (although average dB loss is not reported). All deaf subjects attended an oral school for the deaf. Hearing subjects matched on ‘grade placement’ were also tested. These subjects were slightly younger than the deaf group, their age ranged from nine to thirteen years. Subjects were tested on written digit span for numbers presented on a computer in the following conditions:

• no concurrent task (control)
• concurrent speech - repeating two neutral sounds (‘a’ and ‘u’)
• concurrent manual task - tapping a single finger
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The concurrent speech task was used to tap speech-based coding. The concurrent manual task was used for two purposes, "...suppressing kinaesthetic coding as well as a control for attentional effects on performance" (Chincotta & Chincotta, 1996, pg. 254).

Recall by hearing children was impaired by concurrent speech but not finger tapping. However, recall by deaf subjects was not affected by either concurrent task. Despite this, Chincotta and Chincotta conclude that the deaf children used multiple encoding strategies. Their support for this conclusion comes from informal observations that some subjects mouthed digit names during tapping or signed digit names during concurrent speech. The authors assume that the deaf children were able to strategically switch between speech and sign-based STM codes and therefore were not affected by either task. However, even highly educated deaf college students who are native signers cannot efficiently switch between codes when one code is disrupted, for example by speech similarity (e.g., Hanson, 1982).

There are several more likely explanations of Chincotta and Chincotta's data:

- First, the informal observations indicate that subjects were allowed to label stimuli overtly on presentation. Hitch, Halliday, Schaalstal and Heffeman (1991) showed that young hearing children were more likely to use speech-based coding if they were allowed to label pictorial stimuli at presentation than if they were not. Similarly, children in Chincotta and Chincotta's study may have used both speech and sign-based codes. However, this could have been driven by overt labelling in the modality unoccupied by the concurrent task (sign or speech) rather than a strategic switch in the use of STM codes as argued by Chincotta and Chincotta.

- The lack of effect of either type of concurrent task may mean that neither speech- nor sign-based codes were used in the task. Subjects may have represented the digits using an alternative STM code, such as a visual code. Wallace and Corballis (1973) found that deaf children relied heavily on a visual code for the retention of...
letters yet when this coding system was stretched, by increasing the list length, subjects resorted to either a speech or fingerspelling code to supplement their performance. Similarly, Halliday, Hitch, Lennon and Pettipher (1990) found that hearing five-year-olds showed no effect of concurrent speech or tapping when memory span was tested (Experiment 2). However, when tested using a fixed list length, to ensure that recall was not at floor level, both concurrent tasks impaired performance by five-year-olds (Experiment 3). Chincotta and Chincotta may have found effects of concurrent tasks if they had tested supra-span recall, rather than digit span.

A purely methodological problem with Chincotta and Chincotta’s study is that the concurrent speech task was not one that has been widely used with hearing subjects in the past, such as repetition of a word or non-word. Subjects were asked to repeat two vowels simply described as “a and u” (Chincotta & Chincotta, 1996, pg. 255). No phonetic information is provided about the exact nature of these phonemes. This is particularly important in this study as Cantonese, the first language of these subjects, is a tonal language. Hearing subjects were affected by this task, and this supports the choice of this task. However, as one of the first attempts to investigate the use of a speech-based code by deaf people using concurrent speech, it may have been more appropriate to use a more established task. A final concern regarding this study is one raised by the authors themselves:

‘‘...[given the] ongoing debate concerning the nature of Chinese language processing compared, for example, to say, Indo-European language systems...it would be injudicious to extend the present findings to all deaf populations’’ (Chincotta & Chincotta, 1996, pg. 256).

3.6.ii. The effects of concurrent sign and speech (Kyle, 1986)

The only other study reported in the literature that explored the effect of concurrent speech on recall by deaf people is by Kyle (1986). Kyle (1986) investigated the use of speech and sign-based STM codes by deaf adults of deaf parents (DoD) and deaf
adults of hearing parents (DoH). Subjects were tested on ordered recall of a sequence of four pictures. Following presentation of the stimuli subjects were given a picture grid response sheet. The sheet included both target and distracter pictures. The subject’s task was to select and number the correct pictures according to the serial position in which the items were presented. Subjects were tested in four concurrent task conditions:

- no task
- speech - repeating ‘the, the..’
- signing - repetition of a nonsense sign
- manual activity - holding an object tightly in each hand.

It was predicted that given their early experience of sign language, the DoD group would be most likely to use a sign-based code and therefore show effects of concurrent signing. Surprisingly, recall by the DoD group was affected only by concurrent speech. In contrast, both concurrent speech and concurrent signing affected recall by the DoH group. Recall by neither group was affected by the concurrent manual task.

Kyle concludes that the effect of concurrent speech may indicate the use of a speech-based STM code. However, given the unpredicted effect of concurrent signing Kyle concluded “There is no indication of a simple sign articulatory process here nor is there evidence for a manual/ kinaesthetic effect in short-term recall” (1986, pg. 69).

However, there a number of problems with the study.

- All subjects performed the concurrent conditions in the same order: speech, signing and then the manual task. This order of performance reflects the observed pattern of disruption: concurrent speech had the greatest disruptive effect and the concurrent manual task had least. Therefore the effect of concurrent speech may be due to order effects.
• Alternatively, Kyle himself expresses doubts about the level of hearing loss of the DoD group. In discussing the possibility that this group used a speech-based code alone, Kyle argues that "given the degree of hearing of the subjects concerned this may be a possibility" (1986, pg. 68). Unfortunately, no hearing loss information is reported. All subjects are simply described as 'culturally Deaf'. The use of a speech-based code has been shown to decrease at higher levels of hearing loss (Conrad, 1979). If some of Kyle’s subjects were less than severely deaf, speech-based coding may have characterised several of the subjects and generally produced more variability in recall.

• Kyle argues that the effect of concurrent signing on the DoH group is probably due to general interference. However, to make this claim it necessary to compare concurrent signing to an appropriate control task. The manual task of ‘holding something tightly’ is not an appropriate task since it requires the use of the articulators of sign language - the hands. A non-articulatory concurrent task must be included to substantiate Kyle’s conclusion.

These methodological and theoretical problems make it difficult to draw firm conclusions from Kyle’s study with regard to deaf subjects’ use of speech- or sign-based coding.

3.6.iii. Concurrent hand movement during free recall (Siedlecki, Votaw, Bonvillian & Jordan, 1990)

Siedlecki, Votaw, Bonvillian and Jordan (1990) used concurrent tasks to investigate the use of a sign-based STM code by deaf people. Deaf and hearing college students were tested on immediate and delayed free recall of printed English words. Subjects were tested on written recall in the following conditions:

• no concurrent task (control)
• squeezing a Nerf ball (plastic stress reliever) with their left hand
• squeezing a Nerf ball with their right hand
• squeezing Nerf balls with both hands

Siedlecki et al. predicted that interference would be greatest when using the left hand. This prediction was based on an earlier psycho-physiological study which found that deaf subjects showed greater EMG activity in the left arm than the right during problem solving tasks (McGuigan, 1971).

This study was also designed to investigate the effects of signability and imagibility on recall by deaf subjects. Therefore, the authors also predicted that concurrent manual activity would have the greatest disruptive effect on recall of words of high signability as, they argued, these stimuli were more likely to be represented in a sign-based STM code.

Recall by hearing subjects was not affected by the concurrent tasks. However, recall by deaf subjects was significantly poorer in immediate, but not delayed, recall when squeezing the Nerf balls with 'both hands' than in the control condition. The predictions regarding poorer recall from the use of the left hand and for highly signable words were not supported. Therefore, Siedlecki et al. conclude that the effect of squeezing the Nerf balls with both hands "...is not related to the use of a kinaesthetic sign-based coding strategy" (1990, pg. 192) but rather is due to 'general distraction'.

There are other possible explanations for why these subjects did not use a sign-based code in this study than those proposed by Siedlecki et al.

• Subjects were tested on recall of printed words and there is no substantial evidence that deaf people recode printed words into a sign-based code (e.g., Hanson, 1982).
• Subjects were tested on free recall, but concurrent speech has its most marked effect on hearing subjects when SOR is tested. It is possible that the same is true for a sign-based code.

• Finally, the concurrent manual task may not have been appropriate. No information is given regarding whether subjects were to squeeze the Nerf balls constantly or whether they were to repeatedly squeeze and release them throughout presentation. These two tasks differ in that one involves constant motor movement while the other does not. It is probable that a movement task involving the hands is most likely to disrupt the use of a sign-based STM code, should one be used, given the role of movement in sign phonology.

Neither the Kyle (1986) nor Siedlecki et al. (1990) studies involving concurrent tasks allow firm conclusions to be drawn concerning the use of sign-based STM coding by deaf people. Two well-controlled studies by Wilson and Emmorey (1997a; 1998) are more informative regarding this issue.


Wilson and Emmorey (1997a; 1998) went further than simply investigating the effect of concurrent signing on recall by deaf subjects. They also explored whether concurrent signing interacts with sign similarity and sign length as concurrent speech does with speech similarity and word length in hearing subjects.

Concurrent signing and sign similarity

In hearing subjects, concurrent speech eliminates the speech similarity effect for visual, but not auditory stimuli. According to the working memory model this occurs because visual stimuli must be recoded into a speech-based code via the subvocal control process to enter the phonological store, where the speech similarity effect is thought to occur.
Wilson and Emmorey (1997a) attempted to replicate this pattern across two experiments testing sign-based coding by deaf college students. Sign stimuli were used as an analogue of speech stimuli that gain direct access to the phonological store (Experiment 1) and pictures were used as visual (indirect) stimuli (Experiment 2). In each experiment subjects were tested on recall of sign similar or sign dissimilar stimuli, in concurrent sign and no concurrent task (control) conditions. In the concurrent sign trials, subjects repeated a pseudo-sign, opening and closing a fist with each hand alternately, during presentation of stimuli.

With sign stimuli (Experiment 1) the sign similarity effect persisted in the concurrent task and control conditions. However, with pictorial stimuli (Experiment 2) concurrent signing removed the similarity effect. This replicates the effects of concurrent speech on recall of speech similar stimuli by hearing people (Baddeley, Lewis & Vallar, 1984). This suggests that a sign-based working memory system may function in the same way as a speech-based working memory system. This issue is dealt with in detail in section 3.7.

Of primary concern here is the effect of concurrent signing. This was of borderline significance with sign stimuli (Experiment 1) and non-significant with pictorial stimuli (Experiment 2). Wilson and Emmorey discuss a number of possibilities for the weakness of this effect:

- Deaf subjects may have a wide variety of codes available, therefore reducing sign-based coding effects.
- Subjects with high memory spans may not have been affected by concurrent signing because their performance was at ceiling, therefore weakening the effect.
- The third possibility they propose is of more direct interest to the consideration of whether concurrent signing is a useful technique to tap sign-based STM coding.
They report that in a pilot study a 'much more detailed gesture' was used as the concurrent sign task:

"This gesture, which conformed to the phonology of ASL, used specified locations for the beginning and the end of the movement, and used a handshape change that involved change of which fingers were 'selected'. This form of suppression produced a large drop in performance. (This more effective form of suppression was not used in the present experiments because of the concern that a complex gesture sequence might require attentional monitoring)." (Wilson & Emmorey, 1997a, pg. 318).

This issue of 'attentional monitoring' is an important one. If Wilson and Emmorey were concerned about the 'attentional' demands of the more complex concurrent task, it would have been wise to test hearing subjects on recall of words in this concurrent task condition. If the task really does demand 'attentional monitoring' then recall by hearing controls should also be impaired by this task.

Concurrent signing and sign length

In another study Wilson and Emmorey (1998) investigated the effect of concurrent signing on the sign length effect. In hearing subjects concurrent speech eliminates the word-length effect regardless of stimulus modality. According to the working memory model this occurs because traditionally the locus of the word length effect has been attributed to the subvocal rehearsal process, which is disrupted by concurrent speech.

Deaf college students were tested on SOR of long and short signs under concurrent sign and control conditions (see section 3.5.ii). In this study Wilson and Emmorey used a more complex pseudo-sign than in their previous experiment (1997a). The pseudo-sign consisted of "...forming the ASL 8 handshape (thumb touches middle finger) with both hands, combined with the movement from the sign WORLD (the two hands circle one another, with contact at the end of each repetition)" (1998, pg. 587).
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As with the interaction between concurrent speech and word length in hearing subjects, concurrent signing eliminated the sign length effect. The effect of concurrent signing in this experiment appeared to be more robust than in the sign similarity experiment (Wilson & Emmorey, 1997a). Wilson and Emmorey argue this is "perhaps because it involves a specified location and a more structured handshape, allowing less possibility for concurrent rehearsal" (1998, pg. 590). This explanation may be valid, however the movement involved in the second study is more difficult than the pseudo-sign used in the sign similarity study (1997a). As it is not possible to measure directly the difficulty level of a task, again it is necessary to test hearing non-signers on recall of words to determine whether the task leads to a general cognitive interference effect in these subjects. However, hearing subjects were not tested in this study.

3.6.v. Summary of studies involving concurrent tasks with deaf people

Neither of the studies that investigated the effect of concurrent speech on recall by deaf people addressed the issue that concurrent speech may lead to general executive interference (Chincotta & Chincotta, 1996; Kyle, 1986; see section 2.6). Manual concurrent tasks were included in both studies. However, these tasks were not suitable control tasks. For deaf signers, these tasks involve the articulators of sign language, the hands, and might therefore be considered analogous to articulation of a non-word for hearing people. Rather a non-articulatory concurrent task should be included which does not involve the mouth or the hands.

In studies that investigated the effects of concurrent signing, Siedlecki et al. (1990) and Kyle (1986) used an unsuitable concurrent control task, as it was manual (i.e., articulatory). The Wilson and Emmorey (1997a; 1998) studies have been most successful in showing effects of concurrent signing on recall by deaf people. They
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showed that concurrent signing interacts with sign length and sign similarity in a way similar to that in which concurrent speech interacts with word length and speech similarity in hearing people. Although these results are promising, when interpreting Wilson and Emmorey’s studies it is necessary to bear in mind that all subjects were deaf college students, the majority of whom were native ASL signers. This small subgroup of the deaf population is most likely to establish the use of a sign-based STM code as it is probable that they have had early exposure to sign language. While this suggests that the effects observed by Wilson and Emmorey are truly indicative of sign-based STM coding, there is also a need for caution. Further studies are needed to clarify whether these findings extend to the wider deaf population or are limited to well-educated, native deaf signers. Hearing subjects should also be tested on recall of word stimuli in these conditions to determine whether the effects of concurrent signing are specific to sign language. The experiments in this thesis address some of these issues.

3.7. Is there a sign-based working memory system?

Some of the studies reviewed in the previous sections suggest that deaf signers may be able to represent sign stimuli in a sign-based STM code. Wilson and Emmorey (1997a; 1998; under review) have provided the most comprehensive and systematic investigation of sign-based STM coding by deaf people. In a series of studies using sign stimuli and signed recall, they found effects of irrelevant signs, sign length, sign similarity, and concurrent signing, which, to some extent, parallel the effects seen in speech-based coding by hearing people. Although we should be cautious in generalising these findings to the deaf population as a whole it is worth considering the implications of these findings for the notion of a sign-based working memory system.
The fact that similarities are found between manipulations of speech-based coding and sign-based coding suggests that deaf people are able to develop a sign-based phonological loop. This is likely to be a separate component of working memory than that of a speech-based phonological loop (see Wilson & Emmorey, 1997b). Both loops may have similar characteristics and structure, yet use different representational substrates.

Given that signed and spoken languages are conveyed in different modalities and have different phonological structures, there are also likely to be differences between a sign-based and speech-based working memory system. A study by Wilson, Bettger, Niculae and Klima (1997) supports this. They tested deaf and hearing children on forwards and backwards digit span. Two groups of deaf children were tested: one group consisted of native ASL signers, the other consisted of non-native deaf signers who had all been exposed to ASL by the age of six-years at the latest. In line with previous research, hearing children were poorer at recalling digits backwards than forwards. Deaf non-native signers also showed this effect. In contrast, deaf native signers performed equally well on forwards and backwards recall. Wilson et al. argue that modality of a child’s primary language influences the structure of their working memory system. Specifically, the greater reliance on temporal processing of spoken languages may place restrictions on the order in which items can be recalled. In contrast, spatial processing in sign language may facilitate greater flexibility in immediate recall. This issue is addressed again in section 3.11, which considers differences between SOR and FR by deaf people.

Another issue that should be considered here is that while the representational form used within the phonological loop by hearing people is speech-based it is not clear whether its format is phonological, that is language specific or phonetic, that is language universal. Many of the characteristic effects of the phonological loop can be considered to be phonetic effects, such as speech similarity and word length. The equivalent of acoustic phonetics is not yet established for sign languages. The
clarification of this point may be particularly important in developing a model of sign-based working memory as used by deaf people.

3.8. What subject characteristics relate to the use of a speech-based code?

Some deaf people can use a speech-based STM code. As a speech-based code is often regarded as fundamental to cognitive development of language abilities, much emphasis has been placed on determining the factors that relate to the efficient use of such a code. Conrad (1979, section 3.3.iii) identified the following factors as related to the use of a speech-based code:

*Age at onset of deafness* - The percentage of congenitally, prelingually and postlingually deaf children classed by Conrad as using a speech-based code was 47%, 46% and 93% respectively. Although, early auditory speech exposure is important to the development of a speech-based code, these data clearly demonstrate that even people who are born deaf or become deaf at an early age often have access to such a code.

*Hearing loss* - There was a negative relationship between the use of a speech-based code and hearing loss, such that children with higher levels of hearing loss were less likely to use a speech-based code. Furthermore, the average inner speech ratio (IS-R) of those classed as using a speech-based code fell as deafness increased, indicating that the use of a speech-based code is not ‘all or nothing’. Rather, at higher levels of hearing loss a speech-based code may be less well specified or strategic use of this code may be less efficient than when there is some residual hearing.

*Non-verbal IQ* - This was measured using Raven’s Progressive Matrices. Use of a speech-based code increased as NVIQ increased and was independent of hearing loss.
Speech intelligibility - Hearing loss and NVIQ are both related to speech intelligibility (Musselman, Lindsay & Wilson, 1988). Conrad showed that even when these factors had been controlled for there was a significant relationship between speech intelligibility and the use of a speech-based code. However, some researchers have not replicated Conrad’s findings (e.g., Dodd, Hobson, Brasher & Campbell, 1983; Hanson & Fowler, 1987). A possible reason for this discrepancy is that there is no agreement on how speech intelligibility should be measured.

Reading ability - Conrad found that the use of a speech-based code was related to reading ability. Many other studies have also found this relationship (e.g., Hanson, Liberman & Shankweiler, 1984). However, establishing the direction of causality in the relationship between these two variables is problematic. This will be discussed in more detail later in this chapter.

Educational background - As the majority of Conrad’s subjects attended oral schools, he was unable to compare their performance with that of deaf children attending TC schools. Although Conrad showed that over half of congenitally or prelingually deaf oral deaf children did not use a speech-based code, it is tempting to hypothesise that ‘oral’ children are more likely to establish a speech-based code than children educated in TC environments. In one of the earliest reported studies of STM of deaf people, Pintner and Patterson (1917) found that digit span of oral deaf subjects was greater than that of ‘manual’ subjects. Although educational practices today differ vastly to those of Pintner and Patterson’s time, Wallace and Corballis (1973) also found differences between oral and TC deaf subjects. They showed that both groups of children relied heavily on a visual code for the retention of letters. However, when list length was increased to exceed span, oral subjects resorted to a speech-based code to enhance performance whereas TC subjects resorted to a fingerspelling code.

In contrast, Lichtenstein (1985; see also Lichtenstein, 1998) found no difference in the use of a speech-based code by deaf college students who had attended oral or TC
schools. However, this college-educated sample is not representative of the deaf population at large. Their higher levels of literacy may have enhanced their use of a speech-based STM code. Therefore, the evidence regarding the influence of linguistic background on the use of a speech-based code is inconclusive. This is investigated further in Experiment 2 by comparing STM performance by deaf pupils attending oral and TC schools who were of normal attainment within the deaf schooling system.

In summary, there is a range of subject characteristics that relate to the use of a speech-based code by deaf people such as age at onset of deafness, degree of hearing loss, NVIQ, speech intelligibility and perhaps educational background. Despite awareness of these factors, why some deaf children are more able to use such a code than others is still not clear. Dodd and Murphy (1992) highlight this in the case studies of two very similar deaf girls:

“They are.... a closely matched pair: same sex, age, cause, and degree of hearing impairment, non-verbal intellect, socioeconomic group, family support (both mothers became fluent in sign English), educational experience and provision of speech therapy” (1992, pg. 48).

Performance by these girls on a rhyme task showed that one used a speech-based code to a far greater extent than the other. Dodd and Murphy propose that ‘individual choice’ may be the factor that distinguishes the two girls. Unfortunately, individual choice is not something that can be controlled for experimentally.

3.9. The relationship between the use of a speech-based STM code and higher level cognitive skills in deaf children

Determining the subject characteristics related to the use of a speech-based STM code is one thing. However, specifying the causal relationships between these factors is more problematic. On the basis of data from his large scale study, Conrad proposed that degree of hearing loss has a direct effect on the quality of a deaf child’s external
speech (measured by speech intelligibility). The extent to which the child’s external speech was consistent and discriminable to the child itself was then thought to determine the quality of the speech-based code used (measured by the IS-R). In turn, a good quality speech-based code was thought to lead to enhanced memory span and reading ability. Therefore, Conrad proposed a major role for the use of a speech-based code in the cognitive abilities of deaf children. However, he did not argue that this indicated a direct effect of deafness on reading and memory span but rather an effect mediated by the use of a speech-based code.

Despite placing emphasis on the importance of speech-based coding Conrad acknowledged that a speech-based code may not be the only form of internal representation available to deaf children. Since Conrad’s data showed that less than half of the children with severe or profound hearing losses used a speech-based STM code he argued that oral education had failed to provide the majority of deaf children with a useful internal representation. Therefore, he recommended the use of sign language in the education of deaf children, with spoken language taught as a second language. He argued that perhaps a sign-based representation would be a more useful cognitive tool for profoundly deaf children than a poor one based on speech.

Although this general position has received support from other researchers (see Bernstein & Finnegan, 1983 for discussion) a continuing concern is that Conrad made many causal inferences on the basis of predominantly correlational data. Conrad’s interpretation that the use of a speech-based code has a causal influence on reading ability may be correct. However, it is equally likely that the reverse is true, that reading facilitates the use of a speech-based code. It is also possible that there is a reciprocal relationship between the two factors or a third mediating variable. This issue of direction of causality is important given the potential educational implications in this area of research, and it is yet to be resolved.
Chapter 3

3.10. What is the nature of a speech-based code used by deaf people?

Having considered the characteristics of deaf children identified as using a speech-based STM code and how the use of this code may relate to higher level cognitive functions, the precise nature of a speech-based STM code itself as used by deaf people will now be considered. The nature of a speech-based code as used by hearing people was considered in section 2.4.i. It was concluded that this code consisted of some form of amodal phonological representation. It is possible that a speech-based STM code used by deaf people has the same qualities. Alternatively, a very different speech-based representation may be used.

3.10.1. A speech code based on lip-read information

Hearing people use information from lip-reading to complement auditory information when interpreting distorted speech. The influence of lip-read information on speech perception is demonstrated by the McGurk effect (McGurk & MacDonald, 1976). When hearing subjects are shown the lip-movements of 'ba' and simultaneously hear 'ga', the perceived syllable is usually reported as 'da'—subjects appear to reach a compromise between the conflicting modalities.

This lip-read information, although useful to hearing people, is not vital. However, for deaf people, lip-reading may be the main speech input source (Dodd, 1976; Dodd & Hermelin, 1977). Dodd and Hermelin (1977) tested the type of linguistic input used by deaf teenagers as the basis for rhyme and homophone judgments. They systematically manipulated the following features of linguistic input: lip-reading, orthography, kinaesthetic feedback from self articulation or lexical knowledge. Lip-read information was used most in these tasks, while other factors may have played a contributory role. A study by Campbell and Wright (1989) supports this conclusion. They tested deaf fifteen-year-olds on recall of written non-sense syllables. Some syllables would be easy to lip-read (e.g., FA, THA, GA) others difficult (e.g., DA,
SHA, ZA). Deaf subjects' recall of written lists such as 'DA, SHA, ZA' was worse than for lists such as 'FA, THA, GA', suggesting that information about lip pattern informed their speech-based code. In contrast, hearing subjects were not affected by lip-readability.

Lip-reading may be the main source of knowledge about the phonology of speech for deaf people, however it does not afford full access to speech information. Some phonemes are more difficult to lip-read than others. For example, 'p' and 'b' are difficult to discriminate. They have the same place of articulation and differ only in manner of voicing. This discrimination problem is avoided by a system called Cued Speech (CS) (Cornett, 1967). CS uses handshapes, positioned around the mouth, to disambiguate lip-patterns that are difficult to distinguish. In theory, CS affords a deaf person full access to the phonology of spoken language. Therefore, it is possible that CS users are able to establish a robust speech-based STM code.

Research with CS users by a team in Brussels shows that early use of CS in the home leads to the development of a robust speech-based code. Charlier (cited in Leybaert, 1993) found that early CS users had a higher internal-speech ratio than orally educated deaf children. Early CS users have also been shown to use a speech-based code in rhyming, remembering and spelling tasks (Leybaert & Charlier, 1996). However, these findings do not necessarily establish the specific effectiveness of CS as a system. It is possible that because these subjects received rich language input from an early age, their all-round meta-linguistic skills are superior to other deaf children. It is also possible that the family environment of these children is fundamentally different to that of other deaf children. Parents must be motivated to seek out information about this alternative communication system, as it is not widely used in educational settings in Brussels and not at all in education in the UK. A combination of these factors may make a large contribution to the apparent cognitive success of CS users, as early language exposure and good parental support have
important consequences for the later social, emotional and cognitive development of the child (see Chapter One).

In summary, it appears that deaf people may establish phonological knowledge of spoken language predominantly from lip-reading. This may be further supplemented by lexical knowledge and kinaesthetic feedback from self-articulation. Another primary source of this knowledge may come from orthographic information from reading text.

3.10.ii. A speech code based on orthographic information

Information from lip-reading may form the dominant source of phonological knowledge of spoken language in the early years. However, there is substantial evidence to suggest that once a deaf child learns to read, their knowledge of orthography can also influence their speech-based STM representations.

The majority of studies that support this position have not investigated immediate recall but rather have assessed the phonological awareness skills of deaf people. Hanson and McGarr (1989) tested deaf college students on rhyme generation in response to printed target words. Fifty-two per cent of subjects' responses rhymed. Seventy per cent of these correct responses could be classed as orthographic rhymes (e.g., tie - lie) and thirty per cent non-orthographic rhymes (e.g., tie - fly). Therefore evidence for both speech-based and orthographic strategies was obtained. However, hearing subjects were not tested, therefore it is not clear whether this distribution of responses represent a greater number of orthographic responses than would normally be generated to the target stimuli.

Another way to test awareness of rhyme is to assess rhyme judgment. Campbell and Wright (1988) presented oral deaf teenagers with fifty word pairs. The subject's task
was to classify the pairs as rhyming or non-rhyming. Deaf subjects were poor at this task, particularly when spelling was incongruent (e.g., hair - bare), indicating that they relied heavily on orthographic information. Importantly, the influence of orthography was still apparent when the task was repeated using picture pairs rather than word pairs. That is, the visual orthographic cue did not have to be present for deaf teenagers to make use of orthographic information.

Both the Hanson & McGarr and Campbell & Wright studies demonstrate the influence of orthographic information on deaf subjects' knowledge of rhyme. However, Hanson and Fowler (1987 - Experiment 2) demonstrated that at least for some deaf people, rhyme knowledge is not limited to information derived from orthography. They tested deaf and hearing college students on rhyme judgment of two word pairs matched on orthography, one pair was regular (e.g., cave - gave) the other irregular (e.g., cave - have). Therefore all orthographic cues were removed from the stimuli. The subject’s task was to decide which pairs rhymed. Accuracy by hearing subjects (99.6%) was significantly better than that of deaf subjects (64.1%). However, performance by deaf subjects was significantly above chance (50%). When orthographic information was not available, these deaf college students were able to make use of phonological information possibly derived from lip-reading or some alternative form of speech input. These results support Comad's (1979) conclusion that some deaf people are able to use a speech-based code, although their use of such a code is rarely as efficient as that of hearing people.

3.10.iii. An 'abstract' speech-based code

It is possible that a speech STM code, which is mainly based on non-auditory aspects of speech such as lip-reading and even orthography, functions quite differently to a STM code used by hearing people where the main source of information is auditory speech. However, Dodd (1987) argues that this is not the case and that deaf children
use other forms of speech information to develop the use of a speech-based code in the same way as hearing children, albeit delayed. Dodd further argues that "A phonological code is likely to be a non-modality-specific code that deals with speech, irrespective of whether the phonemes perceived are heard or lip-read" (1987, pg. 188). In support of this, Dodd, Hobson, Brasher and Campbell (1983) found 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). The fact that lip-read and heard speech appear to be processed in the same way in STM reinforces the idea that a speech-based code is likely to be amodal in nature for deaf as well as hearing people (see also Leybaert, 1993).

However, in conflict with this, the results of Campbell and Wright's (1989) study, reviewed earlier, showed that deaf and hearing children were affected differently in their recall of nonsense syllables by lip-readability of stimuli. They therefore concluded that a speech-based code used by deaf people is qualitatively different to that used by the hearing.

One way to reconcile Dodd and Campbell & Wright's positions is not to think of the use of a speech-based code as all or nothing but rather that a speech-based code may be used to varying levels of proficiency. These levels of proficiency are likely to reflect the stages of phonological awareness that a hearing child goes through in early childhood (see Goswami & Bryant, 1990). Deaf children may have difficulty reaching the higher stages of this developmental progression. For example, a child may have a representation of a word at the syllabic level. In contrast, another child may have a fully specified phonological representation of the word with knowledge of its rhyming and phonemic properties. Therefore, it is useful to describe the levels at which different deaf children may use different STM codes.

These levels of knowledge can be investigated directly using explicit tests of phonological awareness. For example, the previous section demonstrated that even
well-educated deaf people have rhyme abilities inferior to those of their hearing peers. These tasks, such as rhyme and homophone judgement, require subjects to use a speech-based code to enable the level of their phonological knowledge to be assessed. In contrast, STM tasks are *implicit* tests of speech-based coding. They explore the type of STM coding that a deaf person uses *spontaneously* to recode information in STM. It is this spontaneous recoding of linguistic stimuli which is the main concern of this thesis.

### 3.11. Do deaf people have a specific deficit in the recall of order?

The previous sections in this chapter have been concerned with the different types of STM codes available to deaf people. This forms the main focus of this thesis. However, this is not simply of theoretical interest. At the beginning of this chapter it was pointed out that, in comparison to hearing peers, deaf people show poorer recall of linguistic but not non-linguistic stimuli. It was suggested that this was due to differences in the efficiency of use of linguistic STM codes. That is, the STM code used, how well specified the code is and proficiency in the use of this code, may influence overall STM *performance*. Differences between deaf and hearing people in performance on different types of immediate recall tasks will now be considered.

It is a common assumption that deaf people have a specific deficit in the recall of serial order of linguistic stimuli (e.g., see Conrad, 1979, pg. 135 for discussion). The studies often cited in support of this position are those by O'Connor and Hermelin (1972; 1973b). In their tasks digits were presented one at a time in one of three horizontally arranged windows. The digits never appeared in a left to right order. Subjects were then asked to recall the numbers they had seen. The type of STM code used was inferred from whether the subject recalled items in a left to right order (spatial coding) or in the order that they appeared (temporal coding). Deaf subjects
were more likely to use a spatial code than a temporal, speech-based, code. In contrast, hearing subjects were more likely to use a temporal code.

However, this finding does not appear to have been replicated (Beck, Beck & Gironella, 1977; see also Das, 1983). Hanson (1990) conducted a similar study using letters. However, here deaf college students were asked to recall spatially or temporally, rather than leaving the subject to interpret what was required, as in O’Connor and Hermelin’s study. In contrast to O’Connor and Hermelin’s study there was no difference in accuracy between deaf and hearing subjects in either task. That is, even when hearing subjects were able to use a robust speech-based code in a SOR task, deaf and hearing people performed equally well when the items were presented spatially. This is an important finding since deaf people are generally found to be poor at SOR of linguistic stimuli. However, it could be that these results are specific to well-educated deaf people, tested by Hanson. Furthermore, subjects were only required to recall three items on any trial. Therefore, it is possible that subjects’ performance was at ceiling. However, a study with deaf children by Sterne (1996 – Experiment 3) confirmed that these results might generalise to the deaf population as a whole.

Sterne’s study was complex and only selected findings are reported here. Sterne tested deaf and hearing twelve-year-olds on a computerised version of the Corsi blocks task. This uses a 3 X 3 grid in which different squares are illuminated in a sequence. The subject’s task was to point to the squares in the serial order in which they were illuminated. Recall by deaf twelve-year-olds (mean number of correctly recalled sequences = 9.12) was significantly greater than that of hearing chronological age (CA) matched controls (mean = 7.08). This pattern was reversed in a traditional visual span test using letters (letters presented in the same location): recall by hearing CA controls (mean = 7.08) was significantly greater than that of deaf subjects (mean = 2.35). The crucial task involved spatial presentation of letters in the Corsi 3 X 3 grid. The nine letters in each of the squares were visible at all times. Subjects were
required to point to the letters or repeat the letters aloud in serial order. There was no difference between deaf and hearing subjects in either of these tasks (deaf: pointing = 9.53, spoken = 10.00; hearing: pointing = 8.92; spoken = 10.75). Thus, spatial cues may enhance SOR of linguistic stimuli by deaf children bringing them to a level equivalent to that of their hearing peers.

However, deaf subjects' performance in the spatial linguistic tasks did not differ from that in the purely spatial Corsi blocks task. As the grid of letters was present throughout recall of the linguistic stimuli it is possible that deaf subjects were not recalling the phonological properties of the item. Rather they may have identified the appropriate spatial location and then named the letter at that position from the screen in front of them. It would be interesting to repeat this study using a signed/ spoken response in the absence of the stimulus grid requiring the child to make a response based on retrieved phonology, not on recognition of a letter in a particular spatial location. This would determine whether recall of linguistic stimuli truly is enhanced by spatial presentation or whether the effect is, in part at least, due to the presence of a cue grid at recall.

Whatever the detailed analysis eventually shows, when spatial cues are not present, as when stimuli are presented in the same location, SOR by deaf subjects is typically worse than that of hearing subjects (e.g., Blair, 1957; Campbell & Wright, 1990; Hanson, 1982; Krakow & Hanson, 1985; Pintner & Patterson, 1917).

Hanson (1982) argues that since a speech-based code is temporal in nature it is particularly suited to SOR of stimuli. She argues, since deaf people are generally less skilled at using a speech-based code, their SOR skills are impaired. Hanson further argued that this deficit should be specific to SOR in contrast to free recall (FR - recall of items without order), which should be similar in deaf and hearing CA controls.
Hanson (1982) tested this hypothesis in two different experiments. In Experiment 1 deaf college students were tested on probed recall of printed English words. A list of words was presented. One of the words was then shown as a cue. The subjects’ task was to identify the word that followed the cue in the original sequence. The word lists were speech-similar, sign-similar or orthographically similar. Each of these stimulus sets had its own control set of dissimilar stimuli, which were matched on frequency to the target set. The effects of similarity of recall in this experiment were discussed in detail in section 3.3.ii. Of importance to the present discussion was subjects’ overall accuracy. Hanson measured this as the percentage of dissimilar items correctly recalled across the three control sets of stimuli. Probed recall of control stimuli by hearing subjects was significantly better than that of deaf subjects.

In Experiment 2 Hanson (1982) tested written FR of sign similar and speech similar words. Again, each experimental set of stimuli had its own control set of dissimilar words matched on frequency. In contrast to Experiment 1, deaf subjects’ recall of the two control sets of stimuli was equivalent to that of hearing controls. Hanson therefore claims that the STM deficits of deaf people are limited to SOR, due to inefficient use of a speech-based code.

Very few studies have examined the FR abilities of deaf subjects. This illustrates how the focus within mainstream research with hearing people on serial processing has influenced deafness research. However, studies that have tested FR by deaf subjects show little support for Hanson’s results. Deaf subjects tend to perform less well than hearing subjects in tests of FR (Bonvillian, 1983; Koh, Vernon & Bailey, 1971; Liben, 1979; Siedlecki, Votaw, Bonvillian & Jordan, 1990). Hanson’s results may be restricted to her deaf college student subjects, with high levels of reading proficiency. Furthermore, Hanson tested different subjects on FR and SOR. Given the importance of subject characteristics on STM performance the same subjects should be compared. This would be a more direct test of the hypothesis that deaf people have a specific deficit in the recall of ordered but not unordered information.
In summary, it is not yet clear whether deaf people have a general deficit in immediate recall of linguistic stimuli or whether they have a specific deficit in SOR of linguistic stimuli. This issue is addressed in the first experiment in this thesis.

3.12. Chapter 3: Conclusions

The studies reviewed in this chapter illustrate that it may not be valuable to search for a single, dominant STM code used by deaf people. The evidence discussed suggests that visual, sign- and speech-based STM codes may be used to recall linguistic stimuli. Deaf people appear to differ in their STM coding abilities and preferences. These abilities and preferences can depend on a range of subject characteristics including: degree of hearing loss; age at onset of deafness; benefit from hearing aids; language background; speech/ sign proficiency and reading level. Furthermore, any one deaf person may use a variety of codes in STM. This variability can be affected by task demands such as stimulus and response modality. If a deaf subject is presented with a task that appears to be English based they may use a speech-based STM code, yet use a sign-based code when presented with sign stimuli (Hanson, 1982).

This review of the literature has shown that at least some deaf people are able to use a speech-based STM code. This is perhaps surprising given that the deaf people tested in these studies only have access to the non-auditory aspects of speech. However, those deaf people that do use a speech-based STM code tend to use it less efficiently than hearing people (Conrad, 1979). The implications of the inefficient use of a speech-based STM code for STM performance in general were also considered in this chapter. It has been argued by Hanson (1982) that deaf people have a specific deficit in SOR because of the poor use of a speech-based code, yet their FR is not impaired.
Although Hanson showed no difference in FR between deaf and hearing college students, other reports in the literature do not support this finding.

3.13. Summary of Chapters 1-3 and questions addressed in this thesis

Chapter One indicated a high degree of variability between deaf children in their access to the auditory component of spoken language. The deaf children selected to participate in this thesis were those whose access to this component of spoken language was limited (severely/ profoundly, prelingually deaf children). Not only is access to spoken language limited for deaf children, access to sign language, which is fully accessible on a sensory basis, is also limited since around 90% of deaf children have hearing parents who do not learn to sign. Therefore, deaf childrens’ development of language, regardless of modality, is usually substantially delayed. All the children tested in this thesis had hearing parents. Hence, although many acquired sign language relatively early, their sign language was unlikely to have the characteristics of a spoken first language for a hearing (monolingual) child of hearing parents.

This language delay is likely to have important knock-on effects for aspects of cognitive functioning, particularly those based on language, including linguistic STM which is the focus of this thesis. In order to gain a fuller understanding of linguistic STM in deaf children, Chapter Two reviewed the literature regarding STM coding and processes in hearing people and the development of these codes and processes in children. This showed a developmental progression in the use of speech-based coding in STM, with task demands, such as stimulus modality, setting the extent of use of this code. Typically, in hearing children speech-based coding becomes the dominant code, used for all types of linguistic STM tasks, only by late childhood (around nine-years).
This framework was then used to review the literature regarding STM coding and processes by deaf people in Chapter Three. This showed that although numerous studies had addressed the intriguing question of 'what do deaf people think in?' as yet there is no clear picture regarding this issue. The experiments reported in this thesis were constructed to clarify some of these outstanding issues by answering the following questions.

1) **Do deaf children have a general deficit in the immediate recall of linguistic stimuli or do they have a specific deficit in SOR of linguistic stimuli?**

No study has directly compared deaf peoples' performance on ordered and unordered recall of linguistic stimuli. The first experiment reported in this thesis addresses this issue by comparing the same subjects on SOR and FR, using the same methodological procedures. Experiment 5 is also relevant to this issue. Here deaf nine-year-olds and their hearing RA and CA controls are tested on FR.

2) **To what extent do deaf people of different ages use speech- and sign-based STM codes in the immediate recall of pictures?**

Experiments 2, 3 and 4 investigate speech- and sign-based STM coding by deaf people. In Experiments 1 and 2 concurrent tasks are used. A review of the few studies that have used such tasks with deaf people demonstrated that studies of concurrent speech have a number of methodological problems and are inconclusive with regard to speech-based STM coding (Chincotta & Chincotta, 1996; Kyle 1986). With regard to the use of concurrent signing, Wilson and Emmorey's (1997a; 1998) studies support the hypothesis that this task leads to specific linguistic disruption as does concurrent speech in hearing people. However, it is unclear whether these concurrent tasks may also lead to some degree of general cognitive interference (see section 2.6.iii). Therefore it is important to compare the effect of concurrent linguistic tasks with a non-articulatory task. This is explored in Experiments 2 and 3 in this thesis.
Experiment 4 investigates the use of sign and speech-based STM coding by deaf subjects using a different technique. In this study subjects are tested on recall of pictures which are similar in terms of speech or sign parameters.

3) What is the nature of the developmental progression in the use of STM codes and strategies by deaf children?

Only one study has investigated the development of STM codes in deaf children (MacDougall, 1979, see section 3.3.i). However, this study only explored the use of a visual STM code, using analysis of substitution errors. To gain a full developmental picture of the use of STM codes by deaf children it is necessary to test the use of a range of different STM codes. Experiment 4 addresses this issue by testing deaf children of different ages on immediate ordered recall of stimuli which are visually, speech or sign -similar.

4) How does pre-linguistic experience relate to STM performance by deaf children?

Experiment 5 is the only experiment in the thesis to investigate a semantic component in immediate recall. Semantic structure has a marked effect in immediate memory (e.g., Bourassa & Besner, 1994). The specific hypothesis tested with deaf children was that immediate memory would be better for pictures of items that had dynamic properties, in contrast to items with little ‘movement semantics’. This was predicted on the basis of the special semantic salience of perceived object movement in a deaf child’s world without sound.
5) *What subject characteristics relate to the use of different STM codes and overall STM ability?*

There is conflicting evidence in the literature regarding the influence of the communication system used at school on a deaf child's use of STM codes. Experiment 2 tests this directly by comparing the use of STM codes by deaf teenagers attending TC and oral schools, who are matched on a range of subject variables which are known to influence the use of speech-based coding.

Correlational analyses are carried out in Experiments 2 and 4 to relate different subject characteristics to the use of speech- and sign-based STM codes and overall STM ability. Of particular interest is the importance of language factors, including speech intelligibility, speech rate and sign rate to the use of different STM codes (Experiment 2b).
Chapter 4: The effect of recall type on immediate recall by deaf teenagers

Introduction

A commonly held assumption in the area of deafness and cognition is that deaf people have particular difficulty with the recall of ordered information (e.g., see Conrad, 1979, pg. 135 for discussion). One explanation for this assumed deficit is that spoken language is serially ordered, whereas sign language is ordered more spatially. Given that the majority of deaf people do not become fully proficient in a spoken language, it is argued that they do not have the linguistic cognitive structures to support efficient SOR. The experiment reported in this chapter examines whether deaf people have a general deficit in immediate recall of linguistic stimuli or whether they have a specific deficit in SOR of linguistic stimuli.

Experiment 1 – A comparison of free and serial order recall by deaf teenagers

Introduction

Hanson (1982) explored probed recall and FR by deaf people across two experiments. This study was reviewed in detail in Chapter 3 (section 3.11). In summary, deaf and hearing college students were tested on probed recall (Experiment 1 - to test order recall) and FR (Experiment 2) of printed English words. Probed recall by hearing subjects was better than that of deaf subjects. In contrast, FR by deaf and hearing subjects did not differ. Hanson argues that a speech-based code is particularly suited to recall of order and that deaf people are less likely to use this code than hearing people. She argues, FR is not dependent upon a speech-based code, hence the equivalent performance by deaf and hearing groups.
However, other studies have shown that deaf people do recall less than hearing people when tested on the FR of printed words (Bonvillian, 1983; Liben, 1979; Siedlecki, Votaw, Bonvillian & Jordan, 1990), pictures with word labels (Koh, Vernon & Bailey, 1971) and sign stimuli (Bellugi & Siple, 1974). Therefore, although it is difficult to make comparisons across studies given the heterogeneity of the deaf population, it is likely that Hanson’s results are due to the specific characteristics of the subjects she tested. All subjects were college students with reading ages well above the average for deaf people.

The aim of this study was to test directly Hanson’s (1982) hypothesis that FR by deaf people is equivalent to that of hearing CA controls, while SOR is impaired. Hanson’s study was not a direct test of this hypothesis as different subjects were tested in two separate experiments, therefore analyses could not be made across the two tasks. Furthermore, the tasks used differed in more than simply the requirement to recall order. Subjects in Hanson’s studies were tested on FR and probed recall. In FR the subject is required to recall as many items as they can from the set presented. In probed recall the subject is required to respond to a cue item with the item that followed it during presentation. Although this is a robust method for investigating recall of order, the task demands are considerably different for the two tasks.

The present study addressed these methodological problems. In this study the same subjects were tested in the same experiment on SOR and FR of pictures. Using pictorial stimuli should not place deaf subjects at a disadvantage, given their lower reading levels. This was ensured by a naming pre-test in which subjects were required to name/ sign the label for the stimuli.

A deaf teenage group and two hearing groups were tested; one chronological-age (CA) matched to the deaf group, the other reading-age (RA) matched. Including CA controls allowed the age appropriate baseline performance on the different tasks to be established. Furthermore, CA controls were judged to be of average intelligence by their class teacher. Since only deaf subjects with non-verbal IQs (NVIQ) within the
appropriate range for their age were selected, they were considered to have NVIQs similar to that of their CA controls. Hearing RA controls were also considered of average intelligence by their class teacher. However, given the generally poor reading levels of deaf children, their chronological age was considerably below that of the deaf group. Inclusion of these hearing control groups allowed us to identify whether the pattern of recall seen in deaf teenagers relates to cognitive development with chronological age (CA controls) or to the development of reading ability (RA controls).

Method

Subjects
Three groups of subjects were tested:
- Deaf 15-year-olds attending a TC school
- Hearing 8-year-olds - RA matched to the deaf group
- Hearing 15-year-olds - CA matched to the deaf group

Deaf Subjects
All deaf subjects attended a TC school and all had hearing parents. Audiograms from school records showed that the group’s mean hearing loss in the better ear was 110dB (range 89-126dB, s.d.=14) and no subjects had any additional disabilities. NVIQ of deaf subjects was measured using matrices from the British Abilities Scales (Elliot, Murray & Pearson, 1983). Subjects were not selected if their standardised score was more than one standard deviation (10) below the population mean (50). The mean NVIQ score for the group was 49.9 (Range: 43-62, s.d.=6.6). Mean chronological age and reading age of this group is shown in Table 4.1.

The deaf school used the Edinburgh Reading Test (Godfrey Thomson Unit, 1993) at the start of each academic year to assess each pupil’s reading ability. However, this experiment was carried out at the end of the academic year. Therefore, following discussions with the headteacher and educational psychologist at the school, it was
decided that the Shortened Edinburgh Reading Test (SERT) would be used to assess these children’s reading ability at the time of test. This score was useful to the school, as it was consistent with their existing records. The SERT tests a range of reading skills, including vocabulary, syntax, sequencing and comprehension.

Ten deaf pupils at the school completed the SERT. This test is designed to identify reading ages between 10;0- and 11;6-years-old. A child with a raw score of 47 is given a reading age of 10;01-years-old. Unfortunately, the SERT proved too difficult for the majority of the pupils tested. The range of raw scores of the deaf pupils was 19-51 and only one pupil scored above 47 (raw score = 51, reading age = 10;8). This problem was not fully recognised until some time after initial testing and therefore the pupils could not simply be re-tested with a more appropriate reading test.

**Standardising SERT scores**

A standardisation procedure was therefore used to establish a regression equation from which a reading age could be predicted for deaf subjects on the basis of their SERT raw score. This involved testing a group of hearing 7- to 9-year-olds on the SERT. Accurate reading ages were available for these subjects, as they had completed the NFER Group Reading Test (NFER-GRT, Macmillan Test Unit, 1985) at school one week earlier.

Twenty-six hearing children, with reading ages (as measured by NFER-GRT) within 6 months of their chronological age, completed the SERT. The chronological age of subjects ranged from 7;1 - 9;7-years-old (mean = 8;3, s.d. = 10 months). Their reading ages (using the NFER-GRT) ranged from 7;1 - 9;8-years-old (mean = 8;4, s.d. = 10 months). There was no significant difference between reading age and chronological age of these hearing subjects ($t(25) = -1.94, p>.05$).

A linear regression was performed on the data with reading age as the dependent variable and SERT raw score as the independent variable. R square was .661,
therefore 66% of the variance in reading age was accounted for by the SERT raw score \((F(1,24)=46.76, p<.0005)\). The regression equation was:

\[
\text{Reading Age} = 79.965 + (.813 \times \text{Raw Score})
\]

This equation was then used to establish a reading age for the 10 deaf pupils originally tested on the SERT\(^1\). The mean reading age for this group was 8;10-years-old. This reading age is in line with research indicating an average reading age for a deaf school leaver to be around 9-years-old (Conrad, 1979). The mean chronological age and mean estimated reading age of the deaf subjects is shown in Table 4.1.

### Table 4.1: Subject characteristics of participants in Experiment 1

<table>
<thead>
<tr>
<th></th>
<th>Chronological age</th>
<th>Reading age</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Deaf 15-year-olds</strong></td>
<td>Mean (range in months)</td>
<td>8; 10</td>
</tr>
<tr>
<td>(N=10)</td>
<td>15; 4 (170-190)</td>
<td>(95-121)</td>
</tr>
<tr>
<td><strong>Hearing – RA controls</strong></td>
<td>8; 8 (95-114)</td>
<td>8; 7 (98-109)</td>
</tr>
<tr>
<td>(N=10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Hearing – CA controls</strong></td>
<td>15; 0 (161-209)</td>
<td></td>
</tr>
<tr>
<td>(N=10)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Hearing subjects*

Two hearing control groups were tested in the main experiment. One was matched to the deaf group on chronological age and the other matched to the deaf group on reading age. All hearing subjects attended mainstream schools in south east England and were judged to be of ‘average’ intelligence by their class teacher. The CA group

\(^1\)This predicted reading age was also used when these subjects were tested in subsequent experiments.
were tested during school examination time. Therefore, availability of subjects was limited, hence the large range in chronological age for this group.

The reading ages of the hearing RA controls were taken from school records and were adjusted for the one-month time lag between the reading test administration and memory test. An independent samples t-test confirmed that deaf 15-year-olds and their RA controls did not differ in reading age ($t(18) = 1.0$, $p > .1$). Table 4.1 shows the mean chronological ages and reading ages of the two hearing groups.

**Design**

A 3 (Group) by 2 (Recall Type) design was used. The three groups were deaf 15-year-olds, hearing CA controls and hearing RA controls. Recall Type was a within-subjects factor. The two levels of this factor were *serial order recall* (SOR), in which subjects were presented with 6 pictures to recall in strict serial order and *free recall* (FR), in which subjects were presented with 12 pictures to recall in any order. Trials were blocked according to Recall Type. Half the subjects performed the SOR trials first and the other half performed the FR trials first. The larger number of stimuli in the FR task led to longer overall presentation time. Therefore subjects performed 5 SOR trials and 4 FR trials.

**Materials**

The stimuli were 48 black and white line drawings of concrete items, printed on 10 cm X 15 cm card. These were chosen from the Snodgrass and Vanderwart (1980) picture norms. Only items with a commonly used sign label were chosen. For example, items that had to be fingerspelled were not included. The other criterion used to select stimuli was that all were rated as highly familiar. Snodgrass and Vanderwart (1980) give familiarity ratings of the items on a scale from 1 (not very familiar) to 7 (very familiar). However, familiarity was used as the selection criterion here rather than word frequency since frequency scores are based on text. Given the poor reading ability of these deaf subjects, it is argued that picture familiarity is more appropriate to how representations are maintained in LTM by deaf people. Furthermore, Snodgrass and Vanderwart argue that familiarity is the more important feature to consider when using pictorial stimuli than word frequency.
familiar) to 5 (very familiar). The mean familiarity rating of the 48 pictures was 3.63 (s.d. = .98). Due to the additional limitation in choosing stimuli with commonly used sign labels two items were included that were given a mean rating below 2, these were ‘snake’ and ‘caterpillar’. However, a naming pre-test confirmed that subjects had no difficulty naming these items. The names of the items chosen are listed in Table 4.2.

Table 4.2: Labels of pictorial stimuli used in Experiment 1

<table>
<thead>
<tr>
<th>apple</th>
<th>book</th>
<th>comb</th>
<th>flower</th>
<th>lion</th>
<th>snake</th>
</tr>
</thead>
<tbody>
<tr>
<td>balloon</td>
<td>brush</td>
<td>cow</td>
<td>fork</td>
<td>monkey</td>
<td>suitcase</td>
</tr>
<tr>
<td>banana</td>
<td>butterfly</td>
<td>cup</td>
<td>fox</td>
<td>mouse</td>
<td>sun</td>
</tr>
<tr>
<td>bed</td>
<td>cake</td>
<td>dog</td>
<td>frog</td>
<td>orange</td>
<td>telephone</td>
</tr>
<tr>
<td>bell</td>
<td>car</td>
<td>drum</td>
<td>hat</td>
<td>pencil</td>
<td>tree</td>
</tr>
<tr>
<td>belt</td>
<td>cat</td>
<td>elephant</td>
<td>horse</td>
<td>ruler</td>
<td>umbrella</td>
</tr>
<tr>
<td>bicycle</td>
<td>caterpillar</td>
<td>eye</td>
<td>key</td>
<td>sandwich</td>
<td>watch</td>
</tr>
<tr>
<td>bird</td>
<td>chair</td>
<td>fish</td>
<td>knife</td>
<td>shoe</td>
<td>whistle</td>
</tr>
</tbody>
</table>

Procedure

Subjects were tested individually. All subjects performed a pre-test in which they were required to name the 48 pictures in sign or speech. All subjects completed this successfully. Subjects then performed one practice trial for each recall type.

In the SOR trials subjects were told they would be shown 6 pictures, which they were to recall in the order presented. Each picture was presented individually, at a rate of two seconds per picture and then placed face down in a pile in front of the subject. Subjects were not allowed to label the stimuli overtly during presentation as this has been shown to influence STM coding by young hearing children (e.g., Hitch, Halliday, Schaalstal & Heffeman, 1991). Subjects were then prompted by the Experimenter to recall the pictures in the order in which they were presented. If the subject could not remember a picture they were told to say ‘don’t know’ at that serial position and move on to the next.
The procedure in the FR trials was essentially the same as in the SOR trials. However subjects were presented with 12 pictures and were told they could recall the items in any order.

Recall was spoken by hearing subjects. Deaf subjects were allowed to recall in their preferred language mode. The most common mode of response for deaf subjects was to simultaneously produce the sign with the English mouth pattern for the word. This is not surprising as it is very rare for an isolated noun to be signed in BSL without the appropriate English mouth pattern.\(^3\)

Predictions
It was predicted that SOR by deaf 15-year-olds would be poorer than that of hearing CA controls but equivalent to that of RA controls. In contrast, it was not possible to make a clear prediction regarding FR performance by deaf 15-year-olds in comparison to the two control groups based on past literature. The pattern of FR performance may be similar to the pattern predicted for SOR performance. That is, FR by deaf 15-year-olds may be similar to that of their RA controls, but poorer than CA controls. Alternatively, FR performance by deaf 15-year-olds may be equivalent to that of their CA controls, as predicted by Hanson (1982). A third possibility is that deaf 15-year-olds show an intermediate level of FR between that of their RA and CA control groups.

Results
In the SOR trials only items that were recalled in the correct serial order were scored as correct. In the FR trials all items were scored as correct if they had appeared in the stimulus set, regardless of the order of recall. To compare the pattern of results across these two types of recall, performance in both conditions was converted to mean

\(^3\) Sutton-Spence (1997) found that in connected signing by Deaf signers, 88% of nouns signed were accompanied by appropriate English mouth patterns.
percentage recalled of the total number of items presented. Table 4.3 and Figure 4.1 show the mean percentage correctly recalled by each group as a function of recall type.

**Table 4.3:** Mean (s.d.) percentage correctly recalled as a function of recall type

<table>
<thead>
<tr>
<th></th>
<th>Serial order recall</th>
<th>Free recall</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Deaf 15-year-olds</strong></td>
<td>45.56 (24.85)</td>
<td>49.83 (7.05)</td>
</tr>
<tr>
<td><strong>Hearing RA controls</strong></td>
<td>44.33 (11.87)</td>
<td>40.67 (11.24)</td>
</tr>
<tr>
<td><strong>Hearing CA controls</strong></td>
<td>80.00 (13.70)</td>
<td>60.00 (10.15)</td>
</tr>
</tbody>
</table>

**Figure 4.1:** Mean % correctly recalled by each group as a function of recall type
The correlation between cell means and standard deviations was not significant \( (r=.087, p>.1) \), therefore a 3 (Group) by 2 (Recall Type) mixed ANOVA was used to analyse the data (see Table 4.4). This showed that there was a main effect of Group \( (F(2,37) = 16.21, p<.0005) \) and Recall Type \( (F(1,27) = 4.32, p<.05) \). The interaction between Group and Recall Type was also significant \( (F(2,27) = 5.28, p<.025) \).

**Table 4.4: ANOVA table for Group by Recall Type**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within and residual</td>
<td>7109.86</td>
<td>27</td>
<td>263.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td>5838.29</td>
<td>2</td>
<td>4269.14</td>
<td>16.21</td>
<td>.000</td>
</tr>
<tr>
<td>Within and residual</td>
<td>3916.12</td>
<td>27</td>
<td>145.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recall Type</td>
<td>626.53</td>
<td>1</td>
<td>626.53</td>
<td>4.32</td>
<td>.047</td>
</tr>
<tr>
<td>Group by Recall Type</td>
<td>1532.34</td>
<td>2</td>
<td>766.17</td>
<td>5.28</td>
<td>.012</td>
</tr>
</tbody>
</table>

Analysis of simple effects of Recall Type within each Group (alpha=.0167) showed that there was no effect of Recall Type on recall by deaf 15-year-olds \( (F(1,27) = .63, p>.1) \) or their RA controls \( (F(1,27) = .46, p>.1) \). However, the effect on the CA control group was significant \( (F(1,27) = 13.79, p<.005) \). Inspection of the means indicates that these subjects recalled a larger percentage of stimuli in the SOR condition than in the FR condition.

Of primary interest here is the pattern of performance *between* subject groups on the two types of recall. The simple effects of Group within each level of Recall Type were significant (alpha = .025): SOR \( (F(2,27) = 13.0, p<.0005) \), FR \( (F(2,27) = 10.06, p<.005) \). These effects were explored using Bonferroni corrected t-tests (alpha=.008).

As predicted, in the SOR condition recall by hearing CA controls was better than that of deaf 15-year-olds \( (t(18) = 3.84, p<.002) \) and RA controls \( (t(18) = 6.22, p<.0005) \). Recall by deaf 15-year-olds and RA controls did not differ \( (t(18) = .14, p>.1) \).
The pattern of performance was less clear cut in the FR condition. Free recall by the CA control group was better than that of hearing RA controls ($t(18) = 4.04, p<.002$). However, FR by deaf 15-year-olds fell between that of the RA and CA control groups and did not differ significantly from either given the adjusted level of significance: deaf 15-year-olds and RA controls ($t(18) = 2.19, p=.042$); deaf and hearing 15-year-olds ($t(18) = -2.6, p=.018$).

Discussion

The aim of this study was to determine whether deaf people have a general deficit in immediate recall of linguistic stimuli or whether they have a specific deficit in SOR of linguistic stimuli. As predicted, SOR by deaf teenagers was poorer than that of hearing CA controls but equivalent to recall by RA controls. These data support previous studies indicating poor SOR of nameable stimuli by deaf people in comparison to hearing peers. Rather, performance appears to be equivalent to that of hearing subjects of a similar reading level.

There was a slightly different pattern of performance with regard to FR. Free recall by deaf teenagers fell between that of RA and CA controls, but did not differ significantly from either group. Given these results, no strong claims can be made regarding the free recall abilities of the deaf teenagers tested here. However the pattern of the raw data suggests that a strong version of Hanson’s (1982) hypothesis was not supported since recall by deaf teenagers was poorer than that of CA controls. This interpretation of this non-significant trend is supported by previous reports in the literature showing poorer free recall of linguistic stimuli by deaf subjects in comparison to their hearing peers (Bellugi & Siple, 1974; Bonvillian, 1983; Koh, Vernon & Bailey, 1971; Liben, 1979; Siedlecki, Votaw, Bonvillian & Jordan, 1990). The overall pattern of results suggests that deaf teenagers have a specific deficit in the serial order recall of linguistic stimuli. In addition, it is possible that they also have a general deficit in the immediate recall of linguistic stimuli even when order information is not required.
Deaf teenagers' pattern of performance across the two recall types was similar to that of their hearing RA controls. Neither group differed in the percentage they recalled in the SOR and FR conditions. In contrast, hearing CA controls recalled a higher percentage of items in the SOR condition than in the FR condition. This may be due to the more efficient use of a rehearsal strategy in the SOR task by older hearing subjects. The finding that SOR by deaf teenagers was equivalent to that of their hearing RA controls suggests that the skills involved in successful SOR may be linked to literacy. More specifically, Hanson proposed that the deficit seen in SOR by deaf people is due to the inefficient use of a speech-based code by deaf people. Thus, deaf people's use of a speech-based STM code and alternative STM codes was investigated in the experiments reported in Chapters 5 and 6.
Chapter 5 - The use of concurrent tasks to investigate STM coding
by deaf people

Introduction

The use of sign and speech-based codes by deaf teenagers and deaf adults was investigated in this chapter using concurrent linguistic tasks. The effect of these tasks on recall by deaf teenagers attending oral and TC schools was compared. A large correlational analysis was also carried out to determine the subject characteristics that were related to the use of different STM codes and overall STM ability. Of particular interest in this analysis were language measures including speech intelligibility, speech rate and sign rate.

Concurrent tasks require a subject to articulate an irrelevant word/ sign during the presentation of stimuli. In terms of the working memory model, concurrent speech is thought to recruit the subvocal rehearsal process. This leads to two effects: the disruption of subvocal recoding of visual stimuli into a speech-based code and the disruption of rehearsal of stimuli in the phonological store. All experiments reported in this chapter used pictorial stimuli. Therefore, either or both of these processes may be disrupted by concurrent tasks. However, regardless of the locus of the effect, specific disruption from concurrent speech is indicative of the use of a speech-based STM code, which is the main focus of this chapter.

As discussed at length in Chapters Two and Three, in order to interpret accurately a disruptive effect of a concurrent linguistic task on recall it is important to control for general cognitive effects. A non-articulatory concurrent task was therefore included in the experiments reported in this chapter. To establish a non-articulatory task of an appropriate level of difficulty a number of pilot studies were carried out with deaf and hearing people.
Pilot Study 1: Recall by hearing teenagers during concurrent tasks involving the hands and the feet

Introduction

The aim of this pilot study was to test the suitability of non-articulatory concurrent activities to act as control tasks for the effects of concurrent speech and sign. To achieve this, it was first necessary to specify the linguistic (sign and speech) concurrent tasks to be used in the studies reported in this chapter.

It is possible to use either pseudo-signs/words or actual lexical signs/words as the stimuli to be repeated in the concurrent speech and sign conditions. Using pseudo-words/signs raises the possibility that the two contrived stimuli may differ in level of complexity given the vastly different phonologies of signed and spoken languages. Therefore, it was decided that repetition of the sign and word for the same lexical item would be used as the concurrent sign and speech tasks. This method also controls for semantic differences between the two stimuli to be repeated.

Previous studies using concurrent tasks to investigate speech and sign coding by deaf people offer little guidance with regard to the choice of stimuli to be repeated. Previous studies that used concurrent tasks to investigate sign-based coding by deaf people were discussed at length in Chapter Three. These studies used one of two approaches. Some required the repetition of a pseudo-sign, that is a movement which is phonologically legal in the signer's sign language but is not a lexical sign (Kyle, 1986; Wilson & Emmorey, 1997a; 1998). Other studies simply required subjects to hold something tightly as stimuli were presented (Kyle, 1986; Siedlecki, et al. 1990). These studies are therefore not informative with regard to the choice of the concurrent sign to be included in the present experiments since they did not use lexical items.
Only two studies have used concurrent speech to investigate speech-based coding by deaf people (Chincotta & Chincotta, 1996; Kyle, 1986, see Section 3.6). Only one of these studies used repetition of a lexical item. Kyle (1986) required deaf adults to repeat ‘the’ during presentation of stimuli. He found that this impaired subjects’ SOR. However, doubts about the level of deafness of subjects in Kyle’s study mean that the results may not be relevant to the present one.

Studies with hearing children have often required that the child repeat a three syllable word such as ‘butterfly’ (Hitch, Halliday & Littler, 1989) or ‘teddybear’ (Halliday, Hitch, Lennon & Pettipher, 1990). Continuous repetition of a three syllable word may be too demanding for a deaf child. Therefore, it was decided that the concurrent speech stimuli in the experiments reported in this chapter should consist of two syllables. Some sign linguists have argued that the movement parameter of signs can be considered equivalent to syllables in spoken language (e.g., Liddell, 1984). Therefore, the chosen items consisted of a two-syllable word and a sign involving two movements. The items chosen to fit these criterion were the word ‘because’ and its glossed sign equivalent - BECAUSE.

BECAUSE is a two-handed sign in BSL. In the first movement, the right hand touches the extended index finger of the left hand (Figure 5.1) and then touches the side of the thumb on the left hand (Figure 5.2).

Since the concurrent sign and speech tasks involved repetition of lexical items, they can be considered linguistic concurrent tasks. Wilding and White (1985) showed that the use of a speech-based code by hearing people was disrupted by a non-verbal articulatory task (chewing), to the same extent as voiced or unvoiced concurrent verbal activity. In the same way, non-linguistic movement involving the hands may lead to disruption of a sign-based STM code used by deaf signers. To test this possibility a hand movement task was included in the experiments reported here.
To ensure that the effects of concurrent speaking, signing and hand movement could be interpreted correctly it was necessary to include a non-articulatory concurrent task. For hearing subjects this meant not using the mouth. For deaf subjects this meant not using the mouth or the hands. A foot movement task was therefore included in the experiments reported in this chapter.

Table 5.1: Concurrent tasks included in the experiments reported in Chapter 5 and their relationship to the articulatory and linguistic skills of deaf signers

<table>
<thead>
<tr>
<th>Concurrent task</th>
<th>Type of task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speech (repeating 'because')</td>
<td>Linguistic</td>
</tr>
<tr>
<td>Sign (repeating BECAUSE)</td>
<td>Linguistic</td>
</tr>
<tr>
<td>Hand movement</td>
<td>Articulatory but non-linguistic</td>
</tr>
<tr>
<td>Foot movement</td>
<td>Non-articulatory</td>
</tr>
</tbody>
</table>
Foot and hand movement concurrent tasks

The purpose of this pilot study was to explore what form the hand and foot movement tasks should take by investigating the effects of these tasks on recall by hearing teenagers. It was decided that the most appropriate way to ensure that the hand and foot movement tasks were of a similar level of difficulty was to require that both the feet and the hands performed the same pattern of movement. Previous studies with hearing people often used tapping a single hand or finger as a control task for concurrent speech. A review of these studies in Chapter Two demonstrated that these tasks may differ from concurrent speech in their level of difficulty as (see section 2.6). Therefore, in this study more difficult movement tasks were piloted with hearing teenagers. In a free recall task subjects were asked to trace the outline of a star with their hands or feet during presentation of pictures to be recalled. This task was easily learned through practice.

Although movement of the hands and feet are non-articulatory tasks for hearing teenagers, they may recruit central executive resources to initiate and maintain the movement. However, if concurrent speech and the non-linguistic concurrent tasks are of a similar level of difficulty, concurrent speech should still impair recall to a greater extent than the non-articulatory concurrent tasks because only concurrent speech should affect speech-based coding.

Method

Subjects

Fifteen hearing 14;01-18;0-year-olds were tested (mean=16,0, s.d.=14 months). All attended a mainstream school in south-east England and all were considered to be of average intelligence by their class teacher.

Design

The experiment had a within subjects design. All subjects performed five trials,
involving free recall of 12 pictures, in each of the following conditions:

- no concurrent task (baseline)
- foot movement - tracing the outline of a star
- hand movement - tracing the outline of a star
- concurrent speech - repeating 'because'

These twenty trials were counterbalanced such that trials were sampled randomly from each condition with the constraint that no two trials from the same condition were performed consecutively.

**Materials**

The stimuli were 48 black and white line drawings of concrete items from the Snodgrass and Vanderwart (1980) picture norms, printed on 10 cm X 15 cm card. These were the same stimuli as used in Experiment 1 and are listed in Table 4.2. The outline of a classic 5 point star shape, printed on was a 32 cm X 32 cm card with the centre point clearly marked, was also used (see Figure 5.3).

**Figure 5.3:** Diagram of star shape subjects were required to trace

![Diagram of a 5-point star with numbers 1 to 5 indicating the points to trace.](image)
Procedure
Subjects were tested individually. The basic task involved free recall of 12 pictures which were presented one at a time, at a rate of two seconds per item. After presentation each card was placed face down in a pile on the table in front of the subject. Recall by subjects was spoken. Subjects performed a single practice trial and five experimental trials in each of the four conditions: baseline, foot movement, hand movement and concurrent speech.

In the concurrent speech condition subjects were required to repeat the word 'because' continuously. The two tracing tasks involved tracing the outline of a classic 5 point star shape, printed on a large sheet of card. The subject was required to move their hands/feet from the centre point (see Figure 5.3) to predetermined points on the star and then return back to the centre point. The pattern was as follows: - right hand/foot (R) and left hand/foot (L) at centre ('C'); R and L to 1; R and L back to ‘C’; R moves to 2, L moves to 5; R and L back to ‘C’; R moves to 3, L moves to 4; R and L return back to C. The pattern is then repeated.

This task is easily demonstrated and subjects were given extensive practice until they performed the task fluently without needing to view the outline of the star. Subjects were told that the accuracy of their movement was not being judged and they were to simply maintain the movement as the stimuli were presented. Subjects were instructed to start the concurrent task just before the first picture was presented and to stop immediately after the seeing final picture.

Results

Table 5.2 shows the mean percentage of items correctly recalled during each condition. Inspection of the means shows that all concurrent tasks disrupted recall to a similar extent. Since the correlation between cell means and standard deviations was
Chapter 5

not significant \((r = -0.682, p = 0.318)\), a one-way repeated measures ANOVA was used to analyse the data. The main effect of Concurrent Task was significant \((F(3,42) = 16.27, p < 0.0005)\). Tukey post-hoc tests for repeated measures (Stevens, 1992) showed that recall during all concurrent tasks was poorer than in the baseline condition (all \(ps < 0.05\)). Recall in the concurrent task conditions did not differ from each other.

**Table 5.2:** Mean (s.d.) percentage correctly recalled during concurrent tasks by hearing 16-year-olds \((N=15)\) tested on free recall

<table>
<thead>
<tr>
<th></th>
<th>Foot movement</th>
<th>Hand movement</th>
<th>Concurrent speech</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>mean</strong></td>
<td>60.22</td>
<td>50.33</td>
<td>48.44</td>
</tr>
<tr>
<td><strong>(s.d.)</strong></td>
<td>(6.17)</td>
<td>(6.27)</td>
<td>(6.89)</td>
</tr>
</tbody>
</table>

**Discussion**

The aim of this pilot study was to determine whether the hand and foot tracing tasks were of a suitable level of difficulty to use as control tasks for the general cognitive demands of concurrent speech. Concurrent hand and foot movement affected FR by hearing teenagers to the same extent as concurrent speech. Since concurrent speech is known to have a specific effect on recoding visual stimuli into a speech-based STM code in the hearing it should disrupt recall to a greater extent that a non-articulatory concurrent task of a similar level of difficulty, however it did not. It is more likely that the hand and foot movement tasks of tracing the outline of a star were more difficult than continuously repeating ‘because’ and consequently led to generalised memory impairment through central executive load.

If the foot and hand tracing tasks were too complex for hearing teenagers to perform as a concurrent task, it is argued that the same would be true for deaf teenagers. To test this assumption directly, a small number of deaf fourteen-year-olds were tested on recall while performing the concurrent tracing tasks.
Pilot Study 2: Recall by deaf teenagers during concurrent hand and foot movement and an investigation of use of a spatial array in ordered recall

Introduction

This pilot study tested three deaf teenagers on recall during the concurrent task conditions described in Pilot study 1. This tests the assumption that because the tracing tasks were too complex for hearing teenagers to perform concurrently with a recall task they would also be too complex for deaf teenagers.

Another design issue was also tested in this pilot study. It had been decided that ordered recall would be tested in the main experiments to be reported in this chapter, since in hearing people, concurrent speech has its most marked effect on recall of order. In comparison to hearing CA controls, deaf people have repeatedly been shown to perform poorly on traditional tests of strict SOR of linguistic stimuli (e.g., Blair, 1957; Campbell & Wright, 1990; Hanson, 1982; Krakow & Hanson, 1985; Pintner & Patterson, 1917). Experiment 1 in this thesis supported this pattern of results. When subjects were required to recall from the first serial position onwards, SOR by deaf fifteen-year-olds was equivalent to recall by hearing RA controls but much poorer than that of hearing CA controls.

This study tested whether two manipulations of the strict SOR task made the task more appropriate for deaf children.

- As in the traditional SOR 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 (see Figure 5.4). 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.

- Responses were scored correct even if subjects did not recall in strict serial order. That is, if a subject identified the correct item at the correct serial position their response was scored as correct despite any variation in the order in which items were recalled. Although this is not strict serial order recall it is nevertheless ordered recall since the items were scored according to the order of presentation. The validity of this method will be assessed further in Pilot study 3 and by examining the serial position curves of recall by deaf and hearing groups tested in Experiment 2 later in this chapter.

These methodological adaptations should make the tasks more accessible to deaf children (and young hearing children) and therefore increase baseline recall performance. This should allow the pattern of effects of the different concurrent tasks to be identified more easily. This procedure was piloted with three deaf fourteen-year-olds in the present study.

**Method**

**Subjects**

Three prelingually, profoundly deaf teenagers attending a TC unit were tested. The chronological ages and reading ages of these subjects can be seen in Table 5.3.
Table 5.3: Subject characteristics of deaf subjects (n=3) tested in Pilot Study 2

<table>
<thead>
<tr>
<th>Subject</th>
<th>Chronological age</th>
<th>Reading age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 1</td>
<td>14; 9</td>
<td>9; 6</td>
</tr>
<tr>
<td>Subject 2</td>
<td>14; 11</td>
<td>9; 6</td>
</tr>
<tr>
<td>Subject 3</td>
<td>14; 8</td>
<td>9; 5</td>
</tr>
</tbody>
</table>

**Design and Materials**

The study had a within subjects design. The stimuli were the same as those used in Pilot study 1. All subjects performed one practice trial and three ordered recall trials in the following concurrent task conditions: no concurrent task (baseline), foot movement, hand movement and concurrent speech. These twelve trials were counterbalanced such that trials were sampled randomly from each condition with the constraint that no two trials from the same condition were performed consecutively.

**Procedure**

All subjects were tested individually. The subjects received the same instructions and practice with regard to performance of the concurrent tasks as in Pilot study 1. In each trial six pictures were presented individually at a single spatial location at a rate of two seconds per item. The cards were then placed face down in a spatial array in front of the subject. The pattern of this array is shown in Figure 5.4.

**Figure 5.4:** Array of stimuli following individual presentation

![Array of stimuli](image)

At recall, subjects pointed to the cards and named the item thought to have been presented in that serial position. Subjects recalled in their preferred language mode, which was a combination of sign and speech for all subjects.
Chapter 5

Results and Discussion

A correct response was scored if the subject recalled the correct item at the correct location despite any variation in the order in which items were recalled. Table 5.4 shows the mean percentage of items correctly recalled during each condition by each subject. Only three subjects were tested, therefore statistical analyses cannot be conducted on these data. However, inspection of the means and the patterns of recall by individual subjects suggests that all concurrent tasks impaired recall to a similar degree. These data support the hypothesis that these tracing tasks were too difficult for deaf teenagers just as they were for hearing teenagers in Pilot study 1.

Table 5.4: Mean percentage correctly recalled during concurrent tasks by deaf 14-year-olds (n=3) tested on ordered recall

<table>
<thead>
<tr>
<th>Subject</th>
<th>Baseline</th>
<th>Foot movement</th>
<th>Hand movement</th>
<th>Concurrent speech</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 1</td>
<td>61</td>
<td>39</td>
<td>33</td>
<td>22</td>
</tr>
<tr>
<td>Subject 2</td>
<td>67</td>
<td>45</td>
<td>28</td>
<td>50</td>
</tr>
<tr>
<td>Subject 3</td>
<td>72</td>
<td>56</td>
<td>38</td>
<td>38</td>
</tr>
<tr>
<td>Total</td>
<td>67</td>
<td>47</td>
<td>33</td>
<td>37</td>
</tr>
</tbody>
</table>

With regard to the manipulations to make the tasks more suitable for deaf children, Table 5.4 shows that mean recall in the baseline condition was 67%. In Experiment 1 deaf subjects of the same age were tested on strict SOR of the same number of pictures. Mean recall in the baseline condition by these subjects was only 45%. Therefore the manipulations to increase task accessibility for deaf children and consequently improve baseline recall were successful.
Chapter 5

Pilot Study 3: Simplifying the concurrent tasks
and exploring concurrent signing

Introduction

Pilot studies 1 and 2 suggested that the hand and foot tracing tasks were more difficult than concurrent speech and therefore inappropriate to use in future experiments in this chapter. In this study hearing subjects are tested on recall while performing hand and foot movements which required them to tap either both hands or both feet alternately (i.e., left, right). Alternate tapping is less complex than the tracing tasks. However, it is more complex than tapping a single finger or hand which has been used in previous studies with hearing people (e.g., Papagno, Valentine & Baddeley, 1991; see Chapter 2) but has been criticised as too simple a control task (see Margolin et al. 1982).

Experiment 2 in this chapter explores the use of sign-based coding by deaf subjects using a concurrent signing task. The results from the first pilot study raise the possibility that recall by hearing subjects may be impaired by concurrent signing simply because of the level of difficulty of the task. This would make it difficult to argue that any effect of this task on recall by deaf people was indicative of sign-based coding as the same explanation would not be valid for hearing non-signers. Therefore, this pilot study also tested the effect of concurrent signing on recall by hearing non-signers.

A further aim of this study was to explore the validity of the methodological variation of strict SOR used in Pilot study 2. If hearing subjects show the same effect of concurrent speech as seen in traditional SOR when strict serial order is not required, then this is further justification to use this procedure in later experiments in this thesis. To test this, subjects in this study were told explicitly that they could recall the pictures in any order so long as the correct item was recalled in the correct serial position.
If the hand and foot movement tasks are of an appropriate level of difficulty it is expected they will have a slight, but non-significant effect on ordered recall by hearing subjects. Similarly, concurrent signing is a non-articulatory task for hearing people. If this task is of an equivalent level of difficulty as the hand and foot movement tasks then this task should not significantly impair recall. However, concurrent speech should impair recall to a greater extent than the concurrent foot and hand movement tasks because this should lead to specific disruption of speech-based recoding.

**Method**

**Subjects**
Seven hearing adults were tested. These were mostly undergraduate students. Their mean age was 28-years-old (range 25-40 years).

**Design and Materials**
Subjects performed four ordered recall trials in each of the following conditions: baseline; foot tapping; hand tapping; concurrent signing and concurrent speech. Trials were sampled randomly from each condition with the constraint that no two trials from the same condition were performed consecutively. The stimuli were the 48 picture stimuli used in Pilot study 1.

**Procedure**
Subjects were tested individually. The basic memory task involved presentation of six pictures, which were shown one at a time at a rate of one every two seconds and then placed face down in a spatial array in front of the subject. Subjects performed one practice trial and four experimental trials in each of the following conditions:
Chapter 5

- Baseline (no concurrent task)
- Foot tapping - continuous tapping of each foot alternately, left then right.
- Hand tapping - continuous tapping of each hand alternately, left then right
- Concurrent signing - repeating the sign BECAUSE (see Figure 5.1 & Figure 5.2).
- Concurrent speech - repeating aloud ‘because, because,....’.

The experimenter set the rate of the concurrent tasks by demonstrating what was required. In line with the pace advocated by Baddeley (1986) the tapping tasks were set a rate of approximately four taps per second. Since the word ‘because’ and the sign BECAUSE involve two syllables and two movements respectively, the concurrent speech and sign tasks could be set at the same rate, approximately two repetitions of ‘because’/ BECAUSE per second. Therefore, across the concurrent task conditions there was approximately an equivalent hand or foot tap for each syllable spoken or movement signed.

Subjects practised the tasks until they were comfortable with them and then performed a practice trial in each condition. During the experimental trials, subjects’ performance of the concurrent tasks was monitored by the experimenter. They were corrected after a trial if they diverted too far from the set pace. After presentation of the last picture subjects stopped the concurrent task. They then recalled the pictures they had seen by saying the name of each item while pointing to the cards in front of them to indicate order. They were told that they could recall in any order as long as the correct item was identified at the correct serial position.

Results and Discussion

Table 5.5 shows the mean percentage correctly recalled by hearing adults as a function of concurrent task. Inspection of the means indicates a large effect of concurrent speech. In contrast, the effects of concurrent foot and hand movement and
signing are minimal. The correlation between cell means and standard deviations was not significant (r=-.044, ns), therefore a one-way repeated measures ANOVA was used to analyse the data. This showed a main effect of Concurrent Task (F(4,24) = 7.53, p<.0005). Post-hoc Tukey analyses, adjusted for repeated measures (Stevens, 1992), showed that recall during concurrent speech was poorer than recall during all other conditions (ps<.05). Recall during foot tapping, hand tapping and concurrent signing did not differ from recall in the baseline condition.

Table 5.5: Mean (s.d.) percentage correctly recalled by hearing adults (n=7) as a function of concurrent task

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Foot tapping</th>
<th>Hand tapping</th>
<th>Concurrent signing</th>
<th>Concurrent speech</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean</td>
<td>78.57</td>
<td>75.60</td>
<td>75.00</td>
<td>70.83</td>
<td>45.83</td>
</tr>
<tr>
<td>(s.d.)</td>
<td>(9.75)</td>
<td>(19.46)</td>
<td>(13.61)</td>
<td>(13.82)</td>
<td>(14.03)</td>
</tr>
</tbody>
</table>

Concurrent hand tapping, foot tapping and signing did not disrupt ordered recall to the same extent as concurrent speech. Given that these tasks are moderately complex motor tasks this suggests that these tasks are of an appropriate level of difficulty to control for the general cognitive demands of concurrent speech.

Importantly, the results showed a specific effect of concurrent speech on recall by hearing adults despite the fact that subjects were not required to recall in strict serial order. However, simply allowing subjects to recall in any order may not lead them to approach the task any differently than in a traditional SOR task. That is, they may have recalled from the first item presented to the last, because this is a useful strategy to recall order. To address whether this was the case, the order in which subjects reported the items in this study was considered.
Order of recall

The order in which items were recalled was recorded for each subject and used to derive a weighted serial recall function. A score of 6 was given to the serial position where the first item was correctly recalled, 5 to the serial position where the second item was recalled and so on. If the 6 items were correctly recalled, the last item received 1 point. This was calculated for each subject, on all four trials across the five conditions. The serial recall function of a subject who correctly recalled all items from the first position through to the sixth position on all four trials would be linear and negative. The weighted recall scores for this perfect recall are shown in Table 5.6.

Table 5.6: Scores received for ‘perfect’ serial recall (position 1 to 6) on all 4 trials.

<table>
<thead>
<tr>
<th>Serial position</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>5th</th>
<th>6th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recall order score</td>
<td>6x4</td>
<td>5x4</td>
<td>4x4</td>
<td>3x4</td>
<td>2x4</td>
<td>1x4</td>
</tr>
</tbody>
</table>

Figure 5.5: Serial position curves for each condition weighted for order of report.

Figure 5.5 shows the weighted serial position curves for each condition. The order in which subjects recalled items in the baseline, foot tapping, hand tapping and concurrent signing conditions largely followed ‘pure’ SOR performance, recalling the first serial position, then the second and so on. Therefore subjects’ recall strategy is
not disrupted by the non-articulatory concurrent tasks. However, the pattern in the concurrent speech condition is rather different, as shown by the flattened curve. Subjects were less likely to recall from serial position one to six in the concurrent speech condition. This in itself is not surprising given that concurrent speech is thought to disrupt subvocal cumulative rehearsal. However, since subjects were not required to recall in strict serial order they could have employed an alternative recall strategy in this condition to compensate for the effect of concurrent speech. However this was not the case. As in a traditional test of SOR, concurrent speech severely impaired recall performance in this ordered recall task. This supports the use of the methodological adaptation used in this study to investigate the effect of concurrent speech on recall by deaf children.

Summary of Pilot Studies 1, 2 and 3

This series of pilot studies was conducted to investigate two methodological issues to be incorporated in Experiment 2 in this chapter:

- the choice of non-linguistic (hand) and non-articulatory (foot) concurrent tasks
- the presentation and scoring method to be used.

Pilot studies 1 and 2 showed that tracing a star with hands or feet during presentation of stimuli was too complex for deaf and hearing subjects. Pilot study 3 showed that the simpler concurrent tasks, tapping alternate hands or feet, were more suitable tasks. These tasks did not significantly affect recall by hearing subjects. Pilot study 3 also showed that recall by hearing subjects was not affected by concurrent signing.

Pilot study 2 showed that an adaptation of the strict SOR procedure made the task more accessible to deaf teenagers. Pilot study 3 explored the use of this method further and showed that when hearing adults were told they could start recall at any serial position the same effect of concurrent speech was observed as shown in
traditional tests of SOR. Therefore, this method of presentation and scoring is used in Experiment 2 in this chapter. This makes the experimental tasks more accessible to deaf children than a traditional test of serial order memory. Making recall easier for deaf subjects, and probably young hearing children, should give a greater spread of scores and therefore allow any differential effects of the concurrent tasks to be identified.
Chapter 5

Experiment 2a: Ordered recall by deaf teenagers during simplified concurrent tasks

Introduction

The main aim of this experiment was to explore speech-based and sign-based STM coding by deaf teenagers using concurrent speech, signing and hand tapping tasks. A review of the literature in Chapter Three showed that few studies had clearly demonstrated the use of a speech-based code by deaf people in a STM task. One study showed that deaf teenagers were affected by word length of stimuli, but only when a spoken response was required (Campbell & Wright, 1990). Similarly, studies that have used concurrent speech to tap speech-based coding by deaf people were inconclusive (Chincotta & Chincotta, 1996; Kyle, 1986). Hanson (1982; 1990) has been successful in identifying the use of speech-based coding by deaf people in a number of studies, which have explored the effect of speech similarity of items on recall. However, the majority of these studies involved deaf college students, and the results may therefore be limited to this exclusive sample of the deaf population.

Conrad’s (1979) study is most relevant to the subject group involved in the present study. Conrad investigated the effects of speech similarity of printed words on deaf school leavers and 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 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 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. In the US, Lichtenstein (1985) found no support for this hypothesis. He investigated the use of a speech-based STM code by deaf college students who had attended oral or TC schools and found no difference between the two groups. However, all subjects were college students and good readers and these subjects represent a small section of the deaf population. Lichtenstein's findings may apply to good deaf readers regardless of their educational background, but not to the majority of deaf people.

The present study tested the hypothesis that language modality used in school could influence STM coding by comparing two groups of deaf teenagers of normal attainment within the deaf schooling system: one group attending TC schools and another attending an oral school. The present experiment also extended the previous studies by Hanson and Conrad by testing recall of *pictorial* stimuli rather than printed English words, since of interest here was the STM coding option used by deaf teenagers *spontaneously* to recode pictorial stimuli.

In this study the use of speech-based coding was investigated using concurrent speech, and the use of sign-based STM coding was investigated using concurrent signing and hand-tapping. To control for the executive demands of these tasks a non-articulatory concurrent task, foot tapping, was also included. On the basis of Pilot studies 1, 2 and 3 these four concurrent tasks appear to be of a similar level of difficulty.

To enable the differential effects of these concurrent tasks to be distinguished it was essential that baseline (i.e., no concurrent task) performance was not at floor level. Two steps were taken to achieve this:
The method of presentation and scoring tested in Pilot studies 2 and 3 was used.

Subjects were screened. Only subjects who recalled at least 50% correct in the baseline condition were included in the analysis. This method has been used in other studies of STM by deaf people (e.g., Kyle, 1986; Wilson & Emmorey, 1997a), as it offers a degree of control over the heterogeneous STM performance of the deaf population.

Two hearing groups were also included in this experiment. One group was chronologically-age-matched to the deaf groups, the other reading-age-matched. These control groups allow us to identify whether the pattern of recall seen in deaf teenagers is similar to that of hearing children of the same chronological age or similar to that of children of equivalent reading level.

**Method**

**Subjects**

Four groups of subjects were tested:

- Deaf 14-year-olds attending a TC school
- Deaf 14-year-olds attending an oral school
- Hearing 8-year-olds, reading age (RA) matched to the deaf groups
- Hearing 14-year-olds, chronological age (CA) matched to the deaf groups

Only subjects who recalled 50% correct in the baseline condition were included in the analysis. The number of subjects from each group who did not reach this criterion was as follows:

- deaf TC subjects - N=5 (29% of total, mean CA = 13, 2, mean RA = 7, 5)
- deaf oral subjects - N=1 (8% of total, CA = 15; 10, RA = 8; 10)
- hearing RA - N=2 (13% of total, mean CA = 8, 3, mean RA = 7, 4)
- hearing CA - N=0
The characteristics of subjects who did reach the 50% correct criterion are shown in Table 5.7 and will now be discussed.

**Deaf subjects**

Twelve deaf subjects were selected from two TC schools for the deaf. Twelve deaf subjects from an oral school for the deaf were also selected. Most of the TC pupils had also attended a TC primary school. Similarly, most of the oral pupils had attended an oral primary school. All deaf subjects had hearing parents and none had any additional disabilities.

These two groups of deaf subjects were matched on:

- Chronological age
- Hearing loss – dB hearing loss in the better ear was established from each child’s audiogram held in school records.
- Non-verbal IQ (NVIQ) – This was assessed using matrices from the British Abilities Scales (Elliot, Murray & Pearson, 1983). Subjects with standardised scores one standard deviation (10) below the population mean (50) were not selected.
- Reading age – Subjects attending the oral school and subjects attending one of the TC schools (N=7) had been assessed on reading ability at school in the two months before the memory test. Both schools had used the Edinburgh Reading Test (ERT, Godfrey Thomson Unit, 1993). For these subjects these scores were used and adjusted for the time lag between reading and memory test. The remaining 5 deaf TC subjects attended a different school and had not been recently assessed on reading ability. The reading ability of these subjects was tested for this study using the Shortened Edinburgh Reading Test (SERT) (see Experiment 1).
The subject characteristics of these groups are shown in Table 5.7. Independent samples t-tests showed that the deaf TC and the deaf oral groups did not differ on chronological age, reading age, NVIQ or hearing loss (all ps>.1).

Table 5.7: Subject characteristics of participants in Experiment 2

<table>
<thead>
<tr>
<th></th>
<th>Chronological age</th>
<th>Reading age</th>
<th>NVIQ</th>
<th>Hearing loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (range in months)</td>
<td>Mean (range)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deaf TC 14-year-olds</td>
<td>14; 9 (145-201)</td>
<td>8; 4 (84-126)</td>
<td>48 (40-59)</td>
<td>106dB (95-125dB)</td>
</tr>
<tr>
<td>(N=12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deaf oral 14-year-olds</td>
<td>14; 3 (149-194)</td>
<td>9; 2 (90-145)</td>
<td>51 (40-64)</td>
<td>103dB (89-114dB)</td>
</tr>
<tr>
<td>(N=12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hearing CA controls</td>
<td>14; 8 (144-194)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(N=12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hearing RA controls</td>
<td>8; 9 (93-127)</td>
<td>8; 7 (93-121)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(N=13)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Hearing groups

There were two hearing control groups: one matched to the deaf groups on chronological age (CA controls) and the other matched to the deaf groups on reading age (RA controls). All hearing subjects were selected from mainstream schools in the south-east of England and all were judged by their class teacher to be of 'average' intelligence. Hearing subjects were approximately matched at a group level to the deaf groups.
The reading ages of the RA controls were taken from school records and were adjusted for the two-month time lag between the reading test administration and memory test. Independent samples t-tests confirmed that there were no significant differences in reading age between the hearing 8-year-olds and the deaf TC group ($t(23) = .699, p>.1$) or the deaf oral group ($t(23) = -1.266, p>.1$). The mean chronological ages and reading ages of the hearing groups are shown in Table 5.7.

**Design**

A 4 (Group) by 5 (Concurrent Task) design was used. The groups tested were: deaf TC 14-year-olds; deaf oral 14-year-olds; hearing 8-year-olds and hearing 14-year-olds. Concurrent Task was the within subjects factor, which had five levels: no task; foot tapping; hand tapping; concurrent signing and concurrent speech. Subjects performed one practice trial and four experimental trials (3 for the younger hearing group) in each condition. Subjects performed 20 experimental trials in total (young hearing group=15). Trials were sampled randomly from each condition with the constraint that no two trials from the same condition were performed consecutively.

**Materials**

The stimuli were the 48 black and white line drawings used in Experiment 1. These were taken from the Snodgrass and Vanderwart (1980) picture norms and printed on 10cm X 15cm white card. Stimulus sets for each trial were pre-determined and each picture was seen approximately the same number of times across trials.

**Procedure**

Subjects were tested individually. All subjects performed a pre-test in which they were required to name the 48 pictures in sign or speech. This was completed successfully by all subjects. The experimental procedure was the same as that in Pilot studies 2 and 3. Subjects were presented with six pictures, which were shown one at a time at a rate of one every two seconds and then placed face down in a spatial array on a table. Subjects were not allowed to label the stimuli at presentation.
The concurrent tasks of foot tapping, hand tapping, concurrent signing (BECAUSE) and concurrent speech (‘because’) were all demonstrated and paced as in Pilot study 3. Practice was given on all tasks. Subjects then performed a practice trial in each condition. As the hearing subjects practiced the sign BECAUSE they were told that the movement meant ‘because’ in BSL and the idea of sign language was explained to the younger hearing subjects if necessary. This was an attempt to equate the linguistic nature of concurrent signing for all groups.

At recall the subject responded by pointing to the cards and naming the item thought to be at the location. Recall was spoken by hearing subjects and in the subject’s preferred mode for deaf subjects. 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. Some subjects also voiced their response.

Predictions
It was expected that the pattern of recall by hearing 14-year-olds would be similar to that of hearing adults tested in Pilot study 3. Concurrent speech should impair recall by these subjects more than all other concurrent tasks. In contrast, recall should not be significantly impaired by the non-articulatory tasks of hand/foot tapping and concurrent signing.

Hitch, Halliday and Littler (1989) showed that concurrent speech impaired recall of visual stimuli by hearing 8-year-olds. However, their study did not include a non-articulatory concurrent task. Concurrent speech may impair recall by hearing children in mid-childhood because of the central executive resources required to perform the task. However, if concurrent speech leads to poorer recall than in the tapping conditions in the present study, then this would be evidence for the specific disruption of a speech-based STM code.
The important comparison for both deaf groups was between the effects of concurrent speech, signing, hand tapping (all ‘articulatory’) and the non-articulatory task of concurrent foot tapping. If deaf teenagers used a speech-based code in this picture recall task they should show a specific effect of concurrent speech. Furthermore, greater exposure to and use of spoken language may lead to more efficient use of a speech-based STM code. If so, then deaf oral subjects may be affected by concurrent speech to a greater extent than deaf TC subjects.

With regard to the effect of concurrent signing, if the level of sign language proficiency of deaf TC subjects was sufficient to support the use of a sign-based STM code, concurrent signing may impair recall by these subjects. Such a sign-based code may even be disrupted by concurrent tapping of alternate hands. It is also possible that pupils attending an oral school are able to use a sign-based code, since many deaf children attending oral schools use sign language with each other outside the classroom. In a short structured interview at the end of the experimental testing session all deaf oral pupils confirmed that they signed with their deaf peers and most said they signed often. Therefore, the use of a sign-based STM code may be seen from the concurrent sign task for deaf pupils attending an oral school as well as those attending a TC school.

Results

Table 5.8 and Figure 5.6 show the mean percentage correctly recalled by each group during each concurrent task condition.
Table 5.8: Mean (s.d.) percentage correctly recalled as a function of concurrent task

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Foot tapping</th>
<th>Hand tapping</th>
<th>Concurrent signing</th>
<th>Concurrent speech</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deaf TC – 14-year-olds</td>
<td>64.93</td>
<td>56.25</td>
<td>51.04</td>
<td>49.65</td>
<td>46.53</td>
<td>53.68</td>
</tr>
<tr>
<td>Deaf oral – 14-year-olds</td>
<td>65.63</td>
<td>52.43</td>
<td>57.29</td>
<td>52.08</td>
<td>39.93</td>
<td>53.47</td>
</tr>
<tr>
<td></td>
<td>(11.80)</td>
<td>(14.59)</td>
<td>(13.78)</td>
<td>(19.18)</td>
<td>(15.84)</td>
<td>(10.14)</td>
</tr>
<tr>
<td>Hearing – CA controls</td>
<td>69.10</td>
<td>67.01</td>
<td>68.75</td>
<td>70.49</td>
<td>34.03</td>
<td>61.88</td>
</tr>
<tr>
<td></td>
<td>(8.04)</td>
<td>(10.28)</td>
<td>(13.82)</td>
<td>(11.85)</td>
<td>(12.16)</td>
<td>(7.20)</td>
</tr>
<tr>
<td>Hearing – RA controls</td>
<td>60.26</td>
<td>47.86</td>
<td>52.14</td>
<td>49.14</td>
<td>34.61</td>
<td>48.80</td>
</tr>
<tr>
<td></td>
<td>(13.95)</td>
<td>(14.62)</td>
<td>(11.01)</td>
<td>(16.17)</td>
<td>(13.82)</td>
<td>(10.00)</td>
</tr>
<tr>
<td>All Groups</td>
<td>64.88</td>
<td>55.73</td>
<td>57.20</td>
<td>55.21</td>
<td>38.69</td>
<td>54.34</td>
</tr>
<tr>
<td></td>
<td>(11.18)</td>
<td>(15.43)</td>
<td>(15.27)</td>
<td>(18.35)</td>
<td>(14.27)</td>
<td>(10.42)</td>
</tr>
</tbody>
</table>

The correlation between the cell means and standard deviations was significant (r = -.488, (20) p < .05). Due to this violation of the homogeneity of variance assumption an arcsine transformation was applied to the data. This was successful in improving the distribution of the data as the correlation between cell means and standard deviations was no longer significant (r(20) = .04, p > .1).

A 4 (Group) X 5 (Concurrent Task) mixed ANOVA was used to analyse the transformed data. The main effects of Group (F(3,45) = 4.24, p < 0.025) and Concurrent Task (F(4,180) = 32.84, p < 0.0005) were significant. The Group by Concurrent Task interaction was also significant (F(12,180) = 3.11, p < 0.0005) (see Table 5.9).
Figure 5.6: Mean % correctly recalled by each group as a function of concurrent task

Table 5.9: ANOVA table for Group by Concurrent Task

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within and residual</td>
<td>3.108</td>
<td>45</td>
<td>0.069</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td>0.879</td>
<td>3</td>
<td>0.293</td>
<td>4.24</td>
<td>.01</td>
</tr>
<tr>
<td>Concurrent Task</td>
<td>3.541</td>
<td>180</td>
<td>0.0197</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group by Concurrent Task</td>
<td>2.585</td>
<td>4</td>
<td>0.6460</td>
<td>32.84</td>
<td>.000</td>
</tr>
</tbody>
</table>

Analysis of the simple effects of Group within each level of Concurrent Task were conducted (alpha = .01). Recall by the four groups did not differ during the concurrent speech (F(3,45) = 2.16, p > .1) or baseline conditions (F(3,45) = 1.36, p > .1). The fact that the groups did not differ in the baseline condition suggests that, as intended, the ordered recall methodology substantially increased recall by deaf 14-year-olds and deaf oral 14-year-olds.
younger hearing subjects. The groups did differ in the effects of concurrent signing \(F(3,45) = 4.56, p<.01\) and the effects of tapping were of borderline significance: hand tapping \(F(3,45) = 4.13, p=.011\) and foot tapping \(F(3,45) = 4.07, p=.012\).

The simple effects analysis of Concurrent Task were significant within each Group: deaf TC 14-year-olds \(F(4,180) = 4.74, p<.005\), deaf oral 14-year-olds \(F(4,180) = 7.97, p<.0005\), hearing CA controls \(F(4,180) = 22.30, p<.0005\) and hearing RA controls \(F(4,180) = 8.54, p<.0005\). Bonferroni corrected t-tests (alpha=0.00125) were used to follow up these simple effects (as recommended by Stevens, 1992). These will be discussed for each subject group.

**Deaf TC 14-year-olds**

Deaf 14-year-olds attending TC schools recalled less in the concurrent speech condition than in the baseline condition \(t(11) = 4.24, p<.00125\). None of the other concurrent tasks reached the adjusted level of significance (alpha=0.00125) in comparison to baseline: hand tapping \(t(11) = 3.00, p=.012\); concurrent signing \(t(11) = 2.59, p=.025\); foot tapping \(t(11) = 1.55, p>.1\).

Importantly, there was no evidence of a specific effect of concurrent speech as there was no difference between recall during concurrent speech and any other concurrent task: foot tapping \(t(11) = 1.89, p=.086\); hand tapping \(t(11) = 1.12, p>.1\) or concurrent signing \(t(11) = .604, p>.1\).

**Deaf oral 14-year-olds**

Deaf 14-year-olds attending oral schools showed the same pattern of recall as their deaf TC peers. Recall during the concurrent speech condition was poorer than in the baseline condition \(t(11) = 4.43, p<.00125\). None of the other concurrent tasks reached the adjusted level of significance (alpha=0.00125) in comparison to the baseline condition: foot tapping \(t(11) = 3.44, p=.006\); concurrent signing \(t(11) = 2.97, p=.013\); hand tapping \(t(11) = 2.57, p=.026\).
Chapter 5

It was predicted that recall by deaf oral subjects would be affected to a greater extent by concurrent speech than deaf TC subjects. However, this was not the case as recall by oral subjects in the concurrent speech condition did not differ from recall during any other concurrent task given the adjusted significance level: hand tapping ($t(11) = 2.68, p = .021$), foot tapping ($t(11) = 2.21, p = .05$) and concurrent signing ($t(11) = 2.28, p = .043$).

*Hearing 14-year-olds*

As predicted, recall by hearing 14-year-olds during concurrent speech was poorer than recall in all other conditions (all $p$s $<$ .0005). All other tasks did not differ significantly from each other.

*Hearing 8-year-olds*

Recall by hearing 8-year-olds was poorer during concurrent speech than in the baseline condition ($t(12) = 4.88, p < .0005$). The effects of the other concurrent tasks failed to reach the adjusted level of significance in comparison to baseline performance ($\alpha = 0.00125$): foot tapping ($t(12) = 3.67, p = .003$), concurrent signing ($t(12) = 2.39, p = .034$) and hand tapping ($t(12) = 1.97, p = .073$).

Recall during concurrent speech was poorer than during hand tapping ($t(12) = 5.54, p < .0005$) but not foot tapping ($t(12) = 2.62, p = .022$) or concurrent signing ($t(12) = 2.99, p = .011$).

*Serial Position data*

The serial position curves of the four groups were compared to assess the validity of the adapted methodology and scoring procedure used in this experiment. If deaf and hearing subjects approach this task differently when allowed to recall in any order, then the comparison of groups on these concurrent tasks may not be valid. Thus, whether there were systematic differences in the serial position curves of deaf and hearing subjects was examined.
Figure 5.7 shows that the serial position curve of each group is very similar. The correlation between the cell means and standard deviations was significant ($r(24)=-.505$, $p<.05$). Due to this violation of the homogeneity of variance assumption an arcsine transformation was applied to the data. This was successful in improving the distribution of the data as the correlation between cell means and standard deviations was no longer significant ($r(24)=.07$, $p>.1$).

A 4 (Group) by 6 (Serial Position) mixed model ANOVA was used to analyse the transformed data. This showed a main effect of Group ($F(3,45) = 4.17$, $p<.025$) and Serial Position ($F(5,225) = 50.06$, $p<.0005$), but no Group by Serial Position interaction ($F(15,225) = 1.46$, $p>.1$). This indicates that the methodology and scoring adaptations did not lead to any systematic differences between groups in their pattern of recall.
Direct comparison of deaf groups

It was predicted that the deaf oral subjects were more likely to be affected by concurrent speech than their deaf TC peers. However, separate analyses of the two deaf groups did not support this hypothesis as both groups showed a very similar pattern of recall. To test this directly, the two deaf groups alone were compared in a 2 (Group) by 5 (Concurrent Task) mixed ANOVA using the transformed data. There was a main effect of Concurrent Task (F(4,88) = 10.10, p<.0005) but not Group (F(1,22) = .001, p>.1). Furthermore, there was no interaction between Group and Concurrent task (F(4,88) = .44, p>.1). This analysis confirmed that there were no differences in overall performance or patterns of recall by the deaf groups.

Effects of concurrent task on deaf teenagers

The main aim of this experiment was to determine the pattern of effects of concurrent tasks on recall performance by deaf teenagers. When the two deaf groups were analysed separately there was no difference in their pattern of performance in the concurrent task conditions. Increasing power, by combining the two deaf groups, should give a clearer picture of the effects of concurrent tasks.

The main effect of Concurrent Task on recall by all deaf 14-year-olds was analysed using Bonferroni corrected t-tests (alpha=.005). The results showed that recall was significantly poorer during all concurrent tasks than in the baseline condition: concurrent speech (t(23) = 6.10, p<.0005), concurrent signing (t(23) = 3.97, p<.002), hand tapping (t(23) = 3.98, p<.002) and concurrent foot tapping (t(23) = 3.31, p<.005). Furthermore, the difference between concurrent speech and foot tapping approached the adjusted significance level (t(23) = 2.96, p=.007). However, the difference between concurrent speech and the remaining concurrent tasks did not: hand tapping (t(23) = 2.76, p=.011) and concurrent signing (t(23) = 1.98, p=.06). No other differences approached significance.
**Summary of results**

Recall performance by deaf 14-year-olds was similar across both groups regardless of educational background. Therefore, subjects in these two groups were combined to increase the power of the analysis. All concurrent tasks impaired performance by deaf 14-year-olds. However, the difference between the effect of concurrent speech and the non-articulatory foot tapping task was of borderline significance, suggesting a specific effect of concurrent speech. This pattern of performance by deaf 14-year-olds was similar to that of hearing children of a similar reading age. Recall by hearing 8-year-olds during concurrent speech was poorer than during hand tapping, but not foot tapping or concurrent signing. As predicted, the hearing CA control group showed a specific effect of concurrent speech. Recall in this condition was significantly poorer than for any other concurrent task.

**Discussion**

As predicted, hearing CA controls showed a specific effect of concurrent speech, which impaired recall to a greater extent than the three non-articulatory concurrent tasks. This effect is interpreted as indicative of speech-based coding. The pattern of recall by hearing RA controls was less clear cut. In comparison to the baseline condition, the effects of the non-articulatory concurrent tasks were of borderline significance. Recall during concurrent speech was poorer than in the baseline and hand tapping conditions. However, it did not differ from recall in the foot tapping or concurrent signing conditions. Therefore, this pattern of recall is inconclusive with regard to the use of a speech-based STM code by hearing eight-year-olds. Since hearing children are only thought to start using the subvocal rehearsal process to verbally recode visual stimuli at around seven-years-old (see Gathercole & Baddeley,

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1 When interpreting these results it should be borne in mind that the hearing group analyses differ in power to the deaf group analyses since they are based on fewer subjects.
1993) the present pattern of results may reflect the use of an under-specified speech-based code by these eight-year-olds.

The main aim of this experiment was to investigate STM coding by deaf teenagers. It was proposed that children attending an oral school may be more skilled in the use of a speech-based code than their deaf peers attending a TC school where there is much less emphasis on the use of spoken language. Separate and combined analyses of these two groups showed very similar patterns of performance in each group for all the experimental tasks. 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 the reading ability or 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.

Recall by the combined deaf teenage groups was similarly impaired by all concurrent tasks in comparison to the baseline condition. This suggests that all concurrent tasks involved a large central executive component for these subjects. These data also suggested a specific effect of concurrent speech on recall in comparison to the non-articulatory, foot-tapping, task. However, this was of borderline significance given the adjusted significance level (p=.007). As suggested with hearing RA controls, this specific, yet weak, effect of concurrent speech may be indicative of the use of an under-specified speech-based code. Alternatively, the use of strategies dependent on this code may be poor or both of these factors may play a role in the effect.

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

Group analyses did not allow us to decide between these possibilities. However, correlational analyses, reported in the next section, may further inform our interpretation of this pattern of results. The group analyses also showed that in comparison to the foot tapping task, a specific effect of concurrent speech on recall by deaf teenagers was of borderline significance. This suggested that these subjects used a speech-based STM code in this immediate recall task. To investigate the subject characteristics that may be associated with the use of this code, the relationships between memory scores and subject characteristics were investigated in a correlational analysis. The theoretical implications of the present experiment will be discussed further following a discussion of the correlational data.
Experiment 2b: Correlational analyses: The relationship between STM ability, individual differences and language measures.

Introduction

The aim of these analyses was to investigate the relationships between characteristics of deaf subjects and their STM ability and use of STM codes. The subject characteristics explored are chronological age, reading age, NVIQ and hearing loss. Of particular interest is the potential importance of language factors to STM ability and STM coding. Conrad (1979) proposed that the quality of a deaf child’s speech is of fundamental importance to the use of a speech-based code in STM, in particular the child’s consistency in their use of speech. The analyses in Experiment 2a tested this hypothesis at the group level by assuming that the external speech of children attending oral schools is better than that of deaf children attending TC schools. However, the results of the group analysis showed no differences between groups in their use of a speech-based STM code as inferred from the effect of concurrent speech. Here, correlational analyses were computed in order to investigate Conrad’s hypothesis at an individual level by correlating STM ability and language production measures from each deaf subject. These language production measures were:

- speech intelligibility
- speech rate
- sign rate

Speech intelligibility

Some studies have shown that speech intelligibility (SI) of deaf subjects is related to the use of a speech-based STM code (Conrad, 1979), susceptibility to orthographic regularity (Hanson, 1986), speed of word reading and performance on a lexical decision task (Leybaert & Algeria, 1993). However, this relationship is not found in all studies. Dodd, Hobson, Brasher and Campbell (1983 - Experiment 2) showed that
there was no difference in SOR of lip-read digits between high intelligible and low intelligible deaf teenagers. Part of this discrepancy may relate to the lack of agreement on how SI should be assessed.

Conrad (1979) assessed SI in two ways. First, teachers were asked to rate subjects on speech quality. Second, tape recordings of deaf subjects reading sentences aloud were played to listeners unfamiliar with deaf speech. The listeners were given the target sentences with two words missing and their task was to fill in the missing items. A subject’s SI was determined from the number of items correctly identified. Conrad found that these two measures were strongly related and that there was a significant relationship between SI and the use of a speech-based STM code, even when the effects of hearing loss and NVIQ, which are related to SI, were controlled for. The present study uses the rating procedure established by Conrad (1979, pg. 211) to assess the SI of the subjects tested in Experiment 2a.

Speech rate

Many studies have found that speech rate is positively correlated with memory span in hearing people (e.g., Baddeley, Thomson & Buchanan, 1975). The working memory model accounts for this relationship in terms of subvocal rehearsal. The quicker items can be rehearsed, the more often they are refreshed within the fixed time window of the loop. This relationship also exists in young children (Hitch, Halliday & Littler, 1989; Hulme, Thomson, Muir & Lawrence, 1984; Hulme & Tordoff, 1989). However, since hearing children may not use subvocal rehearsal routinely until around nine-years-old (Henry, 1991; see Chapter Two) another age related factor must explain this relationship. One possibility is that, as with the revised explanation of the word length effect in young children, articulation rate at output is the locus of this effect (see section 2.5.i). That is, as children get older they are able to output items at a quicker rate, thus less items are lost from the phonological store due to decay (Cowan & Kail, 1996; Henry, 1991). No study in the literature has assessed the speech rates of deaf people in relation to memory span. The
present study explores this relationship.

It is not yet clear from the literature whether the relationship seen between speech-rate and memory span should also be anticipated between *sign-rate* and memory span for sign stimuli. The relationship between STM representations and production rate may function differently for sign than speech. A study that suggests this might be the case was a comparison of speech and sign production rate by Bellugi and Fischer (1972). Three subjects were tested. All were hearing adults of deaf parents and bilingual in ASL and spoken English. Subjects were asked to recount a story from their childhood either in ASL alone, in spoken English alone or simultaneously in sign and speech.

The length of each story was recorded, excluding pause times. All three subjects produced around twice as many words per second as signs per second. However, information expressed sequentially in speech can often be expressed simultaneously in sign language. Therefore, Bellugi and Fischer also compared the time taken to express complete *propositions* in signed and spoken stories. They found "similarities in the length of time per underlying proposition for the two modes" (1972, pg. 184).

These results suggest that although there are superficial differences in production rate of sign and speech, the same amount of information can be conveyed in a given time. However, it is not clear how these measures of fluent signing relate to the rehearsal of lists of unconnected signs in STM. Only one study has investigated this relationship. Mayberry and Waters (1991) explored the sign rate and fingerspelling rate of deaf seven- to fifteen-year-olds in relation to their memory span for signs and fingerspelled words. Memory span for fingerspelled words correlated positively with fingerspelling rate for single words, word pairs and triads. However, only one significant correlation was reported for the sign data. This was between sign production rate for triads and sign span and this held only for native signers. It is possible that the sign proficiency of some of the young deaf children tested by Mayberry and Waters was not yet sufficient to support a sign-based code. The present study reassessed this issue by
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testing older deaf children (fourteen-year-olds) on the relationship between sign rate and immediate recall ability.

Method

Subjects
Speech intelligibility, speech rate and sign rate measures were established for deaf subjects who participated in Experiment 2a. This production data was collected nine months following the main Experiment 2a testing session and 17 of the 23 original deaf subjects were tested.

Procedure

*Speech intelligibility*
The child's class teacher or speech and language therapist was asked to rate the everyday speech of the child on the following 5 point scale:
1 - wholly intelligible
2 - fairly easy to understand
3 - about half understood
4 - very hard to understand
5 - effectively unintelligible

This follows Conrad's (1979) procedure. Conrad asked teachers to rate each pupil's speech intelligibility "with inexperienced listeners in mind" (1979, pg.212). This approach was also used here to help ensure that raters at different schools used a similar baseline from which to score the children.

*Speech and sign rate assessment*
This session was video-taped for later detailed scoring. The procedure and stimuli
were the same in the sign rate and speech rate tasks. The stimuli used were the monosyllabic words, *fish* and *book*, which were used in the STM tasks in Experiment 2a. The signs FISH and BOOK both involve one movement and therefore can be considered monosyllabic signs (Liddell, 1984). Subjects were asked to repeat aloud/sign this pair of items as quickly as possible seven times in succession. They repeated this three times for signs and words. Half the subjects performed the speech rate task first and half performed the sign rate task first.

**Overall STM ability measure**

The dependent measure of STM ability was recall performance in the baseline condition in Experiment 2a.

**Susceptibility to concurrent speech/sign**

Two derived scores can give measures of susceptibility to concurrent task performance. These are:

- *Difference scores* - the absolute difference in recall between baseline and concurrent speech or sign conditions.

- *Proportion scores* - the number of items recalled in the concurrent speech or sign condition as a proportion of the number recalled in the baseline condition\(^2\). Unlike a difference score this method is sensitive to individual differences in baseline recall. For example, if subject A correctly recalled 6 items in the baseline condition and 4 during concurrent speech and subject B correctly recalled 4 in the baseline condition and 2 during concurrent speech, they would have the same difference score. However, the proportion scores for these two subjects is not equivalent. Subject A would have a proportion score of .33 and Subject B .50.

\(^2\)That is, recall in the control condition (C) minus recall in the experimental condition (E), divided by C. This measure is functionally equivalent to the simpler measure of E/C. However, with the former measure higher scores indicate greater susceptibility to the concurrent task and are therefore easier to interpret.
While difference scores and proportion scores are related, neither is intrinsically superior to the other. They reflect different aspects of the data. Both difference and proportion scores were therefore used in the present correlational analyses.

Results

Speech intelligibility

One class teacher from a TC school did not return the rating form for her 3 pupils. Therefore, SI ratings were available only for five TC subjects and nine oral subjects. Mean SI rating for oral subjects was 1.22, while mean rating for TC subjects was 3.4 (see rating scale in Method section). For ease of interpretation in the correlational analyses SI ratings were reversed such that a score of ‘5’ became ‘1’ and so on. This meant that a high score indicated good SI.

Speech/ sign rate

With regard to the speech/ sign rate data each speech/ sign rate trial (3 trials of each) was video-taped and later timed by the experimenter. This was done twice to reduce timing errors. The average of these two scores across the three different trials was then used to establish the speech rate and sign rates of each subject. The data set is incomplete for a number of reasons. First, when asked to repeat aloud the pairs of words, four TC pupils signed the item simultaneously. In such cases the subjects were not asked to repeat the trials using speech alone as this obviously was not their natural form of communication. These data was therefore used as sign rate data for these subjects. Two subjects in the oral group ‘played’ with the signs by speeding them up to be unintelligible. These data could not therefore be included in the analyses. Mean speech and sign rates, expressed as words/ signs per second, are shown in Table 5.10. Data from other studies of production rates by similar age groups are included for comparison.
Table 5.10: Mean words/ signs per second by deaf 14-year-olds in the present study and from comparison studies.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(n=13)</td>
<td>2.92</td>
<td>2.67</td>
<td>2.85</td>
<td>2.38</td>
</tr>
<tr>
<td>(s.d.)</td>
<td>(0.92)</td>
<td>(0.61)</td>
<td>(hearing 11-yr.-olds)</td>
<td>(deaf 14-yr-olds)</td>
</tr>
</tbody>
</table>

Rate of speech production and sign production correlated significantly ($r(11)=.975$, $p<.0005$). Furthermore, independent t-tests show that there was no difference between deaf TC and deaf oral groups in speech rate ($t(11) = .526$, $p>.1$) or sign rate ($t(13) =-.287$, $p>.1$).

Correlational analyses

In this sample of subjects chronological age correlated positively with hearing loss ($r(23)=.52$, $p<.025$). This reflects a sampling artifact and does not have theoretical implications. The only other significant correlation in this analysis was a negative correlation between chronological age and susceptibility to concurrent signing (difference score, $r(23)=-.49$, $p<.025$; proportion score, $r(23)=-.51$, $p<.025$). This suggests that older subjects were less affected by concurrent signing than younger subjects.

Due to the relationship between chronological age and hearing loss in this subject group, chronological age was partialled out of the main analyses. The overall correlation matrix between subject variables and STM measures, controlled for age, is shown in Table 5.11. The final columns are omitted from this matrix since these correlations are confounded by the fact that they are based on the same measures.

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3 Raw data is not provided in this paper. Therefore these means are derived from graphs and converted from seconds per sign to signs per second. These data are from deaf children of hearing parents. Mayberry and Waters (1991) also tested deaf children of deaf parents.
example, susceptibility to both concurrent tasks is based on recall in the baseline condition, for both the difference and proportion scores. These measures are therefore likely to co-vary.

1) Correlations between STM measures and sign rate/speech rate

Although based on relatively few subjects, the speech rate (n=13) and sign rate (n=15) data correlated with a number of other individual difference measures. There was a highly significant relationship between the speech rate and sign rate measures themselves ($r(8)=.975$, $p<.01$). This was reflected in the finding that both measures of production rate correlated positively with STM ability, though the effect for speech rate was of borderline significance: sign rate ($r(12)=.735$, $p<.01$), speech rate ($r(10)=.557$, $p=.06$). Susceptibility to concurrent speech also correlated with sign rate (difference score, $r(12)=.56$, $p<.05$; proportion score, $r(12)=.56$, $p<.05$). Faster signers were more susceptible to concurrent speech. The correlation between speech rate and susceptibility to concurrent speech was in the same direction but failed to reach significance (difference score, $r(10)=.423$, $p=0.17$; proportion score $r(10)=.332$, $p=.29$). There was also a negative correlation between hearing loss and speech rate ($r(9)=-.613$, $p<.05$). The greater the hearing loss the slower the child’s speech.

2) Correlations between STM measures and reading age

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 condition. The relationship between susceptibility to concurrent speech and reading age approached significance (difference score, $r(21)=.39$, $p=.07$). There was also a positive relationship between reading age and the two speech measures: speech intelligibility ($r(16)=.65$, $p<.01$) and speech rate ($r(12)=.870$, $p<.0005$).
Table 5.11: Deaf 14-year-olds - Correlation matrix controlled for chronological age (degrees of freedom in parentheses)

<table>
<thead>
<tr>
<th></th>
<th>Reading age</th>
<th>NVIQ</th>
<th>Hearing loss</th>
<th>SI</th>
<th>Speech rate</th>
<th>Sign rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>NVIQ</td>
<td>.109</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hearing loss</td>
<td>- .233</td>
<td>.199</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speech intelligibility</td>
<td>.646**</td>
<td>.074</td>
<td>-.257</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speech rate</td>
<td>.870**</td>
<td>-.030</td>
<td>-.613*</td>
<td>.432</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sign rate</td>
<td>.279</td>
<td>-.022</td>
<td>-.192</td>
<td>-.202</td>
<td>.975**</td>
<td></td>
</tr>
<tr>
<td>STM ability (baseline condition)</td>
<td>.438*</td>
<td>-.031</td>
<td>-.052</td>
<td>.085</td>
<td>.557</td>
<td>.735**</td>
</tr>
<tr>
<td>Susceptibility to concurrent speech</td>
<td>.385</td>
<td>-.016</td>
<td>-.036</td>
<td>.230</td>
<td>.423</td>
<td>.560*</td>
</tr>
<tr>
<td>Prop. score</td>
<td>.225</td>
<td>.011</td>
<td>-.010</td>
<td>.263</td>
<td>.332</td>
<td>.556*</td>
</tr>
<tr>
<td>Susceptibility to concurrent signing</td>
<td>.079</td>
<td>-.274</td>
<td>-.183</td>
<td>-.096</td>
<td>.286</td>
<td>.314</td>
</tr>
<tr>
<td>Prop. score</td>
<td>-.014</td>
<td>-.299</td>
<td>-.226</td>
<td>-.041</td>
<td>.142</td>
<td>.104</td>
</tr>
</tbody>
</table>

* p<.05, ** p<.01

Diff. Score – difference score, Prop. Score – proportion score
Discussion

The aim of this correlational analysis was to determine what characteristics of deaf subjects were related to STM ability and their use of STM codes. Reading age was an important correlate of STM performance and use of a speech-based STM code as indexed by susceptibility to concurrent speech (though this was of borderline significance). Reading age also correlated positively with speech rate. The relationship between speech rate and STM performance by deaf children had not been previously explored. The findings from these data demonstrated that aspects of language production may be as important to STM of deaf people as it is to hearing people.

Speech rate and sign rate

Traditionally the relationship between speech rate and STM ability in hearing people has been attributed to the use of rehearsal (e.g., Hulme et al., 1984). In the current study there was a positive correlation between sign rate and STM ability and the relationship between speech rate and STM ability was of borderline significance (p=.06). However, this is unlikely to be due wholly to rehearsal for two reasons. First, deaf children’s use of rehearsal can be substantially delayed (see Bebko, 1998). Second, the gradient of the regression functions between memory ability and speech rate, measured by the \( r \) coefficient, is thought to reflect the capacity of the articulatory loop, estimated to be around 1.5 seconds for hearing adults (Hulme et al., 1984). The figures reported for the deaf subjects in this study (speech rate - .557 and sign rate - .735) are similar to those reported by Hulme and McKenzie (1992) for Downs syndrome children (.69). They argued that the flattening of the speech rate recall function reflected absence of rehearsal in these subjects.

If the deaf teenagers tested in the present study were not rehearsing, yet the relationship between memory span and sign/ speech rate was still apparent, another
factor must account for this relationship. The possibility raised in the introduction was that in young hearing children this relationship may be due to effects of articulation rate at output (Cowan & Kail, 1996; Henry, 1991).

In the present analyses however, speech and sign rate correlated with other measures not dependent on production of sign or speech. Hearing loss negatively correlated with speech rate, such that deafer children were slower speakers. Speech rate also correlated positively with reading age. Therefore it seems likely that the relationships between production rate and STM ability and use of a speech-based code, as indexed by susceptibility to concurrent speech, are due to a factor or factors, other than solely production rate at output. It is proposed these relationships reflect the influence of long-term phonological knowledge, both sign and speech-based. Thus, as the child’s long-term phonological representations become better specified, they may be able to output them more quickly. This possibility is discussed further in the Discussion chapter of this thesis.

**Speech Intelligibility**

On the basis of Conrad’s (1979) results it was predicted that SI would relate to the use of a speech-based STM code. However, in this sample this was not the case, nor did SI relate to overall STM ability. However, SI did positively correlate with reading age. The SI measure used here was the subjective rating given by the child’s class teacher or speech and language therapist. Since in all cases the rater knew the child well, it is possible that these ratings reflect the teacher’s, or speech and language therapist’s, overall view of the child’s abilities, including reading, rather than speech ability alone⁴.

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⁴ Data obtained for a larger study of SI of deaf children support this proposal (MacSweeney & Parker, in preparation). Three adults, unfamiliar with deaf speech, watched a video recording of each deaf subject naming ten pictures. Their task was to identify the word spoken. These objective SI scores did not correlate significantly with the deaf student’s reading age or any of the memory measures.
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The fact that hearing loss is not related to STM scores in these subjects should not be taken to indicate that this is unimportant to establishing a speech-based code. The range of hearing loss of the subjects tested was limited (89-126dB). Where a greater range of hearing loss is examined, degree of hearing loss is often an influential factor in the use of a speech-based code (e.g., Conrad, 1979).

In summary, in support of previous studies, the use of a speech-based code and overall STM ability was strongly related to reading ability of deaf subjects. The present data also demonstrate that these memory measures were related to the rate of sign as well as speech production. The suggestion that this relationship may reflect the specification of a deaf child's underlying LTM phonological representations will be discussed further in the Discussion chapter.

Susceptibility to concurrent signing

The analysis above (Table 5.11) was controlled for chronological age because it correlated with hearing loss. When chronological age was left in the analysis, younger subjects were more susceptible to concurrent signing than older subjects. There were similar non-significant trends for the relationship between chronological age and susceptibility to hand tapping (difference score, \( r = -.30, p = .16 \); proportion score, \( r = -.282, p = .18 \)) and foot tapping (diff. score, \( r = -.25, p = .24 \); prop. score, \( r = -.30, p = .15 \)). In contrast, there was no relationship between chronological age and susceptibility to concurrent speech (difference score, \( r = .05, p = .81 \); proportion score, \( r = -.01, p = .96 \)). This link between chronological age and the extent to which performance of an irrelevant concurrent task impairs STM deserves further discussion.

Are some central executive control processes delayed in deaf children?

Recall by young deaf children was impaired by non-verbal concurrent tasks more than recall by older deaf children. Similarly, recall by hearing eight-year-olds tested in Experiment 2a was impaired by concurrent signing and foot tapping (though these effects were of borderline significance). In contrast, recall by hearing fifteen-year-olds
was not affected by these non-articulatory tasks. A possible explanation for this is based on a limited resources hypothesis of the central executive. Processes controlled by the central executive are thought to be recruited for the initiation and maintenance of the concurrent tasks required in the present study. As these tasks become more automated with practice, performance maintenance requires less processing resources. Thus, more resources should be available for performance of the primary supra-span STM task. Thus, if automaticity of the concurrent task increases with age, recall should be less disrupted in older children. An alternative account of the relationship between age and susceptibility to an irrelevant task is that older children are more efficient than young children at allocating processing resources to competing tasks. A procedure thought to be the domain of the central executive. These two explanations are not mutually exclusive and additional explanations, based on the functions of the central executive, are also likely to exist.

Since the pattern of recall by deaf fourteen-year-olds in the present study was similar to that of their younger hearing RA controls, this suggests that developmental progression in central executive processes, such as automatisation and allocation of resources to competing tasks, may be delayed in deaf children. If this rationale is correct, deaf people may attain the same level of central executive efficiency as hearing people, with regard to automaticity and allocation of resources, but at a later age. Experiment 3 explores this developmental hypothesis by testing deaf adults on recall during concurrent task conditions. Testing deaf adults also allows us to reassess the question of whether concurrent signing interferes with the use of a sign-based code in a STM task.
Chapter 5

Experiment 3: Ordered recall by deaf adult signers during concurrent tasks

Introduction

The first aim of this experiment was to test the hypothesis that deaf people show a developmental delay in aspects of central executive processing, including automatisation of repetitive tasks and control over allocation of executive resources. If these processes develop in the same way in deaf people as in hearing people, but are simply delayed, then deaf adults should have developed robust executive control strategies. Concurrent foot tapping should not therefore impair recall by the deaf adults tested in this study.

The second aim of this experiment was to explore STM codes used by deaf adults. Of particular interest was whether concurrent signing disrupted the use of a sign-based STM code. Concurrent signing impaired recall by deaf teenagers in Experiment 2a but only to the same extent as the non-articulatory task of foot tapping. Therefore it is possible that this effect was due to general cognitive interference. Furthermore, deaf teenagers may not be the optimal group in which to test the use of sign-based coding because their facility with sign language may develop slowly (see Chapter One). Deaf adult signers have more extensive exposure to sign language, especially if they are active members of the Deaf community, as in the present study.

If concurrent signing does not impair recall by deaf adults, this would support the idea that concurrent signing impairment on recall by deaf teenagers was due to delay in the development of central executive control processes. Alternatively, a specific effect of concurrent signing but not concurrent foot tapping would suggest that deaf adults use a sign-based STM code. This code may also be susceptible to concurrent hand tapping, a task which engages the main articulators of sign.
Finally, since deaf teenagers in Experiment 2a had shown a *specific* effect of concurrent speech, it was predicted that concurrent speech would probably impair recall by deaf adults to a greater extent than foot tapping. That is, that deaf adults would use a speech-based STM code in this picture recall task.

**Method**

**Subjects**

Eleven deaf adults were tested. All were either severely or profoundly deaf. Subjects were volunteers from a local Deaf club or a TC school for the deaf where they were members of staff. Two subjects were later dropped from the analysis. One did not reach the 50% accuracy level in the baseline condition and the other was dropped because of interruptions during testing. The mean age of the nine remaining subjects was 28-years (range 19-40-years-old). All classed themselves as members of the Deaf community and used BSL as their primary form of communication. Two subjects had deaf parents and the remaining seven had hearing parents.

**Design, Materials and Procedure**

The design, materials and procedure were the same as those used in Experiment 2. Subjects were required to recall six pictures, which were presented one at a time and placed face down in a spatial array. All subjects performed one practice trial and five experimental trials in each of the following conditions:

- Baseline (no concurrent task)
- Foot tapping
- Hand tapping
- Concurrent signing (repeating BECAUSE)
- Concurrent speech (repeating ‘because’)

180
Subjects pointed to the back of each card as they recalled the item in their preferred language mode. As for the TC deaf 14-year-olds, for most subjects recall involved a combination of the sign and English mouth pattern for the item.

Results

Items correctly recalled in the correct serial position were classed as a correct response. Table 5.12 shows the mean percentage correctly recalled in each condition.

Table 5.12: Mean (s.d.) percentage correctly recalled by deaf adults (n=9) as a function of concurrent task

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Foot tapping</th>
<th>Hand tapping</th>
<th>Concurrent signing</th>
<th>Concurrent speech</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>60.19</td>
<td>63.43</td>
<td>62.50</td>
<td>54.63</td>
<td>42.59</td>
</tr>
<tr>
<td>(s.d.)</td>
<td>(8.10)</td>
<td>(12.29)</td>
<td>(15.59)</td>
<td>(14.94)</td>
<td>(17.02)</td>
</tr>
</tbody>
</table>

The correlation between cell means and standard deviations was not significant ($r=.56$, $p=.33$), therefore a one-way within subjects ANOVA was used to analyse the data. This indicated a main effect of Concurrent Task ($F(4,32) = 4.18$, $p<.01$). Tukey post-hoc analyses, adjusted for repeated measures (Stevens, 1992), showed that recall in the concurrent speech condition was poorer than in the baseline, hand tapping and foot tapping conditions (all $p<.05$), but did not differ from concurrent signing. No other differences were significant.

These results support the developmental delay hypothesis since recall by deaf adults was not impaired by the non-articulatory concurrent task. They also indicate that a speech-based STM code tends to be used in the recall of pictures even by fluent and active signers. Concurrent signing impaired recall, however performance in this condition did not differ from recall in the baseline condition nor from any of the
remaining concurrent tasks. The implications of this are unclear: it is possible that the effects of concurrent signing were confined to a subset of subjects who used a sign-based STM code. To investigate this possibility, individual differences within this adult deaf group were explored.

Contrastive patterns of recall by deaf adults

Background information was collected from the deaf subjects in a short interview following the testing session. Subjects were asked general bipolar questions. These were: Are you severely or profoundly deaf? Did you attend a TC or oral secondary school? Do you have deaf parents? What qualifications do you have? The ‘qualifications’ question was classed on whether or not a subject had reached degree level education.

Responses to these questions showed that subjects fell into two clear groups. There were five subjects who were profoundly deaf, who had attended a TC school and had not had higher education. The remaining four subjects were all severely deaf, attended an oral school and three of these subjects were graduates or were in higher education. Two subjects had deaf parents. One subject fell into the severe/oral group, the other in the profound/TC group. Figure 5.8 and Table 5.13 show the pattern of recall by each of these sub-groups.

The small sample sizes of these groups meant that it was not possible to conduct statistical tests on the data. However, inspection of performance by individual subjects shows that in comparison to recall in the baseline condition, recall by three subjects in each subgroup was impaired by concurrent speech.
Table 5.13: Mean (s.d.) percentage correctly recalled during each concurrent task as a function of degree of deafness and language used at secondary school by deaf adults

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Foot tapping</th>
<th>Hand tapping</th>
<th>Concurrent signing</th>
<th>Concurrent speech</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe/ oral</td>
<td>64.58</td>
<td>71.88</td>
<td>69.79</td>
<td>64.58</td>
<td>42.71</td>
<td>62.71</td>
</tr>
<tr>
<td>Profound/ TC</td>
<td>56.67</td>
<td>56.67</td>
<td>56.67</td>
<td>46.67</td>
<td>42.50</td>
<td>51.83</td>
</tr>
<tr>
<td>(N=5)</td>
<td>(6.32)</td>
<td>(12.00)</td>
<td>(6.32)</td>
<td>(10.79)</td>
<td>(17.78)</td>
<td>(8.82)</td>
</tr>
</tbody>
</table>

In contrast, when the concurrent signing task is considered, the pattern between the two subgroups was quite different. In comparison to recall in the baseline condition, recall by four of the five profound/ TC subjects was impaired by concurrent signing. In contrast, recall by three of the four subjects in the severe/ oral group improved when concurrent signing was required. There appears to be a specific deleterious effect of concurrent signing in the profound/ TC group but not the severe/ oral group.
Deaf adults with deaf parents

Finally, recall by the two subjects with deaf parents was considered. One subject was in the severe/ oral subgroup, the other in the profound/ TC subgroup. Both subjects confirmed that their parents used BSL at home when they were growing up. Therefore, both subjects had extensive early exposure to sign language.

Table 5.14: Mean percentage correctly recalled by two Deaf adults of Deaf parents during concurrent tasks

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Foot tapping</th>
<th>Hand tapping</th>
<th>Concurrent signing</th>
<th>Concurrent speech</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 1 (severe/ oral)</td>
<td>75</td>
<td>75</td>
<td>83</td>
<td>46</td>
<td>33</td>
</tr>
<tr>
<td>Subject 2 (profound/ TC)</td>
<td>50</td>
<td>54</td>
<td>50</td>
<td>33</td>
<td>17</td>
</tr>
</tbody>
</table>

Table 5.14 shows that the pattern of recall across conditions is similar for both subjects. Recall by both subjects during the two tapping conditions was either equivalent to or greater than their mean recall in the baseline condition. However, recall by both subjects decreased during concurrent signing and fell further during concurrent speech. Although only based on two subjects this pattern suggests that early and extensive exposure to sign language may support the use of a sign-based STM code.

Discussion

The first aim of this experiment was to determine whether deaf people show a developmental delay in aspects of central executive processing, such as automatisation of tasks and resource allocation. In contrast to performance by deaf teenagers in Experiment 2a, neither concurrent foot nor hand tapping impaired recall by deaf adults in the present study. These deaf adults appear to have established
robust executive control skills and strategies. These had not yet been attained by the deaf subjects in mid-adolescence in Experiment 2a.

This differential pattern between age groups resembles that seen between hearing eight- and fifteen-year-olds in Experiment 2a. In these groups, foot tapping impaired recall by hearing eight-year-olds but not fourteen-year-olds. This suggests that central executive control processes develop in the same way in deaf and hearing people, but this development appears to be extended over time in deaf people.

The second aim of this experiment was to investigate the use of STM codes by deaf adults. As predicted, there was a specific effect of concurrent speech on recall. Concurrent speech impaired recall to a greater extent than either hand and foot tapping. This suggests that deaf adults used a speech-based STM code in this picture recall task as did deaf teenagers in Experiment 2a. Further analysis of subgroups of deaf adults showed an interesting pattern with regard to the effect of concurrent speech. The decrement in recall due to concurrent speech in comparison to the control foot tapping task was 29% for the deaf severe/oral group and 14% for the profound/TC group. Although these figures are based on small sample sizes, the decrement in recall due to concurrent speech shown by the profound/TC group was similar to that of the deaf teenagers in Experiment 2a (11%). In contrast, the level of decrement seen in severe/oral subjects was more similar to that of hearing teenagers in Experiment 2 (33%). These data support the position that there is a wide range of proficiency in the use of a speech-based STM code.

Of particular interest in this experiment was the effect of concurrent signing on recall by deaf adults. Despite the fact that all subjects described themselves as members of the Deaf community and used BSL as their preferred mode of communication with other deaf people, the effect of concurrent signing was ambiguous. Recall in this condition fell between the effect of concurrent speech and all other tasks. Exploration of individual differences between deaf adults showed that concurrent signing did not
impair recall by any severely deaf adult who had attended an oral school and was a graduate or in higher education. In contrast, concurrent signing did impair recall by four of the five profoundly deaf adults who had attended a TC school, and had no university level education. These results may be indicative of the use of sign-based coding by this subgroup. Concurrent signing also impaired recall by two deaf adults with deaf parents, indicating that parental hearing status is also likely to be an important factor with regard to the possible use of a sign-based code.

**General Discussion of Experiments 2 and 3**

The aim of Experiments 2 and 3 was to investigate the STM codes used by deaf teenagers and adults using articulatory concurrent tasks. Foot tapping was included as a non-articulatory task to control for the possible effect of general cognitive interference. Foot tapping impaired recall by deaf teenagers (Experiment 2a) but not deaf adults (Experiment 3). A similar developmental pattern was seen in hearing children, though at an earlier age. In Experiment 2a recall by hearing eight-year-olds was impaired by concurrent foot tapping (though this just failed to reach the adjusted level of significance $p=.003$). However, hearing fourteen-year-olds tested in Experiment 2a were not affected by the non-articulatory tasks of foot tapping, hand tapping or concurrent signing. These results suggest that executive processes, such as automatising tasks and allocation of resources to different cognitive tasks, are mastered by hearing fourteen-year-olds such that they are able to control executive resources, successfully allowing them to de-couple performance on primary and secondary tasks. In contrast, control over these executive processes may occur later in deaf than hearing people, so that it is only by early adulthood that a concurrent non-specific motor task fails to affect memory performance.

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5 Three of the four subjects were studying for or had completed a degree course.
6 Similarly, Halliday, Hitch, Lennon and Pettipher (1990) showed that recall by eleven-year-olds was impaired by the non-articulatory concurrent task of tapping a pen on the table (see section 2.6.iii).
If recall by deaf teenagers was impaired by the central executive requirements of performing a non-articulatory task such as foot tapping, then it is likely that the articulatory concurrent tasks had similar effects. In addition to this general effect, articulatory concurrent tasks may also lead to specific disruption of linguistic coding processes. Each of the articulatory tasks investigated in this chapter and their implications for STM coding by deaf people are now considered in turn.

Concurrent hand tapping
Wilding and White (1985) showed that the speech-based code used by hearing people was sensitive to articulatory movement which was not speech-based (i.e., chewing). The present data did not find a similar effect with deaf signers. The pattern of impairment due to concurrent hand tapping was similar to that of foot tapping. Concurrent hand tapping impaired recall by deaf teenagers (Experiment 2a), but not deaf adults (Experiment 3). This finding is consistent with the findings of Kyle (1986) who showed that recall by deaf adults was not affected by the manual task of ‘holding something tightly’. This suggests that the effect of concurrent hand tapping on recall by deaf teenagers in Experiment 2a was due to general cognitive interference rather than specific impairment of sign-based coding.

Concurrent speech
Deaf teenagers and deaf adults showed specific effects of concurrent speech. In Experiments 2a and 3 concurrent speech affected recall more than the non-articulatory concurrent task, foot tapping. This is indicative of speech-based STM coding by deaf subjects in this picture recall task.

However, regarding the use of a speech-based STM code as a fixed code in terms of its utility and specification is misleading. Rather, a speech-based code appears to be used to different levels of proficiency by different people, as indexed in this chapter by susceptibility to concurrent speech. Correlational analyses of the data from deaf
teenagers showed a positive relationship between susceptibility to concurrent speech and reading age, although in this small sample it just failed to reach significance (p=.07). Reading age was also strongly related to overall STM ability. Thus, in deaf teenagers reading skill appears to be a more important correlate of speech-based coding and overall STM ability than chronological age. Another important correlate of STM ability and use of a speech-based code to emerge from these data was production rate of signs and speech. It is possible that these relationships reflect the degree of structure and specificity of long-term phonological representations, whether the ‘language of the STM code’ is speech-based or sign-based. This possibility will be explored further in the Discussion Chapter of this thesis.

**Concurrent signing**

The effects of concurrent signing in Experiments 2a and 3 were less clear-cut than the effects of concurrent speech. Recall by deaf teenagers during concurrent signing was poorer than in the baseline condition but did not differ significantly from performance on the other concurrent tasks. A correlational analysis showed that susceptibility to concurrent signing decreased with age. This suggested that effect of concurrent signing may have its basis in the same processes that are affected by foot and hand tapping. That is, a developmental delay in subject’s control of central executive resources may account for this result.

Group analysis of recall by deaf adults tested in Experiment 3 further supported this general hypothesis. Nevertheless, individual differences suggested that sign coding may be used by a subgroup of deaf adults. Four of the five profoundly deaf adults who had attended TC schools and had not had higher education recalled fewer items in the concurrent signing condition than in the baseline condition. Although based on a very small subgroup of subjects, this is suggestive of a specific effect of concurrent signing that may be indicative of sign-based STM coding by these subjects.
From these data it is not possible to identify which of these subject characteristics is instrumental in determining who uses a sign-based STM code. Furthermore, there are factors that are likely to differ between these subgroups other than level of deafness and schooling. In particular, these adults may differ in NVIQ, which Conrad (1979) found to be related to the use of a speech-based code in school children. Decisions regarding the educational placement of the deaf adults tested here were made around twenty years ago. At that time it was likely that able deaf children were sent to oral schools and less able children to TC schools, and indeed the majority of the severe/ oral group tested but none of the profound/ TC had reached higher education. It is likely that severe/ oral adults tested in this study had higher reading levels that their profound/ TC peers and may therefore have been more proficient in their use of a speech-based code. This is supported by the greater effect of concurrent speech on recall by severe/ oral subjects in comparison to recall by profound/ TC subjects. Since TC subjects' use of a speech-based STM code was less efficient, they may have supplemented it with one based on sign language.

Conclusions
A number of conclusions can be drawn from the experiments reported in this chapter and the previous chapter.

- Deaf teenagers' baseline STM recall was strongly related to their reading ability, and to their speech and sign production rates. It is possible that this relationship reflects the level of specification of subjects' long-term phonological representations, whether in speech or sign.
- Both deaf teenagers and deaf adults appeared to use a speech-based STM code in their recall of pictorial stimuli. This extends previous studies which have shown that deaf people often use a speech-based STM code to represent printed English stimuli (e.g., Hanson, 1982; Campbell & Wright, 1989).

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7 A similar relationship was not found in Experiment 2b because subjects were screened such that only subjects whose NVIQ scores were within one standard deviation of the mean were included.
• Individual susceptibility to concurrent speech suggested a speech-based STM code was used to different levels of proficiency by deaf subjects.

• Deaf children are delayed in their development of executive control processes for this memory task. Recall by deaf teenagers, but not deaf adults, was significantly impaired by non-articulatory concurrent tasks.

• The effect of concurrent signing on recall by deaf teenagers in Experiment 2 suggests that this task caused general cognitive interference. However, it is possible that the effect of concurrent signing on a small subgroup of deaf adults in Experiment 3 reflects the disruption of sign-based STM coding by these subjects.

In general, STM performance and the use of STM codes by deaf teenagers resembled that of hearing children of the same reading age. Furthermore, the correlational analyses showed that reading age was an important correlate of STM ability. This study has therefore highlighted the importance of reading age to STM ability in deaf children both at group and individual levels. To explore whether this relationship between reading age and STM ability is apparent at different developmental stages, Experiment 4 investigated STM performance and the use of STM codes by deaf children of different ages. In Experiment 4 the perceptual/encoding parameters of stimuli to be recalled were manipulated. This meant that no additional performance requirements were placed on the subject unlike the concurrent tasks used in this chapter. Therefore, Experiment 4 may offer converging evidence for the conclusions drawn from this chapter.
Chapter 6 – The development of STM coding by deaf children: the effects of stimulus similarity and the role of saliency of semantic features

Introduction

Experiments 2a and 3 explored the use of a speech- and sign-based STM codes by deaf teenagers and adults. Experiment 4 re-examines this issue using a different technique, that of stimulus similarity. The use of a visual STM code by deaf children is also tested. Experiments 1, 2a and 2b indicated the importance of reading age to STM ability and coding in deaf children. In Experiment 4 different age groups of deaf children are tested. This allows further exploration of the influence of reading age at different chronological ages. By testing the use of a range of STM codes the developmental progression of change in STM code use in deaf children can also be examined in relation to reading age. It is possible that in deaf children reading age is a better predictor of a switch to speech-based coding than chronological age.

Experiment 5 considers STM performance by deaf children from a different perspective. This is the only experiment in the thesis to investigate a semantic component in immediate recall. Semantic structure has a marked effect in immediate memory. For example, span for concrete words is greater than that for abstract words in hearing adults (Paivio & Csapo, 1969) and for high imagability words than low imagability words (Bourassa & Besner, 1994). Furthermore, Baddeley (1966b) showed that there was a small yet significant effect of semantic similarity on recall of words in comparison to semantically dissimilar words. The specific hypothesis tested with deaf children was that immediate memory would be better for pictures of items that had marked dynamic properties, in contrast to items with little 'movement
Chapter 6

semantics'. This was predicted on the basis of the special semantic salience of perceived object movement in a world without sound.

**Experiment 4 – The effect of visual, speech and sign similarity on picture recall**

**Introduction**

The developmental stages of STM coding through which hearing children progress were discussed in detail in Chapter Two. Many of the studies that have investigated this progression in the use of STM codes have used a stimulus similarity approach (e.g., Ford & Silber, 1994; Hitch, Halliday, Schaafstal & Heffernan, 1991; Hulme, 1987; Johnston & Conning, 1990). Stimuli are presented which are similar in some feature, for example letter names which rhyme (e.g., T, B, V). Poor recall of these items in comparison to dissimilar items (e.g., S, T, M) suggests the use of a STM code based on the manipulated feature (i.e., a speech-based code) (Conrad & Hull, 1964). As with the speech similarity effect, poor recall of visually similar items suggests a visual STM code is used. Hitch, Halliday, Schaafstal and Schraagen (1988) showed that hearing five-year-olds made confusion errors in SOR of visually similar pictures, yet their recall of pictures whose names sounded similar was unimpaired (see also Hayes & Schulze, 1977). In contrast, recall by ten-year-olds was impaired for items with similar sounding names, but not visually similar items. This pattern of results suggests that between five and ten years of age children develop the ability to subvocally label visual stimuli. This ability may emerge at around seven-years-old, as at this age children start to show effects of speech similarity in picture recall (for a review see Gathercole & Hitch, 1993).

The aim of the present experiment was to explore the effects of stimulus similarity on recall to determine whether the use of visual and speech-based STM codes develops
in the similar stages in deaf children as in hearing children. The few studies which have explored the use of visual coding in recall of linguistic stimuli by deaf people have mainly tested recall of letters (e.g., MacDougall, 1979; Wallace & Corballis, 1973, see section 3.3.i). However Hanson (1982) showed that the use of printed English stimuli may induce a speech-based code in deaf students, which they may not spontaneously use for other stimulus material. In the present study, deaf children’s use of a visual STM code was investigated with visually similar pictures. Subjects were also tested on recall of pictures similar in terms of speech and sign parameters. Using this approach to investigate STM coding by deaf children may provide converging support for the pattern of STM coding observed in Experiment 2a using concurrent tasks.

Five subject groups were tested in this study to gain a fine-grained developmental picture. The two deaf groups tested were eight- and fourteen-year-olds. In Experiment 2a, deaf fourteen-year-olds were identified as using a speech-based code. Therefore it was expected that they would also use a speech-based code in the present STM task. Since the use of a speech-based code by deaf fourteen-year-olds in Experiment 2a was similar to that of RA controls and appeared to be under-specified, it is possible that they use a visual STM code in addition to a speech-based code. If so, their recall of visually similar pictures should also be impaired.

Deaf eight-year-olds were also tested. This is the age at which most deaf children start to read text. Hearing children at this stage of reading development, typically four/five-year-olds, still use a visual STM code for the retention of pictorial stimuli (e.g., Hayes & Schulze, 1977). Similarly, it was predicted that recall by deaf eight-year-olds would be impaired by visual similarity of pictures. It was also predicted that deaf eight-year-olds may not be affected by speech or sign similarity. This prediction was based on the fact that the majority of deaf children have very limited language exposure in their early years, as discussed in Chapter One. The language proficiency of a typical deaf eight-year-old of hearing parents is unlikely to be greater than that of
a hearing five-year-old. Since hearing five-year-olds do not recode pictorial stimuli into a speech-based STM code, deaf eight-year-olds were not expected to recode pictorial stimuli into either a speech or sign-based code. In summary, both deaf groups were predicted to show patterns of recall similar to those of hearing RA controls.

Three hearing control groups were tested in the present study: hearing five-, eight and eleven-year-olds. As the focus of the current experiment was the pattern of recall by each group across the stimulus sets rather than overall recall performance, a hearing group chronological-age matched to the deaf fourteen-year-olds was not included. Hearing eleven-year-olds were included as by this age hearing children are thought to use a robust speech-based STM code (Hitch, Halliday, Schaalstal & Schraagen, 1988). These subjects should therefore show a pattern of recall similar to that of appropriate hearing CA controls. It was predicted that speech similarity, but not visual similarity, would impair recall by these subjects.

Hearing eight-year-olds were included in this study as RA controls for the deaf fourteen-year-olds. Hearing eight-year-olds' were predicted to show impaired recall of speech-similar stimuli. As there is no reported study of hearing eight-year-olds' recall of visually similar pictures their performance in this condition is of interest in its own right. They may switch directly from the use of a visual to a speech-based code, or there may be a transitional period in which both visual and speech-based codes are used.

Hearing five-year-olds were included in the current experiment as an approximate reading-matched group to the deaf eight-year-olds (see previous page). It was

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1 In a pilot study (see Appendix I) hearing adults showed a robust speech similarity effect in the recall of the stimuli used in this experiment. Therefore, it is argued that hearing fourteen-year-olds would have exhibited the same pattern of recall as these hearing adults.
predicted that these two groups would show similar patterns of recall, showing effects of visual similarity of pictures but not speech similarity (Hitch et al., 1988).

Method

Subjects

Five groups of subjects were tested (Fig. 6.1 shows the relationships between groups).

- Deaf 8-year-olds - attending a TC school and units
- Deaf 14-year-olds - attending both TC and oral schools
- Hearing 5-year-olds - reading age (RA) matched to the deaf 8-year-olds
- Hearing 8-year-olds - reading age (RA) matched to the deaf 14-year-olds
- Hearing 11-year-olds

Figure 6.1: Relationships between subject groups tested in Experiment 4
Chapter 6

As in Experiment 2a, a 50% accuracy cut off criterion was used. Only subjects who correctly recalled 50% of items in the baseline (dissimilar stimuli) condition were included in the analysis. In an attempt to equate the level of difficulty between subject groups deaf 14-year-olds and hearing 8- and 11-year-olds were presented with 6 pictures to recall, whereas deaf 8-year-olds and hearing 5-year-olds were presented with only 3 pictures. None of these younger subjects failed to reach the recall criterion. The characteristics of subjects who did not reach this criterion in the older groups were as follows:

- Deaf 14-year-olds - N=4 (15% of total, mean CA = 15.4, mean RA = 7.5)
- Hearing 8-year-olds - N=1 (9% of total, mean CA = 8.3, mean RA = 8.7)
- Hearing 11-year-olds - N=3 (20% of total, mean CA = 11.6, mean RA = 10.8)

The characteristics of subjects who did reach the 50% correct criterion will now be discussed. Table 6.1 shows the subject characteristics of each group.

**Deaf subjects**
All deaf subjects had hearing parents. Audiograms from school records were used to establish the mean hearing loss for each deaf group, this is shown in Table 6.1. No subject had any additional disability.

**Deaf 8-year-olds**
Eleven deaf 8-year-olds were tested. The children either attended a primary school for the deaf or one of two hearing impaired units within mainstream primary schools. The schools and units all used TC. Non-verbal IQ of these subjects was measured using the Raven’s Colored Progressive Matrices (Raven, Court & Raven, 1992). The mean centile score for the group was 37 (range: 10 – 75). Subjects were not excluded on account of poor NVIQ performance, as was the case for older deaf subjects, because it was felt that many young deaf children scored poorly on this test simply through lack
of attention. Because subjects completed the NVIQ tests in groups of four or five, many rushed the task to be the first in the group to finish. This may have lead to under-performance on the NVIQ test.

Two of the deaf 8-year-olds had a cochlear implant within the last twelve months and one within the last five years. It is possible that the implant could affect the STM codes used by these subjects. The analysis was therefore conducted both with and without these three subjects (see pg. 206). Audiograms were not available for three of the eleven subjects. The mean hearing loss shown in Table 6.1 is derived from the remaining eight subjects.

The children were also tested on the NFER Group Reading Test (NFER-GRT, Macmillan Test Unit, 1985), which assesses reading ages between 6 and 12-years. Of the 11 children tested, only 4 scored sufficiently highly to obtain a reading age of 6-years-old or above. The mean reading-age of these four subjects was 6; 5, however the estimated reading age of the group as a whole was below 6-years.

Deaf 14-year-olds

Twenty-three deaf 14-year-olds were tested. They either attended an oral school (N=10) or one of two TC schools for the deaf (N=13). Pupils from both types of school were analysed together in this experiment. Subjects from TC and oral schools were matched on chronological age, reading age, hearing loss and NVIQ.

NVIQ of deaf subjects was assessed using matrices from the British Abilities Scales (Elliot, Murray & Pearson, 1983). Subjects were not selected if their standardised score was more than one standard deviation (10) below the population mean (50). The mean NVIQ score for the group was 48 (s.d. = 6.6, range 40-62).
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Reading ability of ten of the deaf subjects was assessed using the Shortened Edinburgh Reading Test (see Experiment 1 for details of administration of this test). The remaining thirteen deaf subjects attended different schools where they had completed the full Edinburgh Reading Test one month earlier. These scores were used and adjusted for the time lag between the reading test and memory test.

<table>
<thead>
<tr>
<th>Table 6.1: Subject characteristics of participants in Experiment 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chronological age</strong></td>
</tr>
<tr>
<td>-----------------------</td>
</tr>
<tr>
<td>Deaf 8-yr-olds</td>
</tr>
<tr>
<td>(N=11)</td>
</tr>
<tr>
<td>Deaf 14-yr-olds</td>
</tr>
<tr>
<td>(N=23)</td>
</tr>
<tr>
<td>Hearing 5-yr-olds</td>
</tr>
<tr>
<td>(N=14)</td>
</tr>
<tr>
<td>Hearing 8-yr-olds</td>
</tr>
<tr>
<td>(N=10)</td>
</tr>
<tr>
<td>Hearing 11-yr-olds</td>
</tr>
<tr>
<td>(N=12)</td>
</tr>
</tbody>
</table>

Speech intelligibility of all deaf subjects was assessed using the procedure outlined in Experiment 2. The child's teacher or resident speech and language therapist assessed each child's speech on the following 5-point scale:
Chapter 6

1 - wholly intelligible
2 - fairly easy to understand
3 - about half understood
4 - very hard to understand
5 - effectively unintelligible

Hearing subjects
There were three hearing control groups: 5-, 8- and 11-year-olds. All hearing subjects attended mainstream schools in south-east England. They were selected by their teachers to be of ‘average’ intelligence. The reading ages of the hearing 8- and 11-year-olds children were taken from school records and were adjusted for the two month time lag between the reading test administration and memory test. An independent samples t-test confirmed that there was no significant difference in reading age between the deaf 14-year-olds and their reading age matched group, hearing 8-year-olds (t(31) = .898, p>.1). Reading age scores were not available for the youngest subjects, hearing five-year-olds, who were assumed to be starting to read appropriately for their chronological age.

Design
A 5 (Group) X 4 (Stimulus Type) design was used. The Groups tested were; deaf 8- and 14-year-olds and hearing 5-, 8- and 11-year-olds. Subjects were tested on ordered recall of the following pictorial stimuli:

- Visually similar
- Speech similar
- Sign similar
- Dissimilar in all above features

Deaf 8-year-olds and hearing 5-year-olds were presented with three pictures on each trial and deaf 14-year-olds and hearing 8- and 11-year-olds were presented with six pictures to equate the difficulty of the task between groups. Subjects performed five
trials in each condition. However, hearing 8-year-olds performed four trials in each condition as they were more distractible than the older subjects. This reduction in number of trials was not necessary for hearing 5-year-olds or deaf 8-year-olds as they were presented with only three pictures, therefore reducing the overall time taken per trial.

Trials were randomly ordered from each condition with the constraint that no two trials from the same condition were performed consecutively.

Materials
The stimuli were four sets of twelve black and white line drawings of concrete items, printed on 11 cm x 15 cm card. Forty-one of these were chosen from the Snodgrass and Vanderwart’s (1980) standardised pictures and norms. Two pictures were taken from the British Picture Vocabulary Scale. The remaining five were drawn specially for the experiment. The selection criteria were that pictures from the Snodgrass and Vanderwart norms had high familiarity scores. Also, all items had a commonly used sign label, for example, items that had to be fingerspelled were not included. Examples of items in each set are shown in Figure 6.2 and a full list given in Table 6.2. Each of the stimulus sets will now be discussed in detail.

All speech similar items had the vowel sound /a/, for example, cat, flag. A pilot study showed that these stimuli elicited a speech similarity effect in hearing adults (see Appendix I). The visually similar items were long, thin and pictured in the same orientation, for example, flute, knife. Both the visually- and speech-similar sets were based on those used by Hitch and colleagues (Halliday, Hitch, Lennon, & Pettipher, 1990; Hitch, Halliday, & Littler, 1989; Hitch, Halliday, Schaafstal, & Heffernan, 1991; Hitch, Halliday, Schaafstal, & Schraagen, 1988). However, some items were substituted where the equivalent BSL sign was problematic. For example, map was not included in the speech similar set since the BSL sign for this item is to fingerspell the English word.
Sign similarity was based entirely on handshape (Hanson, 1982), rather than one of the alternative parameters of sign language: place of articulation, movement or orientation. Having chosen handshape as the restricting parameter two similar handshapes were used to construct the ‘sign similar’ set (there were not sufficient concrete items using a single handshape). The handshapes were: ‘A’ (5 items) and ‘A\(^\wedge\)’ (7 items). Handshape ‘A’ is described in the BSL Dictionary as “Fist handshape in which the thumb is usually held against the side of the finger” (Brien, 1992 – see Figure 6.3). The ‘A\(^\wedge\)’ handshape is described as “the bent index finger is extended from the fist, enclosing the top of the extended thumb” (Brien, 1992 – see Figure 6.4)). Therefore although classed as different handshapes they are closely related.
One-way ANOVAs on the features of the four stimulus sets, using available item norms (41 items: Snodgrass & Vanderwart, 1980), showed no differences in name agreement, familiarity or complexity between stimulus sets (all ps>.1). Age of acquisition norms of these word labels were available for 43 of the 48 pictures (Morrison, Chappell & Ellis, 1997). These showed no significant difference between stimulus sets (p>.1).

Stimulus sets were also matched, as closely as possible, on number of two-syllable words and number of two-handed signs. These details are given in Table 6.2. Two-syllable words were included as it was extremely difficult to establish a set of monosyllabic sign similar pictures. However, despite efforts to match for syllable length, the sign similar set has more two-syllable names than the other sets. This could be a confounding factor in this experiment. If so, it should lead to hearing 11-year-olds showing poorer recall of these lists (a word length effect) as by this age a secure speech code should be in use.
### Table 6.2: Labels of pictorial stimuli used in Experiment 4

<table>
<thead>
<tr>
<th>Disssimilar</th>
<th>Visually similar</th>
<th>Speech similar</th>
<th>Sign similar</th>
</tr>
</thead>
<tbody>
<tr>
<td>cup</td>
<td>nail</td>
<td>flag</td>
<td>bell</td>
</tr>
<tr>
<td>monkey</td>
<td>ruler</td>
<td>pan</td>
<td>cap</td>
</tr>
<tr>
<td>shoe</td>
<td>spoon</td>
<td>cat</td>
<td>coat</td>
</tr>
<tr>
<td>chair</td>
<td>bat</td>
<td>backpack*</td>
<td>comb</td>
</tr>
<tr>
<td>apple</td>
<td>needle</td>
<td>lampstand</td>
<td>curtains*</td>
</tr>
<tr>
<td>bed</td>
<td>flute</td>
<td>hat</td>
<td>drum</td>
</tr>
<tr>
<td>flower</td>
<td>file</td>
<td>pram</td>
<td>hammer</td>
</tr>
<tr>
<td>whistle</td>
<td>pencil</td>
<td>fan*</td>
<td>jumper</td>
</tr>
<tr>
<td>book</td>
<td>knife</td>
<td>hand</td>
<td>key</td>
</tr>
<tr>
<td>watch</td>
<td>fork</td>
<td>tap*</td>
<td>marble*</td>
</tr>
<tr>
<td>belt</td>
<td>axe</td>
<td>handbag</td>
<td>racket</td>
</tr>
<tr>
<td>eye</td>
<td>brush</td>
<td>man*</td>
<td>rubber*</td>
</tr>
</tbody>
</table>

| No. with two syllables | 4 | 3 | 3 | 6 |
| No. of two-handed signs | 5 | 6 | 5 | 5 |

* denotes stimuli that were not selected from the Snodgrass and Vanderwart (1980) standardised pictures and norms.

### Procedure

**Naming pre-test**

All subjects were tested individually. In a pre-test subjects were asked to label each picture, in sign or speech. For older groups, deaf 14-year-olds and the hearing 8- and 11-year-olds, the only problem that arose was one of name agreement, for example calling the ‘pram’ a ‘buggy’. When this occurred the child was asked if they agreed with the designated name for the item and was asked to refer to it with that name. The subject was then asked to name the set of pictures again to ensure that the designated name was used. This was successful on all occasions.

When a hearing 5-year-old or deaf 8-year-old gave a wrong name to an item or did not recognise the picture, that item was dropped from the set used for that child. Since these groups did not need to sample as many pictures per trial, this procedure did not markedly reduce the number of available pictures. Examples of items that these younger subjects could not name were ‘flute’ and ‘rubber’.

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Experimental Trials

After the naming pre-test each subject performed two practice recall trials with stimuli not included in the experimental sets. Deaf 14-year-olds and hearing 8- and 11-year-olds were presented with six pictures to recall, whereas deaf 8-year-olds and hearing 5-year-olds were presented with three. The procedure was the same as that used in Experiment 2a. Pictures were shown one at a time at a rate of one every two seconds and then placed face down in a spatial array in front of the subject. Subjects were not allowed to label the pictures overtly at presentation. After the final picture was presented subjects recalled the items by pointing to the cards and naming the item at that location. Recall was spoken by the hearing groups and in the preferred mode of deaf subjects. This usually involved a combination of sign and speech by the TC subjects and speech alone by most oral subjects.

Predictions

Hearing subjects

It was predicted that hearing subjects would not be affected by the sign-similar stimuli, as they had no knowledge of sign language. Hearing five-year-olds were predicted to show poor recall of visually similar pictures in comparison to dissimilar pictures, indicating the use of a visual code. No effect of speech similarity on recall was expected for this group. Since hearing 11-year-olds are thought to use a robust speech-based STM code it was predicted that they would show poorer recall of speech similar pictures but no effect of visual similarity.

Some studies report the use of a speech-based code by the age of eight (e.g., Hitch et al, 1989), so it was predicted that recall by this age group would be impaired by speech similarity. However, it was not known if their recall would also be affected by visual similarity of pictures. If hearing children by this age have made a full transition to the use of a speech-based code then they should not be affected by visual similarity
of stimuli. However, they may still use a visual code alongside a speech-based code and thus be affected by visual similarity.

**Deaf subjects**

The deaf groups were predicted to show similar patterns of recall to their hearing RA controls. Thus, recall by deaf 8-year-olds should be impaired by visual similarity. However, these young subjects were not expected to be susceptible to speech or sign-similarity, as their language ability was not thought to be at a sufficient level to support the use of a speech or sign-based STM code.

Recall by deaf 14-year-olds should be impaired by speech similar stimuli as speech coding by this age group was shown in Experiment 2a. However, this may not be the only coding system used by deaf teenagers. They could also be affected by the visual similarity of pictures. Experiment 2a found no clear evidence for a specific effect of sign coding in deaf adolescents. However, this may reflect a relatively insensitive task (concurrent sign). Recall of formationally similar stimuli impairs sign-based coding in deaf adults when sign stimuli are used (e.g., Hanson, 1982; Wilson & Emmorey, 1997a). If deaf subjects also use a sign-based code to represent pictorial stimuli they may show a sign similarity effect.

**Results**

A correct response was scored if the subject recalled a correct item in the correct location. That is, the temporal order of recall was not marked. As deaf 8-year-olds and hearing 5-year-olds were presented with only three stimuli, their data were analysed separately from the older groups.

---

2 It should be borne in mind that the selection of sign similar stimuli had to include a spoken word-length confound.
Deaf 8-year-olds and hearing 5-year-olds

Table 6.3 and Figure 6.5 show the mean percentage of pictures correctly recalled as a function of stimulus type by deaf 8-year-olds and hearing 5-year-olds. Inspection of this table shows a very similar pattern of recall by the two groups. Both groups show poorer recall of all three stimulus types compared with dissimilar pictures and visually similar pictures appear particularly vulnerable.

Table 6.3: Mean (s.d.) percentage correctly recalled as a function of stimulus type

<table>
<thead>
<tr>
<th></th>
<th>Dissimilar</th>
<th>Visually similar</th>
<th>Speech similar</th>
<th>Sign similar</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deaf – 8-year-olds</td>
<td>79.39</td>
<td>63.64</td>
<td>69.70</td>
<td>69.09</td>
<td>70.45</td>
</tr>
<tr>
<td></td>
<td>(15.33)</td>
<td>(14.01)</td>
<td>(17.98)</td>
<td>(13.75)</td>
<td>(11.97)</td>
</tr>
<tr>
<td>Hearing – 5-year-olds</td>
<td>80.95</td>
<td>60.95</td>
<td>75.24</td>
<td>69.05</td>
<td>71.55</td>
</tr>
<tr>
<td>Both groups</td>
<td>80.27</td>
<td>62.13</td>
<td>72.80</td>
<td>69.07</td>
<td>71.07</td>
</tr>
<tr>
<td></td>
<td>(14.46)</td>
<td>(17.18)</td>
<td>(16.09)</td>
<td>(16.20)</td>
<td>(12.67)</td>
</tr>
</tbody>
</table>

The correlation between the cell means and standard deviations was not significant (r = -.477, p > .1), therefore a 2 (Group) X 4 (Stimulus Type) mixed model ANOVA was used to analyse the data (see Table 6.4). There was a main effect of Stimulus Type (F(3, 69) = 10.97, p < .0005) but not Group (F(1,23) = .04, p > .1). Nor was the Group X Stimulus Type interaction significant (F(3,69) = .56, p > .1).³

³ The same pattern of effects was found when the three deaf subjects with cochlear implants were excluded from the analysis.
The main effect of Stimulus Type was investigated using Tukey post-hoc comparisons, adjusted for mixed models (Stevens, 1992). This showed that both visually similar and sign similar stimuli were less well recalled than dissimilar pictures (ps<.05). However, the effect of speech similar stimuli was not significant. Furthermore, recall of visually similar pictures was significantly poorer than that of speech similar pictures (p<.05).

**Table 6.4:** ANOVA table of Group by Stimulus Type analyses for deaf 8-year-olds and hearing 5-year-olds

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within and residual</td>
<td>15390.12</td>
<td>23</td>
<td>669.143</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Group</strong></td>
<td>29.44</td>
<td>1</td>
<td>29.44</td>
<td>.04</td>
<td>.836</td>
</tr>
<tr>
<td>Within and residual</td>
<td>8983.62</td>
<td>69</td>
<td>130.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Stimulus type</strong></td>
<td>4286.22</td>
<td>3</td>
<td>1428.74</td>
<td>10.97</td>
<td>.000</td>
</tr>
<tr>
<td><strong>Group by Stimulus type</strong></td>
<td>219.04</td>
<td>3</td>
<td>73.01</td>
<td>.56</td>
<td>.643</td>
</tr>
</tbody>
</table>
These results support the prediction that STM performance by deaf 8-year-olds is similar to that of hearing RA controls. Both groups used a visual code but not a speech-based code to recall pictorial stimuli. The effect of sign similarity on these groups was not predicted and will be discussed further in the Discussion section.

*Deaf 14-year-olds and hearing 8- and 11-year-olds*

Before the main analysis of all the older subject groups, deaf subjects attending TC and oral schools were compared in a 2 (Group) X 4 (Stimulus Type) mixed ANOVA to ensure that combining deaf 14-year-olds from different educational backgrounds was valid. There was a main effect of Stimulus Type (F(3,63) = 10.68, p<.0005). However, importantly there was no main effect Group (F(1,21) = .10, p>.1) nor Group by Stimulus Type interaction (F(3,63) = 1.94, p>.1). Combining subjects from different educational backgrounds therefore appears to be justified.

Table 6.5 shows the mean percentage of pictures correctly recalled as a function of stimulus type by deaf 14-year-olds and hearing and 8- and 11-year-olds.

**Table 6.5: Mean (s.d.) percentage correctly recalled as a function of stimulus type**

<table>
<thead>
<tr>
<th></th>
<th>Dissimilar</th>
<th>Visually similar</th>
<th>Speech similar</th>
<th>Sign similar</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Deaf – 14-year-olds</strong></td>
<td>67.39</td>
<td>52.61</td>
<td>58.70</td>
<td>57.25</td>
<td>58.99</td>
</tr>
<tr>
<td></td>
<td>(11.50)</td>
<td>(11.89)</td>
<td>(12.82)</td>
<td>(14.24)</td>
<td>(9.80)</td>
</tr>
<tr>
<td><strong>Hearing – 11-year-olds</strong></td>
<td>78.06</td>
<td>70.00</td>
<td>61.94</td>
<td>75.28</td>
<td>71.32</td>
</tr>
<tr>
<td></td>
<td>(13.29)</td>
<td>(12.95)</td>
<td>(12.35)</td>
<td>(10.68)</td>
<td>(8.32)</td>
</tr>
<tr>
<td><strong>Hearing – 8-year-olds</strong></td>
<td>58.00</td>
<td>46.83</td>
<td>42.75</td>
<td>48.92</td>
<td>49.13</td>
</tr>
<tr>
<td></td>
<td>(8.60)</td>
<td>(7.71)</td>
<td>(8.84)</td>
<td>(10.84)</td>
<td>(7.20)</td>
</tr>
<tr>
<td><strong>All groups</strong></td>
<td>68.15</td>
<td>55.96</td>
<td>56.01</td>
<td>60.20</td>
<td>60.08</td>
</tr>
<tr>
<td></td>
<td>(13.40)</td>
<td>(14.26)</td>
<td>(13.77)</td>
<td>(15.79)</td>
<td>(11.76)</td>
</tr>
</tbody>
</table>
Figure 6.6 shows the pattern of recall by deaf 14-year-olds and hearing 8 and 11-year-olds. There was no correlation between cell means and standard deviations ($r=.546$, $p>.05$), therefore a 3 (Group) X 4 (Stimulus Type) mixed model ANOVA, was used to analyse the data. There was a main effect of Group ($F(2,42) = 17.25$, $p<.0005$) and Stimulus Type ($F(3,126) = 17.60$, $p<.0005$). The Group by Stimulus Type interaction was also significant ($F(6,126) = 2.48$, $p<.05$) (see Table 6.6).

![Figure 6.6: Mean % recalled by three older groups as a function of stimulus type](image)

Table 6.6: ANOVA table of Group X Stimulus Type analyses for older subject groups

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within and residual</td>
<td>13357.10</td>
<td>42</td>
<td>318.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td>10974.29</td>
<td>2</td>
<td>5487.15</td>
<td>17.25</td>
<td>.000</td>
</tr>
<tr>
<td>Within and residual</td>
<td>10581.75</td>
<td>126</td>
<td>83.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stimuli type</td>
<td>4435.02</td>
<td>3</td>
<td>1478.34</td>
<td>17.60</td>
<td>.000</td>
</tr>
<tr>
<td>Group by Stimuli type</td>
<td>1251.98</td>
<td>6</td>
<td>208.66</td>
<td>2.48</td>
<td>.026</td>
</tr>
</tbody>
</table>
Analysis of the simple effects of Group within each Stimulus Type showed that there were differences in recall between groups at all levels of Stimulus Type (all Fs>8.0, ps<.005). Although the main focus of this study is the pattern of recall within each subject group across conditions, the finding that recall differed between groups in the baseline condition warrants further analysis. Bonferroni corrected t-tests (alpha = .006) on recall in this condition showed that the hearing 11-year-olds recalled more than hearing 8-year-olds (t(20) = 3.98, p<.005). However, recall by deaf 14-year-olds lay between that of the two hearing groups, and the differences did not reach the adjusted level of significance: 8-year-olds (t(31) = 2.26, p=.031), 11-year-olds (t(33) = 2.47, p=.019). This point will be discussed further in the Discussion section.

Before exploring the pattern of recall of different stimulus sets within each group, the serial position curves of each group will be considered. This will determine whether the method of recall used in this study, ordered recall without requiring strict serial order, led to any systematic differences in pattern of recall between groups.

Figure 6.7 shows that the serial position curves were similar for the three groups tested. This was confirmed using a 3 (Group) by 6 (Serial Position) mixed ANOVA, which showed main effects of Group (F(2,42) = 15.6, p<.0005) and Serial Position (F(5,210) = 64.83, p<.0005). However, critically the Group by Serial Position interaction was not significant (F(10,210) = 1.33, p>.1). This suggests that the method of recall used in this study did not lead to any potentially confounding differences in pattern of recall between deaf and hearing groups.
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Figure 6.7: Serial position curves for each group across all conditions

Within Group analyses
Analysis of simple effects showed that there were differences within each Group across Stimulus Type (all Fs>4.0, all ps<.005). The pattern of recall within each group will now be considered. Due to differences in sample size post-hoc tests are conducted using Bonferroni corrected t-tests (Stevens, 1992) (alpha=.006).

Hearing 11-year-olds
Recall by hearing 11-year-olds was not affected by visual or sign similarity of pictures (t=1.93 and t=.989 respectively). The predicted effect of speech similarity was of borderline significance given the adjusted level of significance (t=2.72, (11), p=.02). As a speech similarity effect had been predicted for this group the power of this effect was examined. This showed that the power to detect an effect at the .05 significance level with the number of subjects tested was moderate (0.62). A significant effect of speech similarity would probably have been obtained with a few more subjects in this group.
**Hearing 8-year-olds**

As predicted, recall by hearing 8-year-olds was impaired by speech similarity of stimuli \((t=3.797, (9), p<.005)\). Recall was also impaired by visual similarity \((t=3.798, (9), p<.005)\) and sign similarity \((t=3.649, (9), p<.006)\). The effect of sign similarity was not expected and will be considered further in the Discussion section.

There are two possible explanations for the finding that both visual and speech similar stimuli impaired recall by hearing 8-year-olds.

- First, these subjects may use both STM codes simultaneously in a **transitional** stage between the use of a visual code and dependence on a speech-based code.
- Second, it is possible that children do switch directly from one code to another and that the effect of both types of similarity on recall was due to individual differences in the rate of developmental progression. That is, the effect of visual similarity may be due to some of the group using a visual code, while the effect of speech similarity may have been due to the sole use of a speech-based code by the rest of the group.

A measure described by Palmer (1997) was used here to decide between these two explanations. Visual and speech difference scores were established for each subject. For example, a subject's mean recall of visually similar pictures was subtracted from their mean recall of dissimilar pictures. This difference score was a measure of the extent to which recall by that subject was affected by visual or speech similarity of pictures.

The group's standard deviation (SD) of recall in the control condition was used to determine whether these individual difference scores fell within the normal range of variation in recall of dissimilar pictures. The SD was to set a somewhat arbitrary cut-off point to distinguish between those who used a specific STM code and those that did not. For example, if the SD of recall of dissimilar pictures by a group was 10%, a
subject with a visual difference score (dissimilar minus visually similar pictures) greater than 10% was considered to use a visual code. However, if the difference score is less than 10%, this variation was considered to be within the possible range of their recall of dissimilar stimuli, and not classed as indicating a specific effect of visual similarity.

Figure 6.8 shows the visual and speech difference scores of each hearing 8-year-old. Also shown on Figure 6.8 are reference lines representing one standard deviation (s.d. = 9.6), above and below the mean recall of control pictures by the whole group (represented by 0). Any child whose visual or speech similarity difference score was greater than 9.6% was considered to be using a visual or speech-based STM code respectively.

This analysis showed that: five hearing eight-year-olds (50%) were affected by both visual and speech similarity; two (20%) were affected by speech similarity alone; one (10%) was affected by visual similarity alone and two (20%) subjects were not affected by either type of similar stimuli. The dominant trend was for hearing 8-year-olds to use both visual and speech-based codes. This supports the hypothesis that there is a transitional period during which both STM codes were used.
Deaf 14-year-olds

The simple effect of Stimulus Type within the deaf 14-year-old group was explored using Bonferroni corrected t-tests (p=.006). As predicted, performance by deaf teenagers was similar to that of hearing RA controls. Their recall was impaired by visual similarity (t= 5.71, (22), p<.0005) and speech similarity (t= 3.34, (22), p<.005). There was also a significant effect of sign similarity (t= 3.90, (22), p<.005). However, this effect is difficult to interpret given that recall of these stimuli was also impaired in hearing, non-signing, 5 and 8-year-olds and this is again deferred to the Discussion.

The significant effect of both visual and speech similarity on recall by deaf teenagers could indicate the simultaneous use of both visual and speech-based codes, as with RA controls. Alternatively, individual differences in code use may have led to the significant effects of both types of stimuli. These possibilities were tested using an analysis of visual and speech difference scores as outlined above for hearing 8-year-olds. The standard deviation for recall of dissimilar stimuli by deaf 14-year-olds was 11.5%. A difference score greater than 11.5% would indicate the use of a specific STM code. Difference data for each subject are shown in Figure 6.9.

Figure 6.9: visual and speech difference scores of deaf 14-year-olds
This analysis showed eight deaf subjects (35%) were affected by both visual and speech similarity; seven (30%) were not affected by either type of similarity; six were affected by visual similarity alone (26%) (one of whom showed enhanced recall of speech similar pictures) and two were affected speech similarity alone (9%).

This distribution of 'difference scores' does not suggest a simple developmental switch from one code to another. Together with the findings from the RA control group, these data indicate that a developmental stage occurs when many individuals use both visual and speech-based codes in immediate recall. Moreover, some deaf teenagers may be insensitive to both speech and visual manipulations.

In summary, group analyses of these data showed that the pattern of STM coding observed in deaf subjects was similar to that of hearing children of the same reading age. In terms of susceptibility to structural similarity (visual or speech-based), recall by deaf 8-year-olds resembled that of hearing 5-year-olds and that by deaf 14-year-olds resembled that of hearing 8-year-olds.

**Correlational analyses**

Correlational analyses were carried out to explore which subject characteristics were related to STM performance by deaf subjects. The subject characteristics explored were reading age, chronological age, NVIQ, hearing loss and speech intelligibility (SI). Three aspects of STM coding were explored;

- Overall STM ability - measured by recall of dissimilar pictures
- Susceptibility to speech - similarity of pictures
- Susceptibility to visual - similarity of pictures
Two measures of susceptibility to the experimental manipulations were derived from the data; a difference score and a proportion score (as in Experiment 2b). Both of these measures are used in the correlational analyses reported here.

_Deaf 8-year-olds_

Most deaf 8-year-olds failed to reach any measurable reading age on the NFER-Group Reading Test, which requires a minimum score of 12. Raw scores on the reading test, including those below 12, were used in the analyses below. The correlation matrix for this group is shown in Table 6.7.

<table>
<thead>
<tr>
<th>Table 6.7: Deaf 8-year-olds correlation matrix (n=11)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>reading</strong></td>
</tr>
<tr>
<td><strong>raw score</strong></td>
</tr>
<tr>
<td><strong>chronological age</strong></td>
</tr>
<tr>
<td><strong>non-verbal IQ</strong></td>
</tr>
<tr>
<td><strong>hearing loss</strong></td>
</tr>
<tr>
<td><strong>speech intel.</strong></td>
</tr>
<tr>
<td><strong>STM ability (dissimilar stim.)</strong></td>
</tr>
<tr>
<td><strong>susceptibility to visual similarity</strong></td>
</tr>
<tr>
<td><strong>Diff. score</strong></td>
</tr>
<tr>
<td><strong>Prop. score</strong></td>
</tr>
<tr>
<td><strong>speech similarity</strong></td>
</tr>
<tr>
<td><strong>Diff. score</strong></td>
</tr>
<tr>
<td><strong>Prop. score</strong></td>
</tr>
</tbody>
</table>

Diff score – difference score. Prop. Score – proportion score. **p<.01
There were no significant correlations between any individual difference variables and any memory measures. However, the pattern with regard to speech intelligibility was similar to that seen in Experiment 2b. There was a positive correlation between teachers’ ratings of SI and reading ability, which was of borderline significance ($r(11) = .59, p = .054$). This relationship was not due to possibly confounding effects of a significant correlation between SI and hearing loss ($r(8) = -.86, p < .001$). When hearing loss was partialled out of the analysis the correlation between SI and raw score on the reading test remained significant ($r(5) = .93, p < .005$). However, as in Experiment 2b, it is possible that this relationship reflects teachers’ global view of their pupils’ abilities, rather than a measure of speech quality per se.4

Deaf 14-year-olds

The relationships between memory measures and subject characteristics of deaf 14-year-olds are shown in the correlation matrix in Table 6.8.

STM ability correlated positively with reading age ($r(23) = .53, p < .01$). Reading age also correlated positively with susceptibility to visual similarity ($r(23) = .49, p < .05$). This implies that as reading age increased so did the use of a visual STM code. However, there was no relationship between reading age and susceptibility to speech similarity.

The pattern with regard to SI and reading ability replicates that seen in Experiment 2b and with deaf 8-year-olds in this study. There was a positive correlation between reading ability and SI, which just failed to reach significance ($r(13) = .55, p = .051$). This effect was also significant when the possibly confounding effects of hearing loss were partialled out of the analysis ($r(10) = .64, p < .05$). However, there is the possibility

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4 As in Experiment 2b, a more objective measure of SI in these children was collected which required hearing adults, unfamiliar with deaf speakers, to identify words spoken by the deaf child. This measure did not correlate with reading ability ($r = .30, p > .1$).
that this relationship may simply reflect teachers’ overall impression of the pupil’s ability rather than speech ability alone.

Table 6.8: Deaf 14-year-olds correlation matrix (n=23)

|                           | reading age | chron. Age | NVIQ | hearing loss | speech intel.
|---------------------------|-------------|------------|------|--------------|----------------
| chron. age                | .199        | (23)       |      |              |                
| non-verbal IQ             | -.105       | -.090      | (23) | (23)         |                
| hearing loss              | .094        | .349       | .206 | (23)         |                
| speech                    | .550        | .063       | -.232| -.384        |                
| intelligibility           |             |            | (13) | (13)         | (13)           
| STM ability               |             |            | .531**| .016         | .037           | .193 | .144 |
| (dissimilar stim.)        |             |            | (23) | (23)         | (23)           | (23) | (13) |
| susceptibility to         |             |            | .490*| -.024        | -.086          | .204 | .129 | Diff score
| visual similarity         |             |            | .349 | .096         | -.112          | .169 | .103 | Prop. score
| susceptibility to         |             |            | (23) | (23)         | (23)           | (23) | (13) |
| speech similarity         |             |            | .131 | -.210        | -.021          | .360 | -.169 | Diff score
|                           |             |            | (23) | (23)         | (23)           | (23) | (13) |
|                           |             |            | .057 | -.292        | .030           | .329 | -.183 | Prop. score
|                           |             |            | (23) | (23)         | (23)           | (23) | (13) |

Diff score – difference score. Prop. Score – proportion score. *p<.05, **p<.01

Discussion

The aim of this experiment was to determine whether the use of visual and speech-based STM codes develop in similar stages in deaf children as in hearing children.

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5 Reading age did not correlate with the more objective test of SI: the number of words correctly identified by listeners unfamiliar with deaf speakers (r(13)=.03, p>.1).
The use of a sign-based STM code by deaf subjects was also explored. Since it was predicted that the pattern of recall seen in deaf subjects would reflect that of hearing RA controls, the findings from the hearing groups will be discussed first.

**Hearing Groups**

As predicted, recall by hearing five-year-olds was poorer for visually similar but not speech similar pictures in comparison to dissimilar stimuli. This indicates the predominant use of a visual code by these children, and supports the findings of Hitch et al. (1988). Hearing eight-year-olds showed poorer recall for both visually similar and speech similar pictures. Further analysis of individual coding patterns suggested that this was because most children used both visual and speech-based codes. Hearing eight-year-olds appear to be in a transitional stage between the use of a visual code and the efficient use of a speech-based code. Recall by the oldest hearing group, eleven-year-olds, was affected only by speech similarity (though this was of borderline significance) indicating the use of a dominant speech-based code.

The developmental pattern seen in hearing children in this study reflects the pattern of STM coding outlined in the literature (Gathercole, 1998; Gathercole & Baddeley, 1993, see Chapter 2). This study further contributes to our knowledge about this developmental progression. Although hearing children start to use a speech-based code for pictorial stimuli in mid-childhood, this may be used in conjunction with a visual STM code. That is, until the use of a speech-based code becomes more efficient and robust, a visual STM code may still be used to support immediate recall of pictorial stimuli. This conclusion is supported by the results of Hitch, Woodin and Baker (1989) who showed that when the use of a speech based code was impaired by requiring subjects to perform concurrent speech, even eleven-year-olds were affected by visual similarity in a picture recall task.

Despite their lack of knowledge of BSL, recall of sign similar stimuli by hearing five- and eight-year-olds was impaired. One explanation for this may relate to the fact that
the sign similar items used in the present study had somewhat longer spoken labels than items in the other sets (see Table 6.2). It had been predicted that if this were a confounding factor then recall by hearing eleven-year-olds should be impaired as they would demonstrate a traditional word length effect, but this was not the case. However, it is possible that the effect of the sign similar stimuli found in these young hearing children may reflect preparation for output of these slightly longer words (e.g., Henry & Millar, 1991). This aspect of the word length effect might sometimes affect younger subjects more than older ones.

Deaf Groups

The main aim of this experiment was to investigate the developmental progression in the use of visual, speech and sign-based STM codes by deaf children. Previous studies of STM coding by deaf people have focussed mainly on deaf adults (e.g., Hanson, 1982; Wilson & Emmorey, 1997a; 1998; under review) or deaf teenagers (e.g., Conrad, 1979). By including younger deaf subjects, the present study draws a fuller picture of the developmental progression in the use of STM codes by deaf children.

The overall pattern of results showed that visual and speech-based STM codes were used similarly in deaf and hearing children of the same reading age. Deaf eight year-olds appeared to use a visual STM code, while deaf fourteen-year-olds used both visual and speech-based STM codes. One aspect of the data from young deaf subjects requires further comment. In this group, unlike their older peers, there was no correlation between individual reading scores and STM performance. This may reflect a relatively narrow range of raw reading scores in this group. Implicit tests of phonological awareness and a signed or spoken vocabulary test (see Harris & Beech, 1995; Harris & Beech, 1998) may have been more appropriate at this early stage of language development and may have demonstrated stronger links with STM factors.
The correlational analysis of data from deaf fourteen-year-olds indicated that individual reading ability positively correlated with overall STM ability. The same pattern of results was found in Experiment 2b. However, in contrast to Experiment 2b there was no relationship in this study between reading age and susceptibility to the manipulation of speech-based coding, speech similarity, although reading age correlated positively with susceptibility to visual similarity of pictures. These findings suggest that visual coding may play an important role in reading for deaf children even in teenage years. This supports previous findings which have indicated the importance of visual/orthographic information to reading and spelling performance by deaf adults (e.g., Hanson, Shankweiler & Fischer, 1983). Alternatively, these subjects may be at a stage of reading development that uses visual processes that are also used in remembering pictures. However, determining the direction of this relationship is not possible from the correlational data presented here.

Reading age also correlated positively with the SI ratings given to deaf eight- and fourteen-year-olds by their teacher or speech and language therapist. However, further analysis suggested that, as in Experiment 2b, this relationship may be spurious as it may simply reflect the raters’ overall impression of the child’s abilities, including reading age, rather than the SI of the child. Given this discrepancy it is not possible at this stage to make claims regarding the apparent link between SI and reading age in these data and how this may relate to STM performance.

Effects of sign similarity
Recall by deaf eight and fourteen-year-olds was impaired for pictures which were similar in terms of sign parameters. This accords with studies which have demonstrated a sign similarity effect in the recall of signed stimuli by deaf people (e.g., Hanson, 1982). However, the effect of sign similarity is difficult to interpret in this study since hearing five and eight-year-olds, with no sign language knowledge, were also poorer at recall of sign similar stimuli compared to dissimilar stimuli. The effect on hearing children was explained, primarily, in terms of the effect of
preparation for output for longer words. However, the majority of deaf subjects predominantly used signs to recall the items, so preparation for output may not have been important. However, given that deaf fourteen-year-olds did show effects of speech-coding in this study the possibility that word length affected recall by these subjects, and even possibly younger deaf subjects, in another way cannot be ruled out. The range of explanations of this effect means it is not possible to make strong claims regarding the use of a sign-based code by deaf subjects tested in this study.

Finally, although the main focus of this study was the pattern of recall of different stimulus sets within subject groups, the results showed that recall of dissimilar stimuli by deaf fourteen-year-olds was intermediate between that of hearing eight-year-olds and hearing eleven-year-olds. No difference in recall in the baseline condition was found in Experiment 2a for deaf and hearing fifteen-year-olds. The discrepancy between these two experiments appears to lie with the choice of older hearing control subjects. Recall by deaf fourteen-year-old and hearing eight-year-old groups was consistent across the control conditions (no concurrent task and dissimilar pictures) of Experiments 2a and 4. Recall differed only by two per cent for each group across these two conditions despite the fact that, on the whole, different subjects participated in the two experiments. However, hearing fourteen-year-olds in Experiment 2a recalled 69 per cent correct in the baseline condition, whereas hearing eleven-year-olds in the present experiment, using the same methodology, correctly recalled 78 per cent of dissimilar pictures. This suggests that the hearing fourteen-year-olds tested in Experiment 2a may have been of below-average ability and the hearing eleven-year-olds tested in the present experiment may have been of above-average ability. Therefore, bias in the schools selected may have caused this unexpected outcome.

Summary

In support of Experiment 2a and 2b this experiment has shown that STM ability and coding by deaf children is strongly linked to reading ability. This was shown at both the group level and at an individual difference level:
The developmental progression in the use of visual and speech-based STM codes by deaf children was similar to that of hearing children of similar reading age. Deaf eight-year-olds used a visual STM code alone, while deaf fourteen-year-olds used visual and speech-based STM codes.

Correlational analyses supported the hypothesis that reading ability is closely linked to overall STM ability and the developmental progression in STM coding.
Experiment 5 - The role of dynamic semantic information in LTM representation of deaf children

Introduction

The previous experiments in this thesis explored visual and phonological (both sign and speech) STM coding by deaf children. Also considered was the development of these coding strategies (Experiment 4) and the development of central executive processes (Experiment 2a). In this study another aspect of STM development is considered. Specifically, this is the impact that the special experience of deafness may have on the way that items may be represented in long-term memory (LTM) and its subsequent impact on STM.

Semantic effects in STM

It is well established that STM does not process information in isolation from LTM. Co-dependency between these two memory systems is demonstrated by better recall of high frequency than low frequency words (e.g., Glanzer, 1972). Also, recall of words is better than recall of non-words matched on phonological complexity (Hulme, Maughan & Brown, 1991). In deaf subjects too, recall of highly signable words is better than recall of low signable words (Bonvillian, 1983; Conlin & Paivio, 1975). Semantic knowledge contributes to these frequency and word/non-word effects. In support of this Baddeley (1966b) showed that semantic similarity of stimuli significantly impaired SOR by adults, though the effect was small in comparison to the effect of similar sounding items. With pictorial stimuli such influences of semantic features may be even more marked. When presented with a picture, rather than a printed word, a structural/visual description of the item can be achieved which can then directly access semantic information.

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*I would like to acknowledge Jim Kyle for the inspiration to investigate this topic.*
Until recently the working memory model (Baddeley, 1986) focussed closely on non-semantic properties of input. However, recent adaptations (e.g., Baddeley, Gathercole & Papagno, 1998; Logie, 1995; 1996) provide a means of modelling the relationship between STM and LTM. Logie argues that working memory does not simply act as a gateway for information to LTM. Rather, a stimulus event activates all relevant LTM representations, including phonological, orthographic and semantic representations. These can then be transferred to the workspace of working memory, which forms the content of the working memory system. Thus all forms of stored information activated by the presentation of the stimulus can be used in immediate recall. Though this activation view of STM is not new (e.g., Monsell, 1984), Logie’s proposal has the benefit of retaining the original structure of the working memory model, which has formed the framework for the experiments reported so far in this thesis.

The purpose of this study is to explore the possibility that differences in deaf and hearing children’s long-term semantic representations of concepts can impact on STM performance. Indeed, it seems likely that deaf and hearing children differ in their organisation of LTM given differences in their early experiences (for a review see Marschark, 1993b). However, difference does not necessarily indicate deficiency. Friedman (1987) showed that deaf children were as good as CA controls at categorising objects (e.g., furniture, tools) despite the fact that many deaf subjects did not know the names of the items. Thus deafness does not appear to impair basic concept acquisition. The specific hypothesis explored here is that deaf children may give greater salience to the semantic property of type and degree of movement intrinsic to a concrete object and thus have richer LTM representations for such objects. This may be reflected in better recall for stimuli with marked dynamic properties than for those with fewer dynamic properties. This may hold even when these are presented as simple line drawings.

Object movement is an important feature of hearing infants’ pre-verbal representations (see Mandler, 1994). Mandler and McDonagh (1993) showed that by
seven-months, hearing infants could distinguish still pictures of animate and inanimate objects. Thus, the semantic feature of 'dynamicity' is well established and relevant to categorisation even in infancy. The present study is concerned with this particular semantic feature and how it may affect memory systems of deaf people.

Models of semantic organisation, whether defining attribute theories (e.g., Collins & Quillian, 1969), feature comparison theories (e.g., Rips, Shoben & Smith, 1973) or prototype theories (e.g., Rosch, 1978) all make use of features or attributes which enable categorisation to occur reliably. Objects in the world have many perceptual features such as colour, smell, sound, size and shape. That such perceptual features of objects can influence recall in a STM task is demonstrated by the fact that recall of high imagery items is better than that of low imagery items (Bourassa & Besner, 1994) and this also holds for deaf people (Bonvillian, 1983; Bonvillian, Rea, Orlansky & Slade, 1987). However, object movement carries information not only about the dynamic properties of a given object, but additional information too. For example, movement provides binding information since coherent movement indicates a single object. A moving object also gives information about trajectory, direction, acceleration and whether the movement is self-initiated or caused. In addition shape can be derived from rotatory movement of an object. All of these characteristics are highly informative about the object and impact on the representation of the item.

It is proposed here that the dynamic properties of a concept may be more salient to a deaf than hearing child. For a deaf child there is little useful information about sound or about those properties linked to sound, moreover auditory stimuli cannot readily capture attention. Dynamic visual stimuli in the environment may capture the attention of a deaf child (see Harris & Mohay, 1997). In turn, this early sensitivity to visual movement will lead the deaf child to take special account of movement as a visual characteristic. If so, deaf children may show sensitivity to the semantic feature of 'movement' in recalling lists of pictures.
Of secondary interest in this study was the pattern of free recall (FR) by deaf subjects. Experiment 1 in this thesis found that SOR of pictures by deaf teenagers was poorer than that of hearing CA controls, but equivalent to RA controls. However, FR by deaf teenagers fell between that of RA and CA controls and did not differ from either group. While deaf children have a specific deficit in the recall of ordered linguistic stimuli, they may also have a general deficit in recall of stimuli, however recalled. This study explores FR of pictures in young deaf children and hearing RA and CA controls.

Method

Subjects

Three subject groups were tested:

- Deaf 9-year-olds
- Hearing CA controls
- Hearing RA controls

Deaf subjects

Fifteen deaf 9-year-olds were selected from a school for the deaf or one of two hearing impaired units within mainstream schools. All of these schools/units used a TC approach. All deaf children had hearing parents. NVIQ of deaf subjects was tested using the Raven’s Coloured Progressive Matrices (Raven, Court & Raven, 1992). The mean centile score was 46.6 (range: 10-95). Audiograms, available for 13 of the 15 subjects, showed that mean hearing loss in the better ear was 94 dB (range: 76 – 108dB). Two of the children had cochlear implants. As in Experiment 4, analyses were conducted with and without these subjects to ensure their inclusion did not lead to any changes in the overall pattern of performance.
Chapter 6

All deaf subjects were tested on the NFER Group Reading Test. Only 9 of the 15 subjects obtained a score high enough to be attributed a reading age on this test. The mean reading age of these 9 subjects was 6;11-years-old. However, a more conservative estimate of the reading age of the group as a whole is approximately 6-years-old. The mean chronological age and estimated reading age of this group is shown in Table 6.9.

**Table 6.9: Characteristics of participants in Experiment 5**

<table>
<thead>
<tr>
<th></th>
<th>Chronological age</th>
<th>Reading age</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Deaf 9-year-olds</strong></td>
<td>Mean (range in months)</td>
<td>9; 0 (95-131)</td>
</tr>
<tr>
<td>(N=15)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Hearing CA controls</strong></td>
<td>9; 2</td>
<td>9; 4 (96-132)</td>
</tr>
<tr>
<td>(N=15)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Hearing RA controls</strong></td>
<td>6; 0</td>
<td>6; 0 (61-82)</td>
</tr>
<tr>
<td>(N=15)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Hearing subjects**

All hearing subjects were selected from mainstream schools in south-east England. All were considered to be of 'average intelligence' as judged by their class teacher. Fifteen hearing children were chosen who were chronologically age matched to the deaf group. The reading ages of these children had been assessed recently in school and these scores were used and adjusted for the two-month time lag between reading test and memory test. The deaf 9-year-olds and the hearing CA control group did not differ in chronological age ($t(28) = -.476, p>.1$). However, as would be expected, hearing subjects were better readers than deaf subjects.
Reading age scores were not available for the youngest hearing subjects, six-year-olds. However, it was assumed that these children were beginning to read appropriately for their chronological age. The subject characteristics of the hearing groups are shown in Table 6.9.

**Materials**

Ratings of dynamic properties of pictures were obtained as follows. Thirty-four hearing undergraduates rated 80 items from the Snodgrass and Vanderwart (1980) picture norms. Subjects were given the example of a door versus mountain and it was suggested to them that a mountain is more *immovable* than a door. Subjects were then asked to rate the 80 pictures on a ‘movability scale’ by circling 1 of 5 points on a continuum from 1 - ‘does not move at all’ to 5 - ‘moves a lot’.

A median split was then used to divide these items into high and low dynamic sets. From each group of 40 items, 24 were selected to make up a ‘dynamic’ set of stimuli and a ‘static’ set of stimuli. Picture sets were matched on the following factors: word frequency (Thorndike & Lorge, 1944), familiarity (Snodgrass & Vanderwart, 1980), name agreement (Snodgrass & Vanderwart, 1980), age of acquisition (Morrison, Chappell & Ellis, 1997), number of syllables and the number from different semantic categories. The names of the picture stimuli used are listed in Table 6.10.

The 24 stimuli in each set were then divided into 3 groups of 8. Thus there were 3 sets of 8 ‘dynamic’ pictures and 3 sets of 8 ‘static’ pictures. These stimulus sets were controlled for the number of items included from each semantic category. Each subject performed only one recall trial with each of these 6 sets of stimuli and therefore saw each picture only once across all trials.
Table 6.10: List of pictorial stimuli used in Experiment 5 (semantically grouped)

<table>
<thead>
<tr>
<th>Dynamic stimuli</th>
<th>Static stimuli</th>
</tr>
</thead>
<tbody>
<tr>
<td>animals, fruit</td>
<td></td>
</tr>
<tr>
<td>cat, apple</td>
<td></td>
</tr>
<tr>
<td>dog, banana</td>
<td></td>
</tr>
<tr>
<td>elephant, grapes</td>
<td></td>
</tr>
<tr>
<td>lion, orange</td>
<td></td>
</tr>
<tr>
<td>monkey, peach</td>
<td></td>
</tr>
<tr>
<td>rabbit, pear</td>
<td></td>
</tr>
<tr>
<td>amphibians, food</td>
<td></td>
</tr>
<tr>
<td>fish, cake</td>
<td></td>
</tr>
<tr>
<td>frog, bread</td>
<td></td>
</tr>
<tr>
<td>vehicles, kitchen items</td>
<td></td>
</tr>
<tr>
<td>aeroplane, cup</td>
<td></td>
</tr>
<tr>
<td>bicycle, fork</td>
<td></td>
</tr>
<tr>
<td>boat, knife</td>
<td></td>
</tr>
<tr>
<td>bus, spoon</td>
<td></td>
</tr>
<tr>
<td>car, toaster</td>
<td></td>
</tr>
<tr>
<td>body parts, household items</td>
<td></td>
</tr>
<tr>
<td>eye, fridge</td>
<td></td>
</tr>
<tr>
<td>hand, lamp</td>
<td></td>
</tr>
<tr>
<td>lips, telephone</td>
<td></td>
</tr>
<tr>
<td>various, various</td>
<td></td>
</tr>
<tr>
<td>ball, bed</td>
<td></td>
</tr>
<tr>
<td>balloon, book</td>
<td></td>
</tr>
<tr>
<td>cloud, chair</td>
<td></td>
</tr>
<tr>
<td>flag, church</td>
<td></td>
</tr>
<tr>
<td>kite, house</td>
<td></td>
</tr>
<tr>
<td>sun, mountain</td>
<td></td>
</tr>
<tr>
<td>swing, umbrella</td>
<td></td>
</tr>
<tr>
<td>watch, vase</td>
<td></td>
</tr>
</tbody>
</table>

**Design**

A 3 (Group – deaf/ CA controls/ RA controls) by 2 (Stimulus Type – dynamic/ static) design was used. Stimulus Type was a within subjects factor. Subjects performed 3 free recall trials with items from each stimulus set. Each trial involved presentation of
8 pictures. Performance of trials alternated from ‘dynamic’ to ‘static’ stimuli. Half the subjects performed a ‘dynamic’ stimulus trial first, half performed a ‘static’ stimulus trial first.

Procedure
All subjects were tested individually. In a pre-test subjects were asked to label each picture, in sign or speech. All subjects knew the names (in sign or speech) for all the items.

Following the pre-test subjects were told that they would be shown the items again, but this time they had to try to remember the items, which they could recall in any order. Each item was presented to the subject at a rate of one every two seconds and then placed face down in a pile in front of the subject. When the final (8th) item had been presented, the subject was prompted to recall by the experimenter. Trials with each stimulus set were performed alternately and this was counterbalanced across subjects.

Predictions
If deaf children have developed richer LTM representations of ‘dynamic’ stimuli their immediate recall of ‘dynamic’ stimuli should be better than recall of ‘static’ stimuli. This differential recall of stimuli was not expected in recall by the hearing control groups.

Another area of interest in this study was the FR performance by deaf children in comparison to their RA and CA controls. On the basis of the results from Experiment 1 it was predicted that overall FR by deaf children across both stimulus sets (i.e., both ‘static’ and ‘dynamic’ stimuli) would fall between that of hearing RA and CA controls.
Chapter 6

Results

The mean percentage correctly recalled by each subject group according to stimulus type is shown in Table 6.11 and Figure 6.10.

The correlation between cell means and standard deviations was not significant (r=.61, p>.1), therefore a 3 (Group) X 2 (Stimuli) mixed model ANOVA was used to analyse the data. This showed a main effect of Stimulus Type (F (1,42)=8.11, p< .01) and Group (F (2,42) = 5.09, p<.025). The Group by Stimulus Type interaction just failed to reach significance (F(2,42)= 3.15, p=.053) (see Table 6.12).

Table 6.11: Mean (s.d.) percentage of each stimulus type correctly recalled

<table>
<thead>
<tr>
<th></th>
<th>‘dynamic’ stimuli</th>
<th>‘static’ stimuli</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Deaf 9-year-olds</strong></td>
<td>53.89</td>
<td>43.89</td>
<td>48.89</td>
</tr>
<tr>
<td></td>
<td>(14.81)</td>
<td>(13.90)</td>
<td>(13.57)</td>
</tr>
<tr>
<td><strong>Hearing RA controls</strong></td>
<td>43.33</td>
<td>42.78</td>
<td>43.06</td>
</tr>
<tr>
<td></td>
<td>(8.60)</td>
<td>(9.77)</td>
<td>(7.20)</td>
</tr>
<tr>
<td><strong>Hearing CA controls</strong></td>
<td>57.50</td>
<td>54.45</td>
<td>55.97</td>
</tr>
<tr>
<td></td>
<td>(13.10)</td>
<td>(12.54)</td>
<td>(11.57)</td>
</tr>
<tr>
<td><strong>All groups</strong></td>
<td>51.57</td>
<td>47.04</td>
<td>49.31</td>
</tr>
<tr>
<td></td>
<td>(13.60)</td>
<td>(13.04)</td>
<td>(12.09)</td>
</tr>
</tbody>
</table>
Figure 6.10: Mean % of 'dynamic' and 'static' stimuli recalled by deaf and hearing subjects

![Bar chart showing mean % recalled for different groups and stimulus types]

Table 6.12: ANOVA table of Group by Stimulus Type analysis

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Sig. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within and residual</td>
<td>10354.17</td>
<td>42</td>
<td>246.53</td>
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<tr>
<td><strong>Group</strong></td>
<td>2510.12</td>
<td>2</td>
<td>1255.21</td>
<td>5.09</td>
<td>.01</td>
</tr>
<tr>
<td>Within and residual</td>
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<td>42</td>
<td>57.10</td>
<td></td>
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<tr>
<td><strong>Stimulus Type</strong></td>
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<td>1</td>
<td>463.16</td>
<td>8.11</td>
<td>.007</td>
</tr>
<tr>
<td><strong>Group by Stimulus Type</strong></td>
<td>359.18</td>
<td>2</td>
<td>179.59</td>
<td>3.15</td>
<td>.053</td>
</tr>
</tbody>
</table>

When the same analysis was conducted excluding the two deaf subjects with cochlear implants the same pattern of results was found. However in this case the interaction between Group and Stimulus Type was significant ($F(2,40) = 3.66$, $p<.05$). As group differences had been predicted, simple effects analysis were used to follow up the borderline interaction when all deaf subjects were included in the analysis.
The simple effect of Stimulus Type was significant in deaf group (F(1,42) = 13.14, p<.005) but not in the RA control group (F(1,42) = .04, p>.1) or CA control group (F(1,42) = 1.23, p>.1). Inspection of the means shows that this finding supports the prediction that the deaf group recalled significantly more ‘dynamic’ than ‘static’ pictures. In contrast, the hearing control groups showed no difference in their recall of stimulus sets.

With regard to the pattern of results between groups, there was a significant effect of Group within each level of Stimulus Type: ‘dynamic’ (F(2, 42) = 5.25, p<.01), ‘static’ (F(2, 42) = 4.18, p<.025). These simple effects were followed up using Bonferroni corrected t-tests (alpha=.008).

Hearing CA controls recalled more than hearing RA controls in both the dynamic and static stimuli conditions: ‘dynamic’ (t (28) =3.50, p<.006), ‘static’ (t (28) =2.84, p<.008). The pattern of recall by deaf subjects in relation to the two control groups was more complex. Inspection of the means shows that recall of ‘dynamic’ stimuli by deaf subjects was closer to that of CA controls than RA controls. In contrast, recall of ‘static’ stimuli by deaf 9-year-olds was closer to that of RA controls. However, given the adjusted significance level, recall by deaf 9-year-olds did not differ from either group in either stimulus condition: ‘dynamic’ - CA controls (t (28) =.71, p>.1), RA controls (t (28) =2.39, p=.024); ‘static’ - CA controls (t (28) =2.18, p=.038), RA controls (t (28) =.253 (28), p>.1).

Analyses of the main effect of Group supported the prediction regarding overall FR performance. When recall of both ‘static’ and ‘dynamic’ stimulus sets was combined, recall by deaf children fell between that of their hearing RA and CA controls, but did not differ significantly from either: deaf group and RA controls - t (28) = 1.47, p>.1; deaf group and CA controls - t (28) = -1.54, p>.1. Recall by the RA control group was significantly poorer than the CA control group (t (28) = 3.67, p<.001).
Discussion

The results support the main prediction of this study. Recall of still pictures of ‘dynamic’ objects was better than recall of ‘static’ objects in deaf nine-year-olds. There was no difference between recall of ‘dynamic’ and ‘static’ stimuli by hearing RA or CA control groups. It is suggested that a deaf child’s lack of auditory stimulation, that is deafness itself, leads to the ‘dynamic’ effect on recall. However, there is another possibility. It is possible that this effect reflects deaf children’s experience with a visuo-spatial language, BSL. Movement is one of the defining parameters of sign languages. A change to the movement of a sign, while retaining the same handshape, location and orientation of hands, leads to an alteration in the lexical item represented (see Chapter 3, section 3.2.iii). Numerous studies have shown that deaf signers can have enhanced visuo-spatial abilities. Emmorey and colleagues (Emmorey, in press; Emmorey & Kosslyn, 1996; Emmorey, Kosslyn & Bellugi, 1993) argue that these islands of enhanced performance are limited to those skills related to sign language processing. Furthermore, studies show that these effects are most marked in native deaf signers. Specifically they argue that visuo-spatial cognitive processes such as detecting mirror reversals (Emmorey, Kosslyn & Bellugi, 1993) and face discrimination (Bettger, Emmorey, McCullough & Bellugi, 1997) are enhanced in native deaf signers in comparison with hearing non-signers.

None of the children in the present study satisfied these conditions. None had deaf parents. The majority encountered sign language only when they entered school at the age of four. Therefore, most of the children tested had been exposed to sign language for only four or five years. From Emmorey’s studies it seems unlikely that this limited exposure to sign language was sufficient to support the substantially enhanced recall of ‘dynamic’ concrete objects seen in this study. To test this hypothesis directly it would be necessary in a future study to compare performance by the TC children tested here with deaf children receiving a strictly oral education. However, the explanation favoured here is that dynamic objects hold special attentional qualities for
a deaf child in their pre-linguistic environment, more so than for a hearing child, and that this leads to richer LTM semantic representations for these concepts. If this is the case, it may represent a rare difference between deaf and hearing people in the visual domain which is not dependent upon the use of sign language.

A secondary issue in this study was FR performance by deaf children in comparison to their hearing peers. As predicted, overall recall of static stimuli by deaf nine-year-olds was intermediate between that of hearing RA and CA controls but did not differ significantly from either group. This pattern reflects the findings from Experiment 1, which showed a similar pattern in older deaf children (fourteen-year-olds). In addition to a specific deficit in ordered recall, deaf children may have a general deficit in the recall of nameable stimuli, regardless of whether order information is required.
Chapter 7: General Discussion

7.1 Introduction

The aim of the studies reported in this thesis was to enhance our understanding of STM coding and processes used by deaf people of different ages. The following questions were addressed:

1. Do deaf children have a general deficit in the immediate recall of linguistic stimuli or do they have a specific deficit in SOR of linguistic stimuli?
2. To what extent do deaf people of different ages use speech- and sign-based STM codes in the immediate recall of pictures?
3. What is the nature of the developmental progression in the use of STM codes and strategies by deaf children?
4. How does pre-linguistic experience relate to STM performance by deaf children?
5. What subject characteristics relate to the use of different STM codes and overall STM ability?

This chapter will review the findings from the experiments reported in this thesis that are relevant to each of these questions. The theoretical implications of these findings will then be considered. Finally, suggestions for further work necessary to clarify questions raised by this thesis will be proposed.

7.2 Do deaf people have a general deficit in the immediate recall of linguistic stimuli or do they have a specific deficit in serial order recall?

Hanson (1982) found that deaf college students were poorer than their hearing peers on probed recall of linguistic stimuli. This replicates many other studies in the
literature indicating poor SOR by deaf people (Campbell & Wright, 1990; Hanson, 1982; Krakow & Hanson, 1985; Pintner & Paterson, 1917). Hanson also showed that free recall (FR) by deaf college students was equivalent to that of their hearing peers. Experiment 1 explored this finding with children of normal attainment in deaf schools, to determine whether Hanson’s findings with deaf college students held in this more representative group.

Unlike Hanson, in Experiment 1 the same subjects were tested within the same experiment on both SOR and FR of pictures. Hearing RA and CA control groups were also tested. SOR by deaf teenagers was poorer than that by hearing CA controls but equivalent to that of RA controls, thus supporting findings from previous studies of SOR. In contrast, FR by deaf teenagers fell between that of hearing RA and CA controls, but did not differ significantly from either. The results from Experiment 5 showed a similar pattern of FR even in young deaf children.

The non-significant trends in these experiments, towards poorer FR by deaf children than their hearing peers, do not support a strong version of Hanson’s hypothesis that FR by deaf and hearing peers should be equivalent. Rather the present pattern of results supports previous studies in the literature which have shown poor FR by deaf people (e.g., Bonvillian, 1983; Liben, 1979; Siedlecki, Votaw, Bonvillian & Jordan, 1990).

In conclusion, deaf people appear to have a specific deficit in SOR of linguistic information. However, they may have an additional general deficit in the immediate recall of linguistic stimuli even when order is not required. Hanson attributes poor SOR performance to the inefficient use of a speech-based STM code. Other experiments reported in this thesis investigated the use of a speech-based STM code by different subgroups of the deaf population.
7.3 To what extent do deaf people of different ages use speech- and sign-based STM codes in the immediate recall of pictures?

Hanson (1982) showed that stimulus modality can have a direct effect of the type of STM code used by deaf people in a particular task. Subjects were more likely to use a speech-based code when presented with printed English stimuli and a sign-based code when presented with sign stimuli. The aim of the studies presented in this thesis was to explore the type of STM code that deaf people used spontaneously without being directed to one or other type of coding by stimulus/response requirements. Therefore pictorial stimuli were used in all studies reported in this thesis. This approach also avoids the problem of using printed English stimuli, which may place deaf children at a disadvantage given their generally lower reading levels.

Experiments 2, 3 and 4 investigated the use of speech and sign-based STM coding by deaf subjects of different ages. In these experiments subjects were tested on ordered recall of pictures. To make the task more accessible to deaf children and young hearing children, picture cards were presented in the same location and then placed face down in a spatial array. Subjects were not required to recall in strict serial order. Both these manipulations appeared to enhance recall. Different techniques were used to explore the use of STM codes. Experiments 2 and 3 tested deaf teenagers and deaf adults on recall under conditions of concurrent sign and speech. A non-articulatory task of foot tapping was also included to control for the executive demands of these tasks. If concurrent speech or concurrent sign impaired recall to a greater extent than the non-articulatory concurrent task, this was interpreted as indicating disruption of speech or sign-based coding respectively.

Experiment 4 used the stimulus similarity technique to investigate STM coding. Subjects were required to recall pictures that were similar in terms of visual, speech or sign features. Poor recall of a set of similar stimuli was interpreted as indicating the use of a STM code based on the manipulated parameter. The effect of visual
similarity will be discussed in the following section on development of STM coding by deaf children. The remainder of this section will discuss the findings from Experiments 2, 3 and 4 that are informative regarding the use of speech and sign-based STM codes by deaf people.

### 7.3.i Sign-based STM coding

In Experiment 2a concurrent signing impaired recall by deaf teenagers in comparison to the baseline condition. However, recall was not significantly worse than in the concurrent foot tapping condition. Thus there was no strong evidence for the use of a sign-based STM code by these subjects. This result could have been due to the deaf group not being sufficiently proficient in BSL to support the use of a sign-based STM code. Therefore Experiment 3 tested deaf adult signers on the same tasks. Here, exploration of recall by particular deaf adults suggested that five deaf adults could have used a sign-based STM code. These subjects were profoundly deaf people who had attended a TC secondary school. Overall, the effect of concurrent signing on recall in the experiments in this thesis was weak. The importance of including an appropriate non-articulatory motor control task is underlined by these findings.

In Experiment 4 a different technique was used to investigate the use of sign-based coding by deaf signers. Subjects were required to recall pictorial stimuli whose sign labels were similar in terms of sign phonology (all had a similar handshape). It was hoped that using a different approach to explore sign-based coding than in Experiments 2a and 3 would be more informative regarding the question of whether such a code is used by deaf signers.

Sign similarity impaired recall by deaf eight- and fourteen-year-olds in Experiment 4. However, recall of sign similar stimuli by young hearing subjects was also poor. Therefore interpretation of this effect on deaf subjects is problematic. Poor recall of
sign similar stimuli by deaf subjects may be due to disruption of sign-based coding. However, an examination of the literature indicates that this was unlikely. Following completion of this experiment it became apparent that the parameter on which these items were selected for similarity (handshape) may not have been appropriate.

Parameters of signs: not all are functionally equivalent

Klima and Bellugi (1979, Experiment 2) tested deaf adult signers on recall of ASL stimuli in which one sign parameter was held constant and the remaining two were allowed to vary. For example, the handshape of stimuli was the same but location and movement differed. This allows the importance of each parameter of sign language to be studied independently. Only constant location impaired recall. The authors concluded that location “…may well be the key information associated with the serial position of remembered items” (1979, pg. 124). Kyle (1986) replicated this experiment and also tested the importance of orientation, the fourth recognised parameter of sign. As with Klima and Bellugi (1979) deaf adults of deaf parents showed poorest recall of items when location was constant. Therefore location appears to be the most salient dimension of sign-based STM representations. A similar phenomenon could be vowel representation in rhyme in speech-based representations for the hearing.

The importance of the location parameter of signs to STM does not appear to be widely recognised. Both Hanson (1982) and Wilson and Emmorey (1997a) used constant handshape to investigate the effect of sign similarity. Although location was not controlled for explicitly, both researchers chose signs located in the neutral sign space in front of the signer. Their success in finding sign similarity effects may have been due to the common location of signs rather than the experimentally controlled feature of handshape.

1 Only 3 parameters were tested as ‘orientation’ was not widely accepted as a parameter of sign language by this stage.
In Experiment 4 in this thesis, signs were chosen to be similar on the basis of handshape alone and varied in terms of location. According to Klima & Bellugi and Kyle’s studies, under these conditions it is unlikely that there would be a marked effect of sign similarity on recall by deaf subjects. Since the word labels of the sign-similar stimuli were slightly longer than those for other stimulus sets, recall by all subjects may have been slightly affected by word length.

The only studies in the literature that have clearly demonstrated the general use of a sign-based STM code by deaf people have used sign stimuli. The studies in this thesis failed to clearly demonstrate the use of a sign-based STM code by deaf groups of different ages for pictorial stimuli, despite the fact that the majority of those tested used BSL as their primary language. Furthermore, the task demands were, if anything, in favour of the use of a sign-based STM code rather than a speech-based code. English stimuli were not used, subjects could respond in their preferred modality and subjects were not required to recall in strict serial order which might lead to the use of a speech-based code (Hanson, 1982). However, only a small group of deaf adults showed possible evidence of sign-based STM coding. In contrast, these experiments provided substantial support for the use of a speech-based code by deaf subjects.

7.3.ii Speech-based coding

The speech-based coding manipulations in Experiments 2, 3 and 4 indicated the clear use of a speech-based code by deaf teenagers and adults in the immediate recall of pictures. In Experiment 2a, impaired recall under conditions of concurrent speech was interpreted as indicating the disruption of speech-based STM coding. Deaf teenagers showed a specific deleterious effect of concurrent speech which was greater than the effect of the control task, foot tapping. Experiment 3 also identified a specific effect of concurrent speech on recall by deaf adults.
Experiment 4 used a different approach to tap speech-based coding by deaf eight- and fourteen-year-olds. Subjects were tested on recall of pictures whose labels sounded similar (e.g., *flag*, *cat*). Recall by deaf eight-year-olds was not affected by speech similarity. This resembled the pattern of recall by their hearing RA controls. Deaf fourteen-year-olds also resembled their hearing RA controls (eight-year-olds) since their recall of speech similar stimuli was impaired in comparison to control stimuli.

Together these experiments provide substantial support for the use of speech-based coding in the ordered recall of pictures by deaf teenagers and adults. This conclusion supplements past research which has demonstrated the use of a speech-based STM code for recall of written English stimuli (e.g., Hanson, 1982, 1990; Lichtenstein, 1998), in explicit tests of speech-based coding such as rhyme or homophone judgements (Campbell & Wright, 1988; Hanson & Fowler, 1987; Hanson & McGarr, 1989) or written sentence comprehension (Hanson, Goodwell & Perfetti, 1991). In the experiments in this thesis subjects were presented with pictorial stimuli and were able to recall in their preferred mode, usually a mixture of sign and speech. Therefore deaf people used a speech-based code even when the stimulus and response modality did not necessarily require its use.

Variability in the use of a speech-based code
Evidence for the extent to which a speech-based STM code was used varied between and within the deaf groups, as indexed by susceptibility to speech-based manipulations. Performance by deaf teenagers was similar to that of their hearing RA controls. Deaf adults who were profoundly deaf, had attended a TC school and not reached higher education also appeared to use a speech-based code to a similar level of efficiency as hearing eight-year-olds in Experiment 2. Only severely deaf adults who had attended an oral school and reached higher education were as affected by speech-based variables as hearing teenagers (Experiment 3). Correlational analyses with deaf teenagers (Experiment 2b) suggested that this variability in the use of a
speech-based code is closely related to reading age and not educational environment. This is discussed further in section 7.6.ii.

7.4 What is the developmental progression in the use of STM coding and strategies by deaf children?

Development of STM coding

Hearing children go through a developmental progression in their use of STM codes (see Chapter 2). They are able to represent auditory stimuli using a speech-based STM code from four-years-old and perhaps even earlier, though this has not yet been explored with younger children. However, according to the working memory model (Baddeley, 1986) pictorial stimuli must first be recoded into a speech-based code, via the articulatory control process, to gain access to the phonological store. Young children are not able to do this until around the age of seven. Before then, hearing children remember pictorial stimuli visually, as inferred from their poor recall of visually similar pictures (e.g., Hayes & Schulze, 1977). The aim of Experiment 4 was to determine whether a similar developmental pattern was seen in the use of visual and speech-based STM codes in deaf children.

Experiment 2a and 2b showed that the pattern of recall by deaf teenagers was similar to that of hearing RA controls (8-year-olds). Therefore in Experiment 4, two age groups of deaf subjects (eight- and fourteen-year-olds) and their respective hearing RA control groups were tested on recall of visually, speech and sign-similar stimuli. As predicted, recall by both deaf groups resembled that of their hearing RA controls. Visual similarity but not speech-similarity impaired recall by deaf eight-years-olds, suggesting the use of a visual STM code alone. In contrast, both visual and speech-similarity of pictures impaired recall by deaf fourteen-year-olds suggesting that both types of STM codes were used. Therefore, with regard to the use of visual and speech-based STM codes, deaf children go through a similar developmental
progression as hearing children. However, this progression is substantially delayed in deaf children and appears to be linked to reading age.

The possible development of central executive control strategies

Results from Experiments 2a and 3 showed that recall by deaf teenagers was impaired when concurrent foot tapping was required, an effect which was absent for deaf adults (Experiment 3). Similarly, concurrent foot tapping impaired recall by young hearing children but not hearing teenagers (Experiment 2a). It was suggested that this link between age and susceptibility to an irrelevant concurrent task may be due to the tasks being more automated for the older hearing children and deaf adults. Thus, releasing additional central executive processing resources for the primary STM task. Alternatively, more efficient allocation of resources by the central executive in older subjects may account for this relationship. Further 'central-executive-based' explanations may also be able to account for this relationship, however the current data does not allow the specific cause of this relationship to be identified.

This pattern of results suggests that the development of central executive processes, such as those controlling cognitive resources and automatising irrelevant tasks, may be delayed in deaf children. This may impact on a range of cognitive skills other than STM. The finding, that by adulthood deaf people were able to cope with the cognitive demands of non-articulatory concurrent tasks, highlights the importance of considering the development of cognitive processes in deaf people for longer than is usual in research with hearing people.

7.5 How does pre-linguistic experience relate to STM performance by deaf children?

The fact that STM does not function in isolation from LTM is well known. For example, recall of high frequency words is better than recall of low frequency words. Experiment 5 explored the possibility that the LTM representations of deaf and
hearing people differ. Deaf nine-year-olds and hearing RA and CA controls were tested on free recall of still images of ‘dynamic’ and ‘static’ concrete items. Deaf subjects recalled more ‘dynamic’ than ‘static’ images. In contrast, both hearing control groups recalled as many ‘static’ stimuli as they did ‘dynamic’ stimuli.

Experiment 4 showed that deaf eight-year-olds and their RA controls (five-year-olds) were similarly affected by visual similarity in an ordered recall task. However, in Experiment 5 these two age groups of deaf and hearing children showed quite different patterns of performance. It is likely that both groups were again representing stimuli in a visual STM code. However, it is argued here that the semantic representations that may support STM in addition to this code were especially rich in deaf children for ‘dynamic’ stimuli. This particular sensitivity in deaf children’s recall was thought to be due to the greater salience of dynamic items in a deaf child’s early environment in comparison to a hearing child.

7.6 What subject characteristics relate to the use of different STM codes and overall STM ability? 2

Several characteristics of deaf subjects were tested and related to STM performance. Careful selection of subjects limited the individual difference variables to those of specific interest. The subject characteristics that were of interest in the present studies were:

- Language modality at school
- Reading ability
- Speech intelligibility
- Speech rate and sign rate

2 Careful selection of subjects meant that hearing loss and NVIQ were of limited range in these experiments. Therefore, although these variables are likely to play an important role in STM coding and overall STM ability of deaf people, they were not of primary interest in this thesis.
7.6.i Language modality at school

It was hypothesised that if a deaf child attended an oral school, they may use a speech-based code more efficiently than their TC peers. In Experiments 2a and 4 deaf teenage groups were tested on two different paradigms of immediate recall of pictures: recall when concurrent tasks were required and recall of pictures similar in terms of different features. Deaf groups from TC and oral schools were matched on chronological age, reading age, hearing loss, NVIQ and parental hearing status. The results from both experiments showed that there was no difference in the overall STM ability or pattern STM coding by deaf teenagers attending different schools.

The fact that there was no difference in STM ability between pupils from different educational backgrounds, yet reading age was strongly related to STM performance, suggests that language ability may be more important to overall STM performance than the language environment encountered at school. Lichtenstein (1985) showed that deaf college students who had attended oral and TC schools did not differ on reading ability or the use of a speech-based STM code. However, it was possible that Lichtenstein’s findings were limited to good readers (all subjects were college students). The studies reported in this thesis offer reliable support for the position that language environment at school has relatively little effect on STM coding as all deaf subjects were of normal attainment within the deaf schooling system.

7.6.ii Reading ability

The studies in this thesis suggest that reading ability was the most important correlate of STM ability and speech-based STM coding in deaf children. Support for this position comes from group and individual analyses. In Experiments 1, 2, and 4 STM performance and coding preferences by deaf groups of different ages paralleled that of hearing RA controls.
At the individual level, correlational analyses showed that reading age was positively related to overall STM ability of deaf teenagers in Experiments 2 and 4. A similar relationship was not seen in performance by deaf eight-year-olds in Experiment 4 because many of these subjects did not have testable reading ages. For deaf teenagers, reading age was also related to the use of a speech-based code in Experiment 2, though this was of borderline significance (p=.07). The theoretical implications of these findings will be considered further below (section 7.8).

7.6.iii Speech Intelligibility

Conrad (1979) showed that an important correlate of the use of a speech-based STM code by deaf school children was the rated intelligibility of their speech (by teachers). The more intelligible the child's speech, the greater their use of a speech-based code. This relationship was examined in the present studies. Neither Experiment 2b nor 4 supported the prediction that speech intelligibility (SI) of subjects would relate to their use of a speech-based code, nor was SI related to STM ability. Other studies have also failed to find a relationship between SI and speech-based coding (e.g., Dodd, Hobson, Brasher & Campbell, 1983; Hanson & Fowler, 1987). It is possible that this lack of a relationship is due to differences in the way that SI is measured.

Speech intelligibility did positively correlate with reading age for deaf teenagers and younger deaf children in Experiments 2b and 4. However, questions were raised by the findings in this thesis regarding whether a teacher’s rating was an adequate measure of SI. This may simply reflect the teacher’s view of the child’s abilities rather than the child’s speech quality. More research is needed to determine whether this is a valid explanation (see MacSweeney & Parker, in preparation). This possibility does not alter the overall conclusion that SI, as measured by teacher’s ratings, was not related to STM ability or coding in the experiments reported here.
7.6.iv Speech rate and sign rate

A linear relationship between speech rate and STM ability is well established in hearing children (see section 2.5.v). In older children this is attributed to the effect of subvocal rehearsal. However, since children are not thought to rehearse until the age of approximately nine-years-olds (Henry, 1991) the articulation rate/STM relationship in these subjects has more readily been explained in terms of output effects (Cowan & Kail, 1996).

In Experiment 2b the relationship between speech rate, sign rate and memory span was explored. There was a very high correlation between speech rate and sign rate by deaf teenagers. This consistency was reflected in the fact that both factors positively correlated with overall STM ability, though for speech rate this was of borderline significance (p=.06). More surprisingly, sign rate correlated with susceptibility to concurrent speech, which is regarded as an indicator of speech-based STM coding. The correlation between speech rate and susceptibility to concurrent speech was in the same direction but did not reach significance.

It was argued in Chapter 5 that these relationships were unlikely to solely reflect rehearsal. Furthermore an explanation based purely on faster processing speed at output seems unlikely since the production rate measures, in particular speech rate, correlated with measures not dependent on production. Perhaps most importantly speech rate positively correlated with reading age. It was proposed in Chapter 5 that this may reflect the importance of the specificity of phonological representations in LTM. The validity of this proposal will be discussed further in section 7.8.

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3 It should be noted that these correlations were based on smaller sizes than the other individual difference variables analysed here (speech rate n=13, sign rate n=15).
7.7 Can the working memory model account for the use of multiple STM codes and the impact of semantic features on STM performance demonstrated in this thesis?

The experiments reported in this thesis suggested that deaf people may not use a single STM code to facilitate the temporary storage of pictures. Rather, Experiments 2, 3 and 4 highlighted the use of both visual and speech-based codes. This was not only at the group level but also when individual subjects were analysed on their susceptibility to visual and speech similarity of pictures (Experiment 4). Experiment 3 suggested a small subgroup of deaf adults may also use a sign-based STM code. Finally, Experiment 5 showed that long-term knowledge of perceptual semantic aspects of objects, such as its dynamic features, may also influence STM processing by deaf people.

The traditional working memory model (Baddeley, 1986, see Chapter 2) is not able to account for these findings since multiple representations are not accounted for and it takes little account of semantic factors. However, a development of the working memory model proposed by Logie (1995; 1996) can offer an adequate account of these two findings. Logie proposes that on presentation of stimuli all relevant LTM representations are activated. These activated representations are then transferred to the workspace of working memory and can be used in later recall. For example, the recall of pictures in the present studies may utilise visual, semantic and phonological representations, both speech and sign-based. This hypothesis echoes other multiple-capacity models of STM (e.g., Barnard, 1985; Monsell, 1984) and would seem to give an adequate account of the apparent use of multiple STM codes by deaf people. In hearing people multiple codes or representations may also be activated. However, the phonological representation of the item to be recalled dominates in most situations and therefore use of alternative codes is not apparent in STM tasks.

With regard to the impact of semantic information on STM, according to Logie’s position since all relevant LTM information can be used to aid recall, richer semantic
representations of the item to be recalled will lead to better recall. Thus if a deaf child has richer semantic representations of items that have dynamic properties by virtue of their attention to these items in infancy in a world without sound, their STM for such items may be enhanced, as shown in Experiment 5.

7.8 Can the working memory model account for the relationships between reading ability, speech and sign rates and STM demonstrated in this thesis?

Reading ability and production rates of phonologically structured material were most strongly related to STM ability of deaf teenagers. As already discussed, rehearsal and output effects, based on the working memory model (Baddeley, 1986), are not sufficient explanations for the observed relationship between speech rate and STM. Speech rate also correlated with reading ability suggesting a 'deeper' explanation may be valid.

The phonological readout account of the word length effect in young children proposed by Gathercole and Hitch (1993, see section 2.5.i) may apply here. Gathercole and Hitch argue that for spoken output, stored phonological forms are mapped onto 'abstract articulatory gestures', which may be based on the processes developed for speech perception. Since longer words take longer to prepare for output via this mapping, recall is impaired. Although not stated by Gathercole and Hitch, it is likely that this mapping process is also slowed at output if the long-term phonological representations of items to be recalled are not fully specified, again leading to poorer recall. Thus speed at output may account for the relationship between speech rate and STM ability seen in Experiment 2b. However this may be linked to another factor, such as specification of long-term phonological representations. Although speech-based phonological skill or awareness was not tested directly in this thesis, it is possible that similar abilities are reflected in susceptibility to the speech based coding manipulations tested.
The line of argument that better specified long-term phonological representations lead to quicker output of these items, thus leading to increased memory span, is potentially in conflict with that of Kail (1997). Kail argues that articulation rate and phonological skill make independent contributions to STM development in hearing children. However, the extent to which these two factors co-vary in Kail's data is unclear. It is argued here that for deaf children, there may be a direct relationship between these two factors which, in turn, support STM.

In contrast to the relationship between speech rate and STM ability, accounting for the positive correlation between sign rate and STM ability (Experiment 2b) is more problematic. Here, better long-term representations based on sign phonology may lead to quicker mapping onto sign-articulatory gestures at output. However, this line of argument infers that sign-based representations are used within STM and there was no evidence for this as tested in this thesis.

It is possible that the methods used to test for sign-based STM coding were inappropriate (see section 7.3.i). Alternatively, given that the majority of the subjects tested used a combination of sign and speech and the strong correlation between speech and sign rate, it is possible that the relationship between STM ability and speech and sign rate, reflects the influence of language ability in general. That is, an influence of long-term phonological representations regardless of modality.

The fact that a relationship exists between long-term phonological knowledge and STM ability is well established, however the precise nature of this interaction is still a matter of debate. Logie's development of the working memory model can account for this relationship since his model applies to all modalities of representations of an item held in LTM. However, other models have been proposed that focus only on the relevance of long-term phonological knowledge to STM for linguistic stimuli (see Gathercole, 1997). These models differ in terms of how this information is used to support STM.
Baddeley, Gathercole and Papagno’s (1998) recent expansion of the phonological loop model argues that the representation of stimuli in the phonological store involves the “temporary activation of a structure or network that reflects the influence, though not the dominance, of a phonological long-term system” (1998, pg. 170). This approach regards the influence of long-term phonological knowledge as simply helping to ‘fill in’ representations that are incomplete within working memory, a process termed ‘redintegration’ (Brown & Hulme, 1995). Furthermore, Baddeley et al. regard the relationship between STM and LTM as bidirectional. That is, not only can LTM influence STM but, with substantial exposure, temporary phonological representations in the phonological store are thought to influence LTM representations. Baddeley et al. propose that this relationship forms the basis of the main evolutionary function of the phonological loop, namely, to learn new words and therefore act as a language learning device (see Gathercole & Baddeley, 1989; Gathercole, Willis, Emslie & Baddeley, 1992; Papagno, Valentine & Baddeley, 1991).

In contrast, Gathercole and Martin (1996) proposed an interactive model in which presentation of stimuli activates representations across a phonological network within LTM. Rather than these representations then being transferred to a separate working memory system, as in Logie’s model, Gathercole and Martin argue that the representations active at any one time correspond directly to the supposed contents of the phonological store in the working memory model. With this perspective, there is no need to propose a separate STM store. In this model the activated long-term phonological representations are STM.

Whichever model accounts for the relationship between STM performance and long-term phonological knowledge, all accept the general principle that the better specified the long-term phonological representations the stronger the support for STM processes. In order to establish phonological representations of signs or speech a child
needs good early exposure to appropriate exemplars of items in the language to imitate. This allows phonological representations to be constructed using feedback from good language users. Lip-reading cannot reliably deliver full access to the phonology of a spoken language for most deaf children (see Chapter 3). It may need to be supported by information derived from orthography, as demonstrated by the importance of reading ability to STM performance in this thesis (although the reading skill of deaf children rarely matches that of their hearing peers). With regard to establishing long-term phonological representations of sign language, deaf children of hearing parents often have limited early exposure to sign language (see Chapter 1). Poorer STM performance by deaf children in comparison to their hearing CA peers, on both ordered recall tasks and free recall tasks, may therefore be accounted for in terms of poorer specificity and organisation of phonological representations in LTM. Thus, support from these long-term representations for STM processes will be less secure. This underlines the critical importance of early language exposure to cognitive processing by deaf people.

7.9 Further work

A number of theoretical issues have been raised by the experiments in this thesis which require further investigation.

Do deaf signers use a sign-based STM code in the recall of pictorial stimuli?

The studies presented in this thesis showed no evidence that deaf people generally used a sign-based STM code to facilitate recall of pictorial stimuli. It is possible that the sign similarity manipulation used in Experiment 4 was not sensitive because the parameter on which sign similarity was based (handshape) was relatively insensitive (see section 7.3.i). Further research is needed to determine the implications of Klima and Bellugi's (1979) and Kyle's (1986) studies which showed that location is the most important sign parameter with regard to memory for sign stimuli. Testing deaf
signers' recall of items which were similar in terms of location presented as signs, pictures and printed words, would help clarify whether a sign-based STM code is used by deaf people and if so, for what stimulus modalities.

*Do deaf adults use a visual STM code?*

Experiment 4 showed that deaf eight- and fourteen-year-olds used a visual STM code in the recall of pictures. Deaf teenagers used this in conjunction with a speech-based STM code. This pattern resembled that of their hearing RA controls (five- and eight-year-olds). However, in this study recall by hearing eleven-years-olds was *not* affected by visual similarity of pictures. By this age hearing children use a robust speech-based STM code to recall pictorial stimuli. It is not clear whether the pattern of development seen in deaf children continues and eventually reaches this stage of dependence on a speech-based STM code. Alternatively STM coding by deaf people may remain at the stage of that seen in deaf fourteen-year-olds in Experiment 4 and be dependent on the use of *both* visual and speech-based codes. The latter position seems more likely since the majority of deaf adults tested in Experiment 3 were not as speech-influenced in STM as hearing teenagers. Therefore the use of a weak speech-based STM code may have been supplemented by the use of a visual-code. It would be interesting to address this question directly, to extend our knowledge of the development of STM coding, by testing deaf adults on the stimuli used in Experiment 4.

*Does an articulatory concurrent task impair performance on a visuo-spatial task in deaf children?*

Experiment 2a showed that recall of pictures by deaf teenagers was impaired by a non-articulatory concurrent task. To account for this it was proposed that the development of central executive control strategies is delayed in deaf children, resulting in poor performance when an irrelevant concurrent task was required. If this explanation is valid, given that the central executive is *amodal*, one would predict that an *articulatory* concurrent task would impair performance by deaf teenagers on a
visuo-spatial task. This would offer clear support for the developmental delay hypothesis proposed here.

Further consideration of speech rate and sign rate
Correlational analyses in Experiment 2 showed that speech and sign rate were related to overall STM ability. Furthermore, there was no difference in speech and sign rate by deaf teenagers. An issue not addressed in this study is the rate of sign and speech production by deaf people in comparison to speech rate by hearing people. It is possible that slower sign production rates can account for the observed difference in STM performance between deaf and hearing people. However, there is no direct evidence to support this position. No study has directly compared phonological production rate of unconnected items by deaf and hearing people in relation to their STM performance.

Establishing a valid measure of speech intelligibility of a deaf child
Teachers' ratings of the speech intelligibility (SI) of deaf children did not relate to deaf children’s STM ability or use of a speech-based STM code in this thesis (Experiments 2b and 4). However, SI did relate to reading ability in these studies. Another measure of SI was also established for these subjects as part of a larger project considering the SI of deaf children (see MacSweeney & Parker, in preparation). This measure was a more objective measure of SI as listeners, unfamiliar with deaf speech, were asked to identify single words spoken on videotape by the deaf child. This measure did not correlate with STM ability or reading ability. Further work is in progress to determine the precise relevance of these preliminary findings.

Longitudinal studies
This thesis has demonstrated strong relationships between deaf children’s STM ability, use of STM codes, reading ability and phonological production rate. It was suggested that these relationships may indicate the fundamental importance of long-
term phonological representations to STM performance. Determining the direction of cause and effect between these skills is not possible from the data reported here.

Both STM performance and reading ability may be supported directly and independently by long-term phonological knowledge. In this case the correlation in the present studies between STM ability and reading ability may simply indicate co-variation due to a third factor, namely the specificity of long-term phonological representations (in speech or in sign). Alternatively, long-term phonological knowledge may support reading ability, which in turn may facilitate STM ability. Or, long-term phonological knowledge may support STM ability, which in turn may facilitate reading. There may be reciprocal relationships between these factors (Baddeley et al., 1998). STM ability may contribute to strengthening long-term phonological representations as well as vice versa. Furthermore, reading ability may play a particularly important role in strengthening long-term phonological representations in deaf children, more so than for hearing children, which in turn may help enhance reading ability.

These hypothesised interactions between these factors are not exclusive. Indeed it is likely that all these processes play a role and that truly reciprocal relationships occur between these skills. Longitudinal studies are needed to determine the precise pattern of relationships between these factors. Such a study would follow deaf children’s development of signed and spoken language, their speed of production of speech and sign, reading ability, phonological awareness (of sign and speech), STM ability and STM coding. Only then can the relative importance of each of these factors be estimated. It would also be informative to compare the development of these linguistic and cognitive skills in deaf children of deaf parents and deaf children of hearing parents. This should allow a comparison of the development of relatively proficient and relatively poor language users (see Chapter 1). Establishing a clearer understanding of the interplay between these cognitive variables is likely to have important consequences for the approaches used in the education of deaf children.
The development of assessment tools to access long-term phonological knowledge

Overall it is argued that the studies reported in this thesis support the theoretical position that the strength of LTM representations are fundamental to STM performance, in particular long-term phonological knowledge. Most of the studies that have identified this STM and LTM link in hearing children have tested the repetition of non-words. This ability appears to be closely linked to language acquisition (see Gathercole, 1997; 1998). This test would be inappropriate for use with prelingually deaf children given their general articulation problems. However, given the apparent predictive power of this task, an important area of future research is to develop a task that would tap the same underlying skills in deaf children. Furthermore, the link between sign rate and STM ability demonstrated in this thesis indicates that it may also be useful to develop a test of nonsense-sign repetition to test deaf childrens' long-term knowledge of sign phonology.

Developing such tools is a necessary precursor to increasing our understanding of the influence of long-term phonological knowledge, both sign and speech-based, to STM functioning by deaf people. Without reliable, standardised measures of BSL ability (see Woll, 1998), sign-phonology awareness and nonsense-sign repetition, it will remain impossible to accurately assess language ability of young deaf children. This important area of research needs valid language measures to enable the precise links between these variables and cognitive skills of deaf children to be established.
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Appendix 1: Pilot study for Experiment 4

In this study hearing adults were tested on recall of speech similar and dissimilar items. The purpose of the study was twofold. First, to test the validity of the speech-similar stimuli to be used in Experiment 4. Second, to test whether the phonological similarity effect is robust when ordered recall but not serial order recall was required.

Method

Subjects
Seven hearing adults were tested. They were mostly undergraduate students with a mean age of 24-years-old.

Materials
Two sets of twelve black and white line drawings of concrete concepts, printed on 11 cm x 15 cm card, were used. Twenty-one of these were chosen from the Snodgrass and Vanderwart’s (1980) standardised pictures and norms. One was taken from the British Picture Vocabulary Scales and two were drawn specially for the experiment. The speech similar items all have the middle vowel sound /a/ (e.g., cat, flag). The control stimuli were sounded dissimilar (e.g., book, eye). There were no differences between stimulus sets on name agreement, complexity, familiarity and age of acquisition (all ps>.1). The stimuli are listed in Table 6.2.

Procedure
The procedure was the same as in Pilot study 3. Subjects were tested individually. The pictures were shown at a rate of one every two seconds. After each card had been presented it was placed face down in a spatial array in front of the subject. After presentation of the last card the subjects recalled by naming each card as they pointed
to it. Subjects were instructed that they did not have to start recall at the beginning of the list and could move around the list as they wanted. This was demonstrated explicitly by the experimenter pointing to the backs of the cards in a random order. Speech-similar and dissimilar trials were performed alternately and subjects performed 5 trials in each condition.

**Results**

Only items correctly identified in the correct location were scored as correct. The mean percentage recalled was: control stimuli - 84.3% (s.d. = 17.5), speech similar stimuli recalled - 61.0% (s.d. = 15.1). A repeated measures t-test showed that recall of speech similar stimuli was significantly poorer than recall of dissimilar stimuli (t(6), = 5.27, p<.005).

As in Experiment 3 a SOR curve, weighted for order of report, was constructed. This was to determine whether subjects moved from location to location in recall or whether they simply recalled from position 1 through to 6. This involves scoring the first position recalled as 6, the second 5 and so on. As subjects performed 5 trials in each condition a subject who recalled from position 1 to 6 on every trial would be 30 in the first serial position and 5 in the sixth position. Figure I.i shows that this was the general pattern for both types of stimuli.

![Figure I.i: Serial position curves for each condition weighted for order of report](image-url)
Discussion
These results indicate that the stimuli chosen are appropriate to elicit a speech similarity effect in hearing adults and are therefore appropriate to use in Experiment 4. Furthermore, the speech similarity effect was robust even when memory for strict serial order was not required. However, analysis of the order in which subjects reported the items showed that they did tend to recall both sets of stimuli in serial order although this was not a task requirement. This is not surprising given that, in contrast to concurrent speech (see Pilot study 3) the speech coding manipulation used here (speech similarity of stimuli) does not disrupt rehearsal which is responsible for maintaining the items to be recalled in serial order. As with Experiment 2, whether the change in scoring procedure used in these studies leads to systematic differences between deaf and hearing subjects was assessed in Experiment 4 by analysis of the serial position curves of deaf and hearing groups.