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Memory Skills of Deaf Learners: Implications and Applications

The author reviews research on working memory and short-term memory abilities of deaf individuals, delineating strengths and weaknesses. Among the areas of weakness that are reviewed are sequential recall, processing speed, attention, and memory load. Areas of strengths include free recall, visuospatial recall, imagery, and dual encoding. Phonological encoding and rehearsal appear to be strengths when these strategies are employed. The implications of the strengths and weaknesses for language learning and educational achievement are discussed. Research questions are posed, and remedial and compensatory classroom applications are suggested.

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Some psychologists consider *working memory* (WM) and *short-term memory* (STM) to be synonymous, and to represent a memory store that is constrained both by the number of items that can be maintained and the length of time these items can be active. Denh (2008), however, makes this distinction between STM and WM: STM passively holds information. WM actively processes it.

Research over the past two decades has demonstrated that performance on WM and STM tasks is highly predictive of academic achievement in areas such as

- reading (Cain, 2006; Cain & Oakhill, 2006)
- language comprehension (Engle, Carullo, & Collins, 1991)
- mathematics (Geary, Hoard, Nugent, & Byrd-Craven, 2007; Jarvis & Gathercole, 2003)
- science (Gathercole & Alloway, 2008; Gathercole & Pickering, 2000; Gathercole, Pickering, Knight, & Stegmann, 2004; Jarvis & Gathercole, 2003)

Long-term memory, the repository of knowledge, can acquire very little information unless these two gateways are functioning properly (Denh, 2008). Deficits in WM and STM potentially may limit students' ability to learn and function in school (Alloway, Gathercole, Kirkwood, & Elliott, 2009). Although it is not yet well understood how WM and STM contribute to academic skills, it has been suggested that learning is hampered or fails when task demands exceed memory capacity (Ayres, 2009; Gathercole, Lamont, & Alloway, 2006).

Deficits in memory processes have been found in children with disabilities (Alloway & Gathercole, 2006; Pickering, 2006). For example, children with reading disabilities have specific difficulties in retrieving speech-based codes and monitoring attentional processes (Swanson, Zheng, & Jerman, 2009). WM deficits have also been described for groups of children who exhibit

- mathematical learning disabilities (Geary et al., 2007)
- intellectual disabilities (Henry & Winfield, 2010)
- speech and language impairments (Archibald & Gathercole, 2006)
- autism (Bennetto, Pennington, & Rogers, 1996)
- attention deficit/hyperactivity disorder (Rapport et al., 2008)

A greater understanding of memory limitations in children can ultimately inform the development of communication and classroom practices and may result in improved language learning and school outcomes. To date, however, relatively little research has been conducted toward developing and evaluating innovative approaches that would minimize memory demands in the classroom (Gathercole & Alloway, 2008) or directly improve memory in students who are most at risk for communicative or academic failure (Holmes, Gathercole, & Dunning, 2009; Klingberg et al., 2005; Swanson, Kehler, & Jerman, 2010). The low levels of academic achievement common among deaf individuals (Gallaudet Research Institute, 1996; Marschark, 2006; Meadow-Orlans, 2001; Moores, 2001, 2003; Traxler, 2000) may also have a basis in memory processes (Blair, 1957; Marschark et al., 2009).

In the present article, I review research on WM and STM abilities of deaf individuals. In this article, *deaf* refers to those individuals with a hearing loss of 70 dB or higher. This review focuses on deaf signing individuals. The areas of memory that are reviewed include those in which deaf individuals exhibit deficiencies and strengths. *Deficiencies* refer to areas in which deaf individuals perform less well than hearing individuals, and *strengths* refer to areas in which deaf individuals perform as well as or better than hearing individuals. Areas of deficiency include sequential recall, processing speed, attention, and memory load. Areas of strength include free recall, visuospatial recall, imagery, and dual encoding. Areas that emerge as strengths when a particular strategy is employed include phonological encoding and rehearsal. The implications of the deficiencies and strengths for language learning and educational achievement are discussed. The results of the literature review then form the basis for suggested remedial and compensatory activities to enhance learning. Research questions are also delineated regarding the proposed educational applications.

Memory Skills of Deaf Learners

Memory Deficits and Their Effects on Language Learning and Academic Achievement

Sequential Memory

Sequential memory is recall or processing of a list or other stimulus such as a sentence in the same order as it was presented. Bebko (1984) has noted that deaf individuals have greater difficulty with sequential memory processing tasks than hearing individuals. For deaf individuals compared to hearing peers of similar chronological age, deficits have been found in regard to immediate sequential recall of lists of

- digits (Blair, 1957; Flaherty & Moran, 2004; Koo, Crain, LaSasso, & Eden, 2008; Olsson & Furth, 1966; Parasnis, Samar, Bettger, & Sathe, 1996; Pintner & Patterson, 1917; Tomlinson-Keasey & Smith-Winberry, 1990)
- printed words (Flaherty & Moran, 2004; Hanson, 1982; Krakow & Hanson, 1985)
- pictures (Blair, 1957; Bebko, 1984; Bebko & McKinnon, 1990; Campbell & Wright, 1990)
- American Sign Language (ASL) signs (for deaf subjects) versus English words (for hearing subjects) (Bavelier, Newport, Hall, Supalla, & Boutla, 2008; Bellugi & Siple, 1974; Bellugi, Klima, & Siple, 1975; Boutla, Supalla, Newport, & Bavelier, 2004 ; Geraci, Gozzi, Papagno, & Cecchetto, 2008; Krakow & Hanson, 1985)
- Fingerspelled words (for deaf subjects) versus English words (for hearing subjects) (Krakow & Hanson, 1985)

Various researchers have discussed the reasons for this deficit. Their hypotheses include the longer articulation length of signs in comparison to speech (M. Wilson & Emmorey, 1997), the shorter decay rate of visual/sign memory compared to that of echoic/speech-based memory (Boutla et al., 2004), and the formational complexity of signs versus speech (Geraci et al., 2008). Regardless of the theoretical viewpoint, deaf individuals' sequentially based WM appears to be somewhat limited when compared to that of hearing individuals. A recent review (Marschark & Wauters, 2008) has suggested that deaf children are less likely than hearing children to use sequential processing strategies, and that this may account for at least some of the former's linguistic WM deficit and language comprehension difficulties.

Processing Speed

Processing speed is the speed with which an individual can perform a cognitive task, such as recognizing a word or sign or comprehending a sentence. Speed-of-processing deficits have been found to inhibit the oral and written language as well as the math ability of hearing children (Fletcher, Lyon, Fuchs, & Barnes, 2007; Mather, & Jaffe, 2002; Prifitera, Saklofske, & Weiss, 2005). Slow word recognition while reading has also been related to deficits in reading fluency and comprehension (Johns, 2009; L. Kelly, 1993; Nagy, Anderson, Schommer, Scott, & Stallman, 1989). Results from the processing speed index subtests of the fourth edition of the Wechsler Intelligence Scale for Children (WISC) indicate that deaf students have processing speed deficits (Leutzinger, 2002; Maller & Ferron, 1997). For deaf students, scores on the WISC processing speed index subtests have also been found to correlate positively with academic achievement (Braden, 1990; M. Kelly & Braden, 1990; Stewart, 1981).

According to Felser and Clahsen (2009), children and late second-language learners usually exhibit slower language processing speed than mature native speakers. For children, this slower processing speed is most likely due to their reduced attention and WM spans as compared to those of adults. For non-native late second-language learners, language processing is thought to be cognitively more demanding than for native adults. While children seem to be able to use monolingual adultlike processing routines starting fairly early in development, late learners' processing of some aspects of grammar appear to remain like that of non-natives even at higher proficiency levels.

As learners experience a language, whether spoken or signed, one of the primary tasks is to separate out the discrete symbols of the language from the flow of sound or sign for comprehension or acquisition purposes (Felser & Clahsen, 2009; Hirsh-Pasek & Gollinkoff, 1996). Mayberry and Fischer (1989) found that non-native signers still struggle with this task even in adulthood as compared to native signers, who exhibit language processing skills more indicative of automatic sign recognition. For non-native signers, this "bottleneck" in processing has been related to deficits in the recall and comprehension of signing.

Attention

Attention is the cognitive process of focusing on one aspect of the immediate environment and is of great importance in the function of WM (Engle, 2002). Subjective measurement of attention by means of the Attention Deficit Disorder With Hyperactivity Comprehensive Teacher Rating Scale, the attention-activity section of the Aggregate Neurobehavioral Student Health and Education Review, and Conners' Parent Rating Scale indicated that 14.1% of deaf children of deaf parents would be considered to have attention deficits, compared to 38.7% of deaf children of hearing parents (D. Kelly et al., 1993). Approximately 8%–10% of hearing children in the United States have been diagnosed with attention deficits (Centers for Disease Control and Prevention, 2010). Other subjective rating scales have suggested no difference between deaf and hearing children in attention skills (Meadow, 1976).

On empirical measures of attention, deaf children have been compared to hearing children. These comparisons have revealed both deficits (Altshuler, Deming, Vollenweider, Ranier, & Tendler,1976; Mitchell & Quittner, 1996; Mykelbust & Brutten, 1953; Proksch & Bavalier, 2002; Parasnis, Samar, & Berent, 2003; Werner & Strauss, 1941) and superior ability (Larr, 1956; McKay, 1952).

Deaf individuals are better at attending to and processing information in their peripheral vision than hearing individuals (Chen, Zhang, & Zhou, 2006; Loke & Song, 1991). The lack of hearing to alert the deaf to the location of motion or animate objects in the environment may foster this compensation. However, in a classroom where attention should be centered on the teacher or interpreter, attending to peripheral movement may be problematic (Dye, Hauser, & Bavelier, 2008). Sustaining and appropriately directing attention in the classroom does appear to be troublesome for deaf students. Matthews and Reich (1993) found that deaf high school students attended to a classmate's signing about 30% of the time when that classmate was communicating with the teacher about class material. When the teacher was signing to the whole class, the students attended to the teacher 44% of the time. If the teacher addressed a particular student, that student's attention to the teacher increased to 50%. Marschark and colleagues (2005) found similar levels of inattentiveness among deaf students in college classrooms.

Memory Load

Memory load is the cognitive complexity a task presents to an individual. For example, the memory load inherent in comprehending a 12-word sentence is higher than that for comprehending a 3-word sentence. As memory load increases, performance often decreases (Denh, 2008). One factor that increases memory load is the redundancy and juxtaposition of similar words in a sentence. For hearing individuals, such sentences are termed *tongue twisters* (e.g., "She sells seashells by the seashore"). Tongue twisters increase task memory load. Subsequently, comprehension is significantly less accurate for these sentence types as compared to simple control sentences such as "She buys her clothes at Old Navy" (Kennison, Sieck, & Briesch, 2003; McCutchen & Perfetti, 1982; Perfetti & McCutchen, 1982). Thus, formationally similar items employed in the same utterance can increase memory load.

When processing sign language, deaf adults have been shown to code items based on the cherological (Stokoe, 1960) or sign-based formational features of the items (Bellugi et al., 1975; Hamilton & Holzman, 1989; Hanson, 1982; Shand, 1982; M. Wilson & Emmorey, 1997, 1998). Deaf children have also shown evidence of cherological coding for signs (Hamilton, 1984, 1985; Hirsh-Pasek & Treiman, 1982; Treiman & Hirsh-Pasek, 1983). Print, it appears, can be coded phonologically (Hanson, 1990; Hanson & E. H. Lichtenstein, 1990) or cherologically (Krakow & Hanson, 1985; Shand & Klima, 1981; M. Wilson & Emmorey, 1997, 1998). Treiman and Hirsh-Pasek (1983) examined deaf individuals' comprehension of "fingerfumbler" sentences (Kilma & Bellugi, 1979), in which signs for the printed words were formationally similar. Results indicated that as task difficulty increased, reading comprehension of single sentences decreased for less proficient deaf readers. Comprehension was significantly less for sentences that contained words whose signs were formationally similar, such as "I *ate apples* at *home yesterday,*" than for control sentences, such as "I ate the bananas at work last week." According to Treiman and Hirsh-Pasek, the underlined words have signs that are considered visually similar. These words were culled from the data collected by Bellugi and Siple (1974), Bellugi and colleagues (1975), and Klima and Bellugi (1979). These signed words' similarity lies in the fact that they are all produced in locations around the mouth and lower front side of the face. Also, EAT and HOME share a handshape, while HOME and YESTERDAY share a similar movement and location.

In the area of sequential recall, Rudner and Rönnberg (2008) have provided evidence that deaf adults are similar to hearing adults in sequential recall of pictures when memory load requirements are low. However, as memory load increases, sequential recall becomes more difficult for deaf individuals sooner than for hearing individuals.

Memory Strengths and Research Questions for Language Learning and Education

Free Recall

For *free recall*, that is, recalling a list in any order, memory span is equivalent in adult deaf ASL signers and hearing English-speakers for printed words (Hanson, 1982, 1990) and, respectively, for ASL signs and spoken words (Boutla et al., 2004). In regard to children, Liben (1979) found free recall for line drawings to be similar for deaf and hearing subjects. Similarly, no significant difference has been found between the free recall of sequentially presented shapes by deaf and hearing children (Todman & Seedhouse, 1994). Can this strength be useful in academic learning, where free recall ability is beneficial for tasks such as remembering the names of the states or the bones in the body?

Visuospatial Recall

Visuospatial recall refers to the recall of items presented in some form of visual array such as blocks on a table or objects in a grid. For sequential recall of nonlinguistic visuospatial items, such as in the Corsi block- tapping test, deaf adults and children prove superior to hearing individuals (Alamargot, Lambert, Thebault, & Dansac, 2007; Geraci et al., 2008; Logan, Mayberry, & Fletcher, 1996; M. Wilson, Bettger, Niculae, & Klima, 1997). In the Corsi block-tapping test, the experimenter touches a static series of blocks randomly arranged on a board; the subject must then touch the blocks in the same sequential order. In a similar task, the Knox cube test, which employs a static straight line of blocks, deaf children are also superior to hearing children in sequential recall of a visuospatial array (Blair, 1957). Deaf children have also shown equal sequential visuospatial recall ability to hearing children in the Simon game, in which a sequence of flashing colored lights arranged in a circle is recalled by touching the lights in the order of presentation (Tomlinson-Keasey & Smith-Winberry, 1990).

Also in the nonlinguistic visuospatial domain, Parasnis and colleagues (1996), utilizing the Revised Visual Retention Test (Benton, 1974), found no significant difference between hearing and deaf children in their ability to recall (by drawing) a series of geometric figures presented via a static sequential pattern (a line of figures presented all at once). Hauser, Dye, Cohen, and Bavelier (2007), utilizing adult native deaf signers and the Rey-Osterrieth Complex Figure Test, found no significant difference between hearing and deaf subjects on recall as shown by their drawings of simple and complex geometric figures. The Rey-Osterrieth Complex Figure Test addresses spatial perception and visual memory. Similar results on this test have been found for deaf children (Eldredge, 1984; Eldredge & Zhang, 1988; Parasnis & Kirk, 2004).

Deaf adolescent and adult subjects also have performed equally as well as hearing subjects on recall of static sequential presentation of shapes (a line of shapes shown all at once), but not as well as hearing subjects on recall of temporal sequentially presented shapes (shapes that are presented one at a time and disappear before the next shape appears), which require serial recall. Similar results were found when digits (linguistic stimuli) were used as the recall items (Olsson & Furth, 1966).

Also investigating linguistic items, Flaherty and Moran (2004) studied the sequential recall of deaf and hearing college students who read phonologically based English, and Japanese deaf and hearing college students familiar with reading kanji symbols (logographs), which are not phonologically based. Flaherty and Moran found that deaf participants showed shorter sequential memory spans than hearing participants for English words. However, sequential memory spans were similar for deaf and hearing participants for words in kanji. Japanese deaf students reported using a visual gestalt memory strategy, seeing the sequence as a whole, rather than the sequential strategy often reported by the English-reading deaf students. Similar results were found in a study involving only hearing and deaf Japanese students (Flaherty & Moran, 2001).

Investigating free recall of visuospatially arranged linguistic items, Blair (1957) found deaf children superior to hearing children in the free recall of everyday objects placed on a grid. The children were shown 15 items on a grid for 20 seconds. The items were then removed, and the children's task was to place them back in their original locations.

Deaf individuals' strength appears to lie in the recall of information presented in static visuospatial format. This appears to hold for both nonlinguistic and linguistic items. Can educators devise presentation strategies that allow deaf students to take advantage of this memory strength for the processing of sequential linguistic information, particularly English print?

Imagery

Imagery is the ability to create, maintain, and manipulate a visual image in WM. Enhanced visuospatial abilities of deaf individuals compared to hearing individuals have been reported for imagery (Blair, 1957; Emmorey & Kosslyn, 1995; Emmorey, Kosslyn, & Bellugi, 1993; McKee, 1988) and mental rotation of visuospatial stimuli (Emmorey, Klima, & Hickcok, 1998; McKee, 1988). Can deaf individuals' enhanced imagery ability be used to increase learning and academic achievement in order either to enhance WM or reduce the WM load presented by a learning task?

Dual Encoding

Dual encoding refers to the individual's use of both sign and speech codes when signs and speech are presented simultaneously. This simultaneous presentation is called *Simultaneous Communication* (SimCom). Though such presentation is often maligned in the research literature (Kluwin 1981; Luetke-Stahlman, 1988; Marmor & Petitto, 1979; Woodward & Allen, 1988), simultaneously communicated lists of words have been found to be recalled better than sign-only and speech-only presentations by both hearing and deaf signers. This effect has been shown to be particularly strong for deaf signers (Hamilton & Holzman, 1989). Problematically, however, research has shown that skill in the use of SimCom is often erratic, with elements of the syntax, grammar, and meaning of a message being inconsistent. In the classroom, most teachers use a form of English-like signing (formerly known as Pidgin Sign English) that is neither a strict coding of English nor of ASL, but contains features of both languages, along with speech, and consistently follows English word order (Akamatsu, Stewart, & Mayer, 2004). Hearing teachers using English-like signing often drop signs from signed sentences (Kluwin 1981; Luetke-Stahlman, 1988; Marmor & Petitto, 1979; Woodward & Allen, 1988). In classroom signing, Luetke-Stahlman (1991) found that hearing teachers trying to represent English when signing were able to encode the meaning of the target sentence about 71% of the time, omitted a sign or sign marker over 50% of the time, and used wrong or invented signs. Yet these same signers believed were accurately communicating via signs. Mayer and Lowenbraun (1990), however, found that if teachers were given appropriate training and were committed to signing English, they could effectively sign at a speech-to-sign ratio of greater than 90%. The majority of hearing signers, however, do not exhibit such high levels of skill (Kluwin 1981; Luetke-Stahlman, 1988; Marmor & Petitto, 1979; Woodward & Allen, 1988).

Research is needed in the area of SimCom. Is recall and comprehension of SimCom superior to sign-only communication in the classroom during presentation of information more complex than simple word lists? If so, can the use of SimCom be improved in general, or should it be targeted for controlled simple communication settings?

Memory Strengths if a Particular Strategy Is Employed

Phonological Encoding

Phonological encoding refers to speech-based/articulatory encoding (Dodd & Hermelin, 1977; Hanson, 1991). This forms the basis for the "functional equivalence hypothesis" as stated by McQuarrie and Parrila (2009):

> The central claim of the functional equivalence hypothesis posits that visible speech information (seen articulatory gesture) extracted from the speech signal by the deaf learner is interpreted as a phonologically plausible signal by the brain (Campbell, 1987; Dodd, 1976; Dodd & Hermelin, 1977). . . . On this basis, it has been further suggested that with the help of the visual information acquired through speechreading (Campbell, 1987; Dodd, 1976; Dodd & Hermelin, 1977) and the articulatory feel of words that comes through intensive speech training (Marschark & Harris, 1996), deaf children can develop phonological representations of words. (p. 137)

The use of a speech-based phonological code has been positively correlated with reading comprehension in hearing children (Cain, 2006, P. de Jonge & P. F. de Jonge, 1996; Engle et al., 1991; Engle, Kane, & Tuholski, 1999; Goswami & Bryant, 1990). Consequently, phonological encoding has become a "hot" topic in deaf education, particularly in the area of reading (Allen et al., 2009; Mayberry, del Giudice, & Lieberman, 2011; Paul, Wang, Trezek, & Luckner, 2009; Wang, Trezek, Luckner, & Paul, 2008).

It appears, though, that when reading, some deaf individuals employ phonological encoding while others do not. Research indicates that deaf children are less likely than hearing children to employ phonological encoding in WM, reading, and spelling across a range of tasks (Beech & Harris, 1997; Harris & Beech, 1998; Leybaert & Alegria, 1995; Merrills, Underwood, & Wood, 1994; Nielsen & Luetke-Stahlman, 2002; Transler & Reitsma, 2005). When employed, phonological or articulatorily based encoding has been shown to facilitate sequential recall by deaf adults (Kyle, 1981; S. Lichtenstein, 1998) and children (MacSweeney, 1998), and has been positively correlated with reading comprehension ability in deaf individuals (Campbell & Wright, 1988; Dyer, MacSweeney, Szczerbinski, Green, & Campbell, 2003; Harris & Beech, 1998; Kyle & Harris, 2006, 2010; E. H. Lichtenstein, 1985; S. Lichtenstein, 1998; Perfetti & Sandak, 2000; Wang et al., 2008). No positive relation has been found between phonemic awareness (the ability to hear, identify, and manipulate phonemes) and reading ability in deaf students (Harris & Beech, 1998; Kyle & Harris, 2006; Narr, 2008).

In a meta-analysis of studies investigating phonological encoding and reading in deaf students, Mayberry and colleagues (2011) found that phonological encoding accounted for only about 11% of the variance in reading ability, while language ability accounted for 35% of the variance. Not surprisingly, language does account for more variance in reading ability than phonological encoding. The development of language is crucial in all aspects of a child's life, and sign language is often the most effective tool for facilitating language acquisition by deaf children. That does not negate the fact that phonological encoding does account for some variance in reading ability and is an important area to consider.

Thus, the ability to code information phonologically is a WM strength that should be considered when instruction is being designed. Phonological encoding does not rely on higher-level phonemic awareness, for which hearing ability seems important. Rather, phonological encoding for deaf individuals appears to rely on whole word phonological/articulatory encoding that may be enhanced via the development of speechreading, which has been positively correlated with reading ability in deaf children (Harris & Moreno, 2006; Kyle & Harris, 2006, 2010).

Can speechreading training that specifically targets the development of phonological/articulatory coding enhance the sequential recall and language and reading comprehension of deaf students? Can speech articulation training enhance the quality and use of phonological/articulatory encoding?

Rehearsal

Rehearsal refers to the overt or covert repetition of items to be recalled or learned. For deaf learners, overt sign rehearsal has been shown to increase immediate sequential recall of

- printed words (Bonvillian, Rea, Orlansky, & Slade, 1987)
- images (Bebko, 1984; Bebko & McKinnon, 1990)
- signed phrases (Weaver, Hamilton, Bruckman, & Starner, 2010)

It is important to note that deaf students do not spontaneously use rehearsal as early in life as hearing students. Rehearsal appears in hearing students around the age of 7 or 8 years; by comparison, it appears in deaf signing students at age 10 years or later (Bebko, 1979; Flavell, Beach, & Chinsky, 1966; Gill, Klecan-Aker, Roberts, & Fredenburg, 2003). However, after instruction in overt rehearsal and employment of this strategy, deaf students have performed as well as hearing students in recall tasks (Bebko, 1984; Belmont, Karchmer, & Pilkonis, 1976).

One study has reported evidence of 6- and 8-year-old deaf children spontaneously using both sign- and speech-based rehearsal during recall tasks for pictures, shapes, fingerspelling, and print. Rehearsal, however, did not appear to enhance recall for these children (Liben & Drury, 1977). The emergence of rehearsal in deaf students appears to be directly related to language experience (Bebko & McKinnon, 1990), and more specifically to language proficiency and automatized or automatic language processing (Bebko, Bell, Metcalfe-Haggert, & McKinnon, 1998).

Implications of Working Memory Deficiencies for Learning

Memory Deficits

Perhaps the most striking implication of deaf individuals' deficiencies in WM lies is the fact that they all relate to processes that are used during the comprehension and learning of language. Attention is absolutely necessary as a first step in acquiring language data in the environment. Processing speed must then be adequate for the encoding and manipulation of this data. Automatized recognition of signs is imperative so that the "bottleneck" described by Mayberry and Fischer (1989) does not stress memory load, causing processing difficulties. Finally, the ability to maintain sequential linguistic information in WM is a key component of cognition, particularly during language parsing (McElree, Foraker, & Dyer, 2003; Sperber, D. Premack, & A. J. Premack, 1995). Willis and Gathercole (2001) have suggested that limited, less accurate sequential WM ability may be responsible for slow acquisition of language in hearing children and that, thus, sequential memory skills are considered a crucial part of the language learning mechanism for young children. The lack of sequential processing skills or the failure to use a sequential strategy during processing of linguistic information in WM may limit the deaf individual's ability to grasp syntactic order. Such a deficit can impede language development and, subsequently, the comprehension of signed or printed material, with negative consequences for academic achievement.

With deficient WM abilities, deaf children of hearing parents, in particular, are put in double jeopardy for communicative and academic failure. Not only are these children deprived of language interaction (Gallaudet Research Institute, 2008; Goldin-Meadow, 1999; Goldin-Meadow & Mylander, 1990; Lederberg, 2006) that fosters communicative and academic growth (and most likely WM capacity for language), they are put in the position of attempting to process the relatively few accessible linguistic interactions they are privy to with WM abilities that are subpar compared to those of hearing children, who receive a wealth of linguistic input and interaction. The quantity and quality of language interaction have also been related to language learning and educational achievement of hearing children (Risley & Hart, 2002). Research has found strong predictive relationships between language skills and reading ability, the latter of which is a major component of academic achievement both for hearing children (Bowey & Patel, 1988; Dickinson, McCabe, Anastasopoulos, Peisner-Feinberg, & Poe, 2003; Juel, Griffith, & Gough, 1986; Snow, Tabors, & Dickinson, 2001) and deaf children (Harris & Moreno, 2004; Kyle & Harris, 2006; Mayberry et al., 2011; Padden & Hanson, 2000; Strong & Prinz, 2000). The synergistic relationship among language, WM, and reading is currently realized in deaf high school students, as 50% read at the fourth-grade level or below upon graduation (Gallaudet Research Institute, 1996; Traxler, 2000) and 30% leave high school functionally illiterate (Marschark, 1997; Marschark, Lang, & Albertini, 2002). The academic achievement of deaf students has remained at these levels for approximately 30 years (Qi & Mitchell, 2007), regardless of the educational or language policy of the day. Language delay and educational underachievement of deaf individuals may thus be attributed to at least two factors: lack of accessible linguistic interaction with skilled signers and, subsequently, insufficient WM skills to assist these individuals during language and academic learning.

Memory Strengths

The WM strengths of deaf individuals in the areas of free recall, imagery, visuospatial recall, dual encoding, phonological encoding, and rehearsal all have implications for improving the design and delivery of instruction. The deaf individual's strengths can be utilized and deficiencies remediated or compensated for so that communication and academic achievement can be enhanced. The WM strengths just listed are applied in the instructional design of the WM interventions described below in order to enhance processing skills and subsequent learning. Other strategies may also be useful, and empirical validation is necessary in all cases.

Applications for Learning

WM Interventions

Now that the WM deficiencies and strengths of deaf learners and the subsequent implications have been described, how can these deficiencies be remediated or strengths utilized to enhance learning? One way is through WM interventions. Feifer and DeFina (2000) have suggested that memory intervention is most successful during early childhood and the early elementary school years due to brain maturation. Change is more difficult once neural structures are established and myelination is complete. However, several studies have shown that children ages 7–15 years can benefit from WM intervention (Comblain, 1994; McNamara & Scott, 2001; Minear & Shah, 2006).

Denh (2008) describes interventions for WM as either *compensatory* or *remedial*. Compensatory methods typically involve training in memory strategies and may also include various external aids and methods for bypassing the deficient processes and reducing task demands. Remedial methods generally address the individual's memory deficits in order to reduce them. The research literature is mixed in its findings regarding the effectiveness of remedial interventions. Lee and Riccio (2005) found remedial intervention ineffective, but others (Comblain, 1994; Holmes et al., 2009; Klingberg et al., 2005; Klingberg, Forssberg, & Westerberg, 2002; Mezcappa & Buckner, 2010) have described successful remedial interventions. A combined intervention approach applying both compensatory and remedial techniques has been shown to be the most successful (Denh, 2008).

Interventions can also focus on either domain-specific or domain-general skills. *Domain-specific skills* are those involving specific areas of knowledge such as language skills or math facts. *Domain-general skills* include higher-order, more abstract cognitive skills such as WM capacity (Roberts, 2007). Remedial and compensatory interventions addressing these two domains are described below. This list is not exhaustive, as other activities can also serve to address WM and enhance language learning and academic achievement.

Preschool Years: Birth to Kindergarten

As has been stated in many research articles on deafness, early exposure to accessible language is imperative. This often means sign language. Interaction with fluent signers allows the child to develop the language and processing skills needed to achieve academically. As a rule of thumb for interacting with young children and beginning signers, adults should sign slowly and clearly, and use short sentences so as not to overload the child's memory during processing. This is a strategy used by parents of young hearing children (Snow, 1977) and teachers of children learning English as a second language (E. Kottler, J. A. Kottler, & Street, 2007), and is suggested for teachers of children with WM deficits (Gathercole & Alloway, 2008).

An environment in which the child is surrounded by fluent signers is often not available to most deaf children, however (Gallaudet Research Institute, 2008; Goldin-Meadow, 1999; Goldin-Meadow & Mylander, 1990; Lederberg, 2006). As a substitute, signed videos and video games may be tools that can help enhance the child's facility with vocabulary and automatic sign recognition, and hence his or her WM. However, signed videos and video games cannot be regarded as equal substitutes for interactions with fluent signers.

During the sign presentation in the video or game, it is probably best to have a still image behind the signer, as deaf individuals have been shown to attend to peripheral distractors (Chen, Zhang, & Zhou, 2006; Loke & Song, 1991) rather than to the central information source, which in this case would be the signer. If the media include action that the signer is describing, it may be best to use a sequential presentation in which the signer is followed by the action, again for attention reasons. The efficacy of signed videos and games and the particular presentation formats that facilitate language processing and development are open research questions worthy of investigation. Many signed videos and games are available on commercial DVDs and at no charge at the website of the Electric Language Factory, www.cats.gatech.edu/cats/ELF/index.htm.

Reciting nursery rhymes, singing songs, and performing action chants are applications of rehearsal that can be used with young deaf children to improve their sequential WM skills and, subsequently, their language processing skills. These are common practices in many hearing children's homes and preschools and may serve the unintended purpose of developing sequential WM for language. "Jack Be Nimble" and "The Wheels on the Bus" are, respectively, examples of English-language rhymes and songs. Action chants are simple rhymes that are accompanied by physical actions as opposed to simply saying the rhyme. "Ring Around the Rosie" is an English-language action chant in which children hold hands and walk in a circle reciting the chant; then "all fall down." An ASL action chant that followed the format of an ASL number story might be "ONE, TWO SQUIRRELS HOP-AROUND," after which the persons reciting the chant would hop around the room. Other examples of sign language nursery rhymes, songs, and chants are available on YouTube, at sign2me.com, and in Hamilton (1987, 1988). As I noted earlier in the present article, deaf children are similar to hearing children in the recall of sequential information when trained to rehearse. The rote recitation inherent in producing signs of rhymes, songs, and action chants may aid in the development of sign language and WM skills, particularly rehearsal. Pictures, animations, or physical responses such as hopping, as in the "ONE, TWO SQUIRRELS" action chant, should accompany production of these verses to permit better understanding of the signing.

Completing daily household tasks can further assist the child in sequential WM development. The adult can start by asking the child to do a single task, such as "Get your shirt," then progress to two tasks such as "Get your dirty clothes and put them in the wash," and then to three or more tasks that should be done sequentially. The use of the ASL mechanism for referencing the items on a list on the nondominant hand (Baker-Shenk & Cokely, 1991) may facilitate recall for the child, as this provides a visuospatial reference for each item. Adults could help the child rehearse the tasks to be done, as both use the nondominant hand placeholders. Empirical validation of this ASL mechanism as a memory support tool is needed.

For free recall, the parent can tell the child what items are needed in the store during a shopping trip and then have the child lead the search to find them. For young children who cannot find items in a store yet, the parent can simply tell the child an item or two they need as they go through the store and, when they find the item, repeat its name. Parents can increase the number of items as the child becomes more adept with language. For other activities that address WM in young children, see Gibson (2003).

School Years: Grades 1–12

Regardless of students' language background and WM ability, schools are mandated to teach academic content. For that reason, in the present article I will discuss techniques to address WM skills within the domain-specific areas of language arts, mathematics, and content-area subjects, as well as techniques for managing WM load through instructional design.

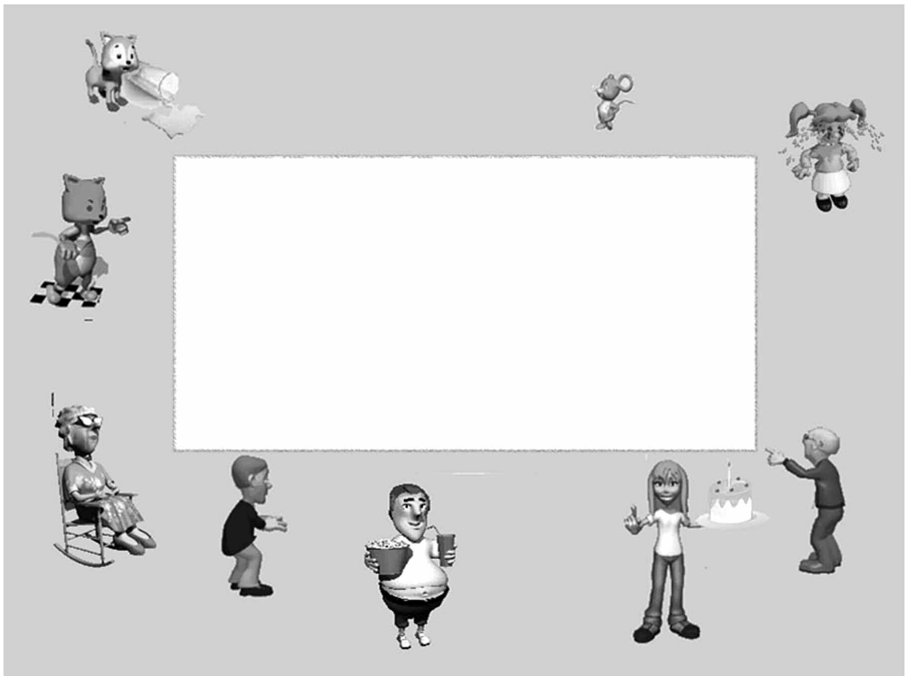
Language Arts: Language Comprehension

The drag-and-drop feature available in PowerPoint provides an easy-to-use tool for teachers to develop activities that focus on sequential memory during sentence comprehension. Figure 1 shows a slide that can be used for such an activity. Many of the images are animated to represent the action of the verb as clearly as possible. These and similar images are available at www.animfactory.com, the website of the Animation Factory, a distributor of still and motion picture images.

Using the slide in Figure 1, the teacher can present a sentence in sign and a student can drag images onto the white area to create a picture that represents the meaning of the sentence. The student must maintain the sequential order of the sentence in WM long enough to comprehend it and then manipulate the images to create the picture. It is important to use sentences in which the subject and object are interchangeable. This forces the student to use sequential information to correctly comprehend the sentence. Short sentences such as "The girl is scolding the man" and "The man is scolding the girl" are two examples. Longer sentences such as "The mouse is looking at the fat man" and "The man with the popcorn and drink is watching the girl who is crying" can be used with this same slide.

It is also important to use absurd or silly sentences that require sequential processing in order to be understood

Figure 1
Drag-and-Drop Slide



Note. Images © 2011 Jupiterimages Corporation.

correctly. The students must follow the word order of the sentence to correctly comprehend the sentence even when the result is an image with a low probability of actually occurring in real life. A sentence such as "The cat is scolding the girl" can be made using the images in Figure 1. Until about age 4 years 6 months, hearing children will often comprehend such sentences by using an "event probability" strategy (i.e., make sense of the sentence regardless of word order), in this case producing a picture showing the girl with the cake scolding the cat near the spilt milk. Evidence for this behavior has been found not only for English-speaking children (Stroehner & Nelson, 1974) but also for speakers of Italian (Bates, 1976; Bates et al., 1984; Duranti & Ochs, 1979), French (Sinclair & Bronckart, 1972), Spanish (Reyes, 2003), and German (Lindner, 2003). Data I have collected in regard to ASL comprehension indicate that non-native signers, hearing and deaf, tend to use "event probability" during language processing, often to a greater extent than hearing children do.

Also of interest in this area is the work of Treiman and Hirsh-Pasek (1983). Their research indicated that sentences that contained signs that were formationally similar were more difficult to comprehend than sentences with formationally dissimilar signs, due to the WM load involved in each (see discussion above under "Memory Load"). When constructing sentences for a comprehension task, teachers should be aware of this phenomenen so that they can either avoid or include such sentences, depending on the students and goal of the lesson.

Language Arts: Reading

Reading English print is primarily a sequential WM processing task, as English uses a rather strict adherence to word order to communicate meaning. For instructional purposes, print can actually serve to reduce WM load inherent in the sequential presentation of signs that appear and then are gone. Print provides a static visuospatial sequential stimulus and allows the teacher to visually reference key words or phrases simply by pointing to them. Thus, the compensatory elements afforded by print and employed by the teacher may help reduce the WM load inherent in processing sequential language for non-native signers. All words used in such an activity must be automatized, or the added memory load of encountering unknown words will negate the advantage gained from the static sequential presentation.

The drag-and-drop task described above can also be used for reading instruction and will allow for imagery to be used by the teacher and students to aid in comprehension. Instead of single sentences, a story could be used as the content for the activity. For illustration purposes, description of a reading activity addressing pronominal reference follows. Using Figure 1, the presented short story could be "The man scolded the cat. He was angry. She spilled the milk." After a picture was created to show the meaning of the first sentence, the images that were created could be used to support further comprehension of the pronominal reference in the other two sentences. The teacher could refer to the image created on the screen to show pronoun reference. The teacher could then present a similar sentence sequence substituting different nouns, ask the students to imagine what the scene would look like, then draw it, drag-and-drop images, or answer questions about the new sentence sequence to indicate comprehension. Pictures and text from storybooks, guided readers, or chapter books could also be used. A commercially available program, the Lindamood-Bell Learning Process, has been shown to improve reading scores of hearing students by teaching the students to use visualization and imagery (Sadoski & Willson, 2006). This may be a useful program for deaf students.

Processing speed is very important during reading (Lesgold & Perfetti, 1978; Perfetti & Lesgold, 1978), and is best represented by the term *automaticity*, the instantaneous recognition of words. Grushkin (1998) has suggested that automatic word recognition can alleviate memory load during the act of reading comprehension. Conversely, struggling to recognize words during reading causes fewer WM resources to be available during reading comprehension (Denh, 2008). Simple repetition activities to foster overlearning of printed words can help the learner attain automaticity.

Reading words or sentences presented for a short period of time can help readers develop speed of processing. This can be done in the classroom by means of PowerPoint presentations with the word, sentence, or short paragraph presented on a slide which is set to transition to a blank slide via the timer feature in PowerPoint. The use of tachistoscope programs may also be useful. Several free programs are available on the Internet, such as RAM4 (http://www.slu.edu/colleges/AS/languages/classical/ram/ram.html) . A low-tech solution is simply to present the target word(s) on a whiteboard, then cover or erase them after a short time.

Captioned video is also useful for building processing speed and sequential WM, as the caption presentation is time limited and sequential. The teacher can pause the video immediately after the presentation of the caption and ask the students what the caption said, and other questions about the caption. The caption presentation also can build focused attention, as the student must ignore the activity on the screen and focus on the captions. Without automatic word recognition, proficient processing speed, sufficient sequential WM, and the ability to focus attention on the caption and not the peripheral action, it seems that captioned video would be nonbeneficial to the viewer.

The lack of knowledge of English printed words also affects reading greatly. When readers know less than 90% of the words in a passage, comprehension drops to 50% or less (Johns, 2009). This is particularly true for deaf readers (Albertini & Mayer, 2011; Davey & King, 1990; LaSasso & Davey, 1987; Paul, 1996; Paul & Gustafson, 1991; Paul & O'Rourke, 1988). During the reading of any print material, online or off, an English-ASL learning aid, the SMARTSign-Dictionary (www.cats.gatech.edu), provides a tool for quickly finding a sign or signs for a word and also reduces the memory load inherent in mentally searching for signs for unknown or nonautomatized words. Students can simply type the English word into the SMARTSign-Dictionary and then see the sign(s) for that word. Often, picture support is provided to enhance the learning of the word-sign pair through the provision of imagery for the concept being represented. This is especially important for young readers who are new to signs and may be encountering the sign for the first time via exposure to the English word in a book. Google Images (www.google.com) provides another powerful tool that allows users to enter words and search for images. Google Images essentially functions as a picture dictionary.

Online electronic dictionary use is common among adult second-language learners. Lan (2005) found that over 70% of the interviewed students at Hong Kong Polytechnic University who were learning English as a second language were online dictionary users. Use of an electronic dictionary such as the SMARTSign-Dictionary may assist deaf readers during the reading process. It can be used on desktop computers or laptop computers, tablet computers, and cell phones for mobility.

As I have already discussed in the present article, language ability accounts for a large part of reading ability. Major contributions to reading comprehension are also made by language skills, vocabulary knowledge, reading fluency as evidenced by the automatized recognition of words, and general world knowledge, as well as by viewing the reading process as a whole (Denh, 2008). Phonological encoding is also important. Phonological encoding can be developed through activities that focus on speechreading (Kyle & Harris, 2006, 2010) and articulation (McQuarrie & Parrila, 2009). It seems important to relate speechread and spoken articulated words directly to known printed words in order to have an effect on reading (Marschark & Harris, 1996).

In the classroom, speaking information during highly contextualized routine situations can help enable phonological encoding by fostering the development of speechreading. If it is time for lunch and the teacher has daily signed "TIME FOR LUNCH," this information can be presented via signs, then speech, and finally through speech alone as the students become familiar with the situation. It is important to ask the students what was said and then also quickly present the print for the spoken words to establish the speechreading-print connection. Asking the students to say the phrase will also build the phonological/articulatory representation of the target phrase. It is likely that the representation the student produces will not need to match a "perfect English" representation of the words. The representation should, however, be different from the representation of other words or phrases. This will allow the student to use an internally consistent phonological/articulatory code, which is of benefit in WM. If the students codes all words with the same articulatory code (e.g., *buh*) it seems less likely that such a code will be beneficial. Speech therapists might be able to make a significant contribution to literacy development by including speechreading and articulation activities related to print in their work with students. Research is needed to determine the empirical validity of this hypothesis.

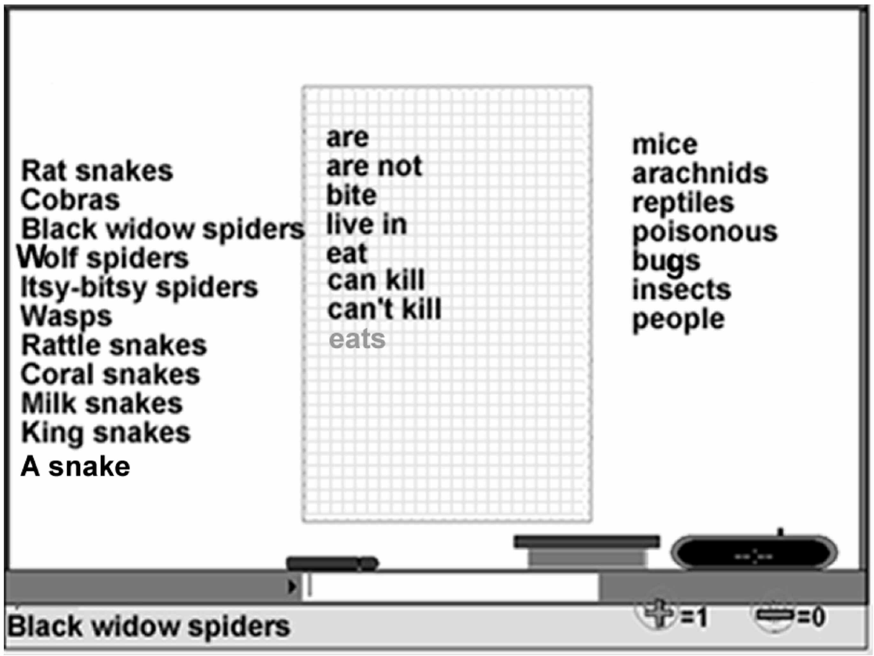
Language Arts: Writing

Building English schemas via visuospatial scaffolding has proven successful in helping deaf students develop basic English writing skills (Hamilton & Jones, 1989). According to Chi, Glaser, and Rees (1982), a schema categorizes elements of information according to the manner in which those elements will be used. Schemas are examples of sophisticated rules and are stored in long-term memory. It is important for schemas to become automatized so that they can be used quickly and effortlessly. Practice with schemas helps them become automatized (Paas, 1992). Learners who have automated a schema have more WM capacity available to use the schema to solve more sophisticated problems (Sweller, 1988).

Denh (2008) describes scaffolding as a strategy that can enhance WM. Scaffolding provides the learner with initial support for the learning task and gradually removes the support while maintaining a low-error environment for the student. As students show success, the support is removed until the student is performing the task correctly without the scaffolding. A tool that provides scaffolding for building schemas for writing basic English sentences, Simple Sentence Lab (SSL), contains activities that are both compensatory and remedial in nature. (SSL is available at no charge at www.cats.gatech.edu/cats/CatSoft/SSL.htm.) Teachers can use any subject matter in SSL simply by typing sentences into the program. The sentences can be about a field trip, storybook, or news event, or academic content from science or social studies. As few as 5 and as many as 15 sentences can be entered. These limits are established to manage WM load by not overloading it. Long stories can be broken into chapters, and content information can be broken into multiple units, if necessary. More than a dozen activities that address sequential memory, sentence production, spelling, chunking of English phrases, rehearsal, and schema building for written English are available and provided in a suggested sequence that initially provides supportive scaffolding and then progressively removes it. Both computer-based and paper-and-pencil tasks are used.

Figure 2 illustrates the schema and visual scaffolding provided for sentences entered into the SSL program. Students can create a story, summarize content, or answer teachers' questions using this schema. As shown in Figure 2, the student has already typed in the subject noun phrase of a sentence and is ready to type the verb phrase. When that is done correctly, the grid and text entry box move to the third column, and the student enters the final phrase. The scaffolding support provided by the columns and sliding grid is faded away as students perform successfully.

Figure 2
Simple Sentence Lab Screen



Note. From the Simple Sentence Lab website: www.cats.gatech.edu/cats/CatSoft/SSL.htm

The English sentences that are produced will be syntactically and grammatically correct due to the responses allowed in each column. The visual schema and procedure of SSL allow only correct syntactic sentences, and a built-in grammar only allows grammatically correct responses. For example, the student can type "Rattle snakes eat mice" but not "Rattle snakes eats mice." As shown in Figure 2, "eats" is grayed out, and SSL's artificial intelligence will not allow it as an acceptable verb due to the subject-verb agreement necessary with "Rattle snakes." The semantic accuracy of the students' responses must be evaluated by the teacher. SSL would allow the grammatically correct sentence "King snakes can't kill mice," when actually the opposite is true. This allows teachers to see what students understand about the target content while providing scaffold-supported practice in writing English.

SSL provides a grammatically "errorless" environment for learning English, which is important for students with WM deficits (Gathercole et al., 2006). Compensatory support via a static visuospatial organization of English draws upon the deaf individual's strength in sequential recall of static visuospatial items (the SSL grid) and also lessens sequential WM load as well as organizes English words via grammatically based chunking. Chunking is the grouping of to-be-remembered items into meaningful rule-governed units. Verbal sequential WM capacity expands as chunks are formed by the items to be managed in WM (Denh, 2008). This process is particularly useful in language processing, as chunking allows an increase of nearly threefold in memory span of native speakers when sentences rather than unrelated words are to be recalled (Baddely, 2003; Case, 1977). Language chunks appear to be based on the rule-governed constituents of the particular language known by the individual such as noun phrases and verb phrases (Case, 1977). Thus, chunking is a very important aspect of maintaining and manipulating linguistic items in WM. Providing external visual aids that show the students English chunks, as in Figure 2, may help them to create chunks corresponding to phrases or clauses, and thereby to create more manageable units of information (Montgomery, 2003).

Language Arts: Vocabulary and Spelling

In the present article, *learning vocabulary* refers to learning the meaning of unknown words or signs. Once a word or sign is part of a student's known vocabulary, the spelling of the printed English word can be learned. The student may be simultaneously learning vocabulary and the spelling of that vocabulary in school.

Learning vocabulary in a classroom can be enhanced through the use of visual imagery. Studies indicate that the imageability of a word is a key factor in determining its ease of acquisition (Gillett, H. Gleitman, L. Gleitman, & Lederer, 1999; Ma, Golinkoff, Hirsh-Pasek, McDonough, & Tardif, 2009). Visual imagery has been shown to be particularly useful for students with deficits in verbal WM when they possess a strong visuospatial WM. Mnemonic strategies in which a verbal utterance, in this case the meaning of a word or sign, is related to a visual image have been successfully used for many years to facilitate recall and learning (Eslinger, 2002; Levin, 1993; Mastropieri & Scruggs, 1998; Paivio & Csapo, 1969). This approach is most effective when the image created is unique, funny, or bizarre (Ritchie & Karge, 1996). As mentioned earlier, the Lindamood-Bell Learning Process program focuses specifically on the use of imagery to enhance reading and its tenets, and such procedures could be employed during vocabulary learning. For deaf students, providing an image along with a sign or signs for vocabulary would appear to be helpful. Combining visualization of the meaning of the verbal string with rehearsal has been found to be more effective than rehearsal alone (Clark & Klecan-Aker, 1992).

Learning the spelling of words (i.e., the sequence of letters in a word) generally involves the use of rehearsal. For increasing sequential WM skills, rehearsal has been found to be a useful strategy (Comblain, 1994; Minear & Shah, 2006), and to facilitate information storage in long-term memory (Denh, 2008). Training deaf students in the use of rehearsal at an early age can pay benefits immediately and in the future.

Chunking can be also used to reduce memory load for deaf students as they learn vocabulary that will be used during reading or writing by taking advantage of the single-sign ASL representation of English phrases such as *look up*, *jump over*, and *get on*. When these printed phrases are recognized as individual chunks, sequential memory span has fewer items to maintain, and memory load is therefore reduced. Teaching students these English phrases, as is done in the Fairview method (Schimmel & Edwards, 2003; Schimmel, Edwards, & Prickett, 1999), may prove beneficial.

For classroom instruction in vocabulary or spelling, the use of SimCom may be beneficial. Deaf individuals have been shown to recall simultaneously communicated lists significantly better than lists presented in sign only (Hamilton & Holzman, 1989). Through use of SimCom for controlled, structured classroom presentation of vocabulary and spelling, the memory enhancement of this dual code may be realized, while the detrimental aspects of SimCom such as dropped signs and faulty syntax are eliminated. Drasgow and Paul (1995) have suggested that the processing requirements for producing simultaneous sign and speech cause signers to delete or incorrectly code signs due to WM overload. Limiting the use of SimCom to short bits of information during vocabulary and spelling instruction may enable WM overload to be eliminated for teachers, while the simultaneous signal enhances recall for students. This suggestion requires empirical validation.

Mathematics

Visual imagery has been shown to be particularly valuable in teaching mathematics both to hearing students (McLean & Hitch, 1999) and to deaf students (Blatto-Vallee & R. R. Kelly, 2007; Lang & Pagliaro, 2010). Nunes (2006) has described visual displays that may enhance mathematics learning by deaf students. These provide scaffolding to support number recognition for early math facts and for more advanced math processes such as word problems.

Static sequential visuospatial presentation of math facts (e.g., $2 + 4 = 6$) provides students with an information format that allows for use of their WM strength in this area and may foster more efficient learning. Providing math fact tables for study may also assist students by providing a visuospatial schema of the facts to be learned. This scaffolding can be faded away as it is internalized and students automatize the math facts.

To increase processing speed and automaticity as well as attention, the teacher can use a timed PowerPoint presentation to flash a math fact, or simply write the math fact on the whiteboard and then erase it. After the math fact is removed from view, students can write it on paper in a race type of format, which will also encourage an increase in processing speed.

Dictating math problems to students may also facilitate the development of WM and math skills. This is a remedial intervention designed to "exercise" and increase WM as opposed to the compensatory strategy described earlier utilizing static sequential visuospatial presentation. The students can write the dictated problem on paper and then solve it. If needed, the words used in the dictation can be randomly displayed to eliminate the WM load caused by unknown spellings. Alternatively, the words can be arranged in a visual schema similar to the one in Figure 2. This schema adds scaffolding for recalling the dictation using English syntax.

Writing the problem on paper enables WM load to be reduced during problem solving; the teacher also can see how much of the problem the students actually recalled. To exercise and enhance WM load capabilities, the teacher can require the students to solve the problem without writing it on paper after they are successful in the writing task. This is an example of scaffolding being removed.

Using the ASL grammatical feature in which objects are located in space and then referred to may also be an effective means of reducing WM load. This type of presentation can also allow deaf students to employ imagery to "see" the math problem, and allow the teacher to manually manipulate the invisible items to explain the necessary mathematical process. For example, the word problem "Jack has 3 dogs. Jill has 2 dogs. How many dogs do they have altogether?" could be signed by placing Jack's 3 dogs in a location in the left of the signing space, placing Jill's 2 dogs in a location to the right, and holding the signs for 3 and 2 in the respective locations. The signs can then be brought together in a middle location showing that 3 and 2 combine.

Teachers can also reduce memory load during math activities by providing calculators for students who have not automatized math facts. This can be helpful to students in learning the process of balancing a checkbook or planning a budget. For higher-order math processes such as those in geometry, trigonometry, or calculus, automatized math facts are imperative so that WM can focus on the math processes involved in these subject areas and not be overloaded by deficient computational knowledge.

Content Areas: Science, Social Studies

Deaf individuals have shown equal free recall abilities relative to hearing individuals across several tasks (Boutla et al., 2004; Hanson, 1982, 1990; Liben, 1979; Todman & Seedhouse, 1994). Two particular types of learning tasks lend themselves to free recall: labeling tasks, such as labeling the 50 states on a map, and categorizing tasks, such as categorizing animals versus plants. These types of activities accompanied by rehearsal practice can enhance the learning of content that is not sequentially bound.

Rehearsal can be valuable in the area of learning factual information in content areas. Using repetition for this important information can facilitate its long-term storage (Denh, 2008) and improve the automaticity of access to it for higher-level cognitive processes such as understanding chemical bonding between atoms or the principles of a democratic government.

Through utilization of the consistent visuospatial schema for English as provided by SSL (see Figure 2) with a variety of content, content information may be learned more efficiently and English skills may increase (Hamilton & Jones, 1989). Variability of practice materials has beneficial effects on the transfer of learning (Cormier & Hagman, 1987; Jelsma, van Merrienboer, & Bijlstra, 1990; Singley & Anderson, 1989). Thus, variability (different subject-area content) of the problem situation (learning the content and producing English sentences) is expected to encourage learners to develop efficient schemas for the target information because it increases the probability that similar features can be identified and that relevant features can be distinguished from irrelevant ones. Consistent use of a tool such as SSL is imperative if it is to be successful in building schemas.

Rudner and Rönnberg (2008) suggest that a presentation style that places less emphasis on the temporal order of information may facilitate deaf individuals' recall performance. The use of visuospatial tools such as flowcharts, boxes, and diagrams fits this presentation style. Such tools reduce memory load (Grushkin, 1998) and subsequently enhance recall and learning. O'Donnell and Adenwalla (1991) compared the use of visually diagrammed information maps and texts by deaf undergraduate biology students. The students scored higher on recall and multiple-choice comprehension tasks when using the visually mapped information for learning purposes.

"Thinking maps" (Hyerle & Yeager, 2007) take advantage of the visuospatial abilities of deaf students for static presentations of information. These are graphic organizers with different visual structures that are designed to consistently represent the same type of relationships between information, thus building a schema for the content. Such graphic organizers are especially powerful when the students create the organization of the visual schema themselves (Davies, 1980). Inspiration, FreeMind, and XMind are computer programs that allow for quick free-form construction of visual graphic organizers. FreeMind (freemind.en.softonic.com) and XMind (www.xmind.net) are free and available online. Luckner, Bowen, and Carter (2001) have also described visual displays for reducing WM load for deaf students.

General Concerns for All Instruction

Attention

Attention is extremely important during WM processing (Engle, 2002). If a student is not attending, little information can be acquired or comprehended. An attention strength of deaf individuals may also be a problem during language processing. Deaf individuals are highly attuned to information in peripheral vision. Thus, movement on either side of the student or teacher can be distracting. To develop attention to the signer and not peripheral movement, a teacher can give directions while standing near a computer or television screen displaying some type of movement. Students can then follow the directions, with the teacher starting with short, simple directions and progressing to longer directions. It may be useful to explain to the students the purpose of the activity in order to enlist a metacognitive strategy that encourages them to make a concerted effort to attend to the signer. Also, by adding a distractor such as a moving image to a slide of information being presented, a teacher can also address focused attention. However, one should be aware that adding such distractors may cause even greater loss of attention to the teacher than the 50% reported by Matthews and Reich (1993). Research into the use of such attention-building activities is needed.

Memory Load

The classroom is notorious for overloading the memory abilities of all students on a daily basis (Denh, 2008). Assessing the WM load of a task and adjusting it as necessary is important for facilitating student success. These are some general principles for reducing WM load:

- Language processing, particularly of long utterances, may overload WM. Comprehension of verbal material will be enhanced through the use of language that is simple, structured, and redundant.
- Multitasking by students places undue strain on attention, and hence on WM. The teacher should focus on one activity at a time.
- Students with WM deficits can learn if they have ample exposure to material while the demands on WM are minimal.
- Students should be allowed time to process new information. More learning occurs when students are given time to rehearse the information and apply memory strategies.
- Repetition or practice of a task is very important.
- External supports such as visual cues, checklists, and prompts will reduce WM load.
- Learners should be provided with graduated learning support (scaffolding) until the support is no longer needed. Gathercole and colleagues (2006) have suggested that "errorless learning," in which errors are prevented or minimized, is much more effective for individuals with WM deficits than "errorful learning," essentially learning by trial and error. Several studies have shown this to be the case (Baddeley & B. A. Wilson, 1994; Clare, B. A. Wilson, Carter, Roth, & Hodges, 2002; Hamilton & Jones 1989). If a child has a WM deficit, it is extremely important to minimize task failure due to WM load.

ASL may also help reduce WM load. Geraci and colleagues (2008) suggest that ASL grammar has evolved over time to utilize the enhanced visuospatial memory abilities of deaf individuals and downplay the deficits. Such a development seems only natural. Research should address how the use of ASL (to reduce WM load) and SimCom (to provide an enhanced signal that is recalled better than sign alone) can be best used for communication and instruction.

WM Activities in the Classroom

Denh (2008) suggests the following tenets for addressing WM in the classroom. WM activities should

- be brief
- be focused on only one strategy
- be spaced, with two or three per week over a long period
- provide plenty of practice that allows the child to utilize the target strategy
- encourage the child to attribute his or her success to the strategy
- provide multiple sessions so that ultimately the strategy is overlearned
- provide positive reinforcement for successful use of the strategy
- include teaching a child when and how to use a strategy so that the child can apply this metacognitive knowledge as necessary
- match the needs of the learner and be adaptive; as the child's skills increase, so should task difficulty (Holmes et al., 2009; Klingberg et al., 2002, 2005)

Applying these tenets and enhancing WM can facilitate language learning and academic achievement of deaf students.

Conclusion

In the present article, I have reviewed literature on the memory skills of deaf learners and described activities that take advantage of the deaf individual's memory strengths to facilitate learning and reduce memory load or to reduce deficiencies in memory skills that are important to learning. The deaf learner's areas of memory deficiency include sequential memory, processing speed, attention, and memory load. Areas of strength include free recall, visuospatial recall, imagery, and dual encoding. When utilized, phonological encoding and rehearsal emerge as strategies that enhance recall. These strategies are not spontaneously used by all deaf individuals, however, and may be prime candidates for inclusion in instruction.

Instructional design and classroom practices can draw upon deaf learners' memory strengths, compensate for weaknesses, and attempt to remediate basic information processing skills so that linguistic competence and academic achievement can be increased. Activities that can address these areas are described in the present article. Not all suggested activities have been empirically validated, as the importance of WM in education is just now being realized. Ten specific questions should be investigated:

- Can visuospatial organization facilitate recall and learning of sequential linguistic information such as English syntax?
- Can deaf individuals utilize imagery for increased learning and academic achievement?
- Can viewing signed video and playing sign-enhanced video games enhance language learning?
- Given the visual constraint of being able to attend to only one item at a time (Wolfe, 2000), what particular presentation formats for media can best facilitate language comprehension and learning?
- Can attention to the signer, rather than to peripheral distractors in a classroom, be taught so that it exceeds the current 50% benchmark?
- Can speechreading training that specifically targets development of phonological/articulatory coding enhance the sequential recall and language and reading comprehension of deaf students?
- Can speech articulation training facilitate phonololgical/articulatory coding to enhance recall regardless of vocal intelligibility?
- Is recall and comprehension of SimCom superior to sign-only communication in the classroom during presentation of information more complex than simple word lists? If so, can SimCom use be improved? Is SimCom best used only in limited presentation/communication instances, as opposed to open-ended communication?
- Can use of spatially established ASL referents and manipulation of these referents facilitate math problem solving?
- How can ASL (to reduce WM load) and SimCom (to provide an enhanced signal that is recalled better than sign alone) be best used for communication and instruction?

Finally, instructional practice can adopt the suggestions of Denh (2008) and others for limiting WM load and creating error-free learning environments to enhance learning. For example, the use of visual schemas and scaffolding holds great promise for deaf education because of these two techniques' ability to reduce memory load and call into play the visuospatial WM strengths of deaf students.

The present article has provided a starting point for raising the awareness of educators of deaf students on the important issue of WM. It also includes detailed suggestions for areas of future research into the utility of specific WM activities. The field of WM and its application to education provide new and exciting possibilities for enhancing language learning and academic achievement of deaf students.

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