The Effect of Communication Mode on Story Recall

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ABSTRACT

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Most learning occurs in social contexts through interaction with other people. Such learning is possible only when individuals are able to communicate with understanding. Currently, the most commonly used mode of communication for instruction in schools for the deaf in the United States is a bimodal form of signs and speech referred to as "simultaneous communication" (SIMCOM). Numerous studies have addressed the practicability of teachers' attempts to produce this mode for instruction, but fewer have attempted to understand its impact on deaf children's comprehension. This study examined the effect of communication mode on story recall performance in thirty-six 11- to 14-year-old deaf students. Participants were presented with a series of short stories "bimodally" (using simultaneous sign and speech/SIMCOM) and "unimodally" (using sign only) and then asked to recall whatever they could remember.

A within-subjects analysis was used to examine the differences in recall scores as a function of communication mode. Analysis of secondary variables was included to note effects on the dependent variable. Mode of participants' response was also coded and analyzed. Results of the study showed statistically significant differences in the mean story-retell scores between the two conditions, with participants scoring higher during the sign-only condition than in the SIMCOM condition. Age, gender, pure-tone average, type of hearing-assistive technology (hearing aids or cochlear implants), and home language did not affect overall retell scores, except

that older students performed slightly better than did younger students. Standardized reading scores were strongly correlated with retell scores in both conditions, suggesting that these students had higher overall language skills. Most participants responded using a sign-only mode, and this was taken to mean that sign only was the dominant mode for these participants.

These results provide support for the idea that for these deaf participants, simultaneously received speech and sign messages may have compromised comprehension by competing for limited attentional resources. In this study, attempts at comprehension of SIMCOM may be evidence of the redundancy principle, which states that attention is split when the same information is presented in multiple modalities. Continued research on deaf students' ability to integrate simultaneously presented auditory and visual language is suggested.

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Chapter 1

Introduction to the Study

Much learning occurs in social contexts through interaction with other people and is facilitated when individuals are able to communicate with understanding. A commonly used mode of communication for instruction in schools for deaf[1] children in the United States is a bimodal form of signs and speech referred to as "simultaneous communication," or SIMCOM. Simultaneous communication makes use of spoken language and signed language presented simultaneously toward the goal of providing both auditory and visual access to the rule systems of English needed to support the development of literacy skills (Hyde & Power, 1991). Although this mode has been predominant in schools and programs for deaf students for the past 50 years, empirical evidence of its effectiveness toward increased academic achievement is not overwhelming (Lederberg, Schick, & Spencer, 2013; Mayer, 2007; Nicholas & Geers, 2003).

This study used a story-recall task and a within-subject design to compare deaf children's comprehension of stories presented in SIMCOM with their comprehension of stories presented in American Sign Language (ASL), which is the visual, gestural language of the deaf community in the United States. Story recall, like language production in general, relies on the ability to maintain and actively integrate linguistic information in working memory (Dodwell & Bavin, 2008; Swanson & Berninger, 1996). According to Cornish (1980), a story-recall task is considered to be a measure of verbal working memory and was used here to explore whether SIMCOM overloads working memory to the point where comprehension of a message is compromised. The following section provides background describing these two modes of communication in deaf education and the rationale for and inherent challenges presented by each

[1] In this study, deaf refers to those individuals with a hearing loss of 70 dB or higher.

mode. It also sets the context of the study within the framework of cognitive information processing, cognitive-load theory, and working memory.

Background

The territory. The deaf and hard-of-hearing population is diverse. Wide variations are found in the cause of deafness, level of hearing, age at onset, communication methods, and cultural identity. The term *Deaf* (capitalized) refers to a community of people who share a language (ASL) and hold a set of beliefs about themselves and their connection to greater society (Padden & Humphries, 1990). The noncapitalized form, *deaf*, is an audiological term used to refer to individuals whose level of hearing interferes with their ability to process speech and language (World Health Organization, 2015). These individuals are considered to have severe to profound deafness based on the pure-tone average (PTA) in the better ear of both unaided ears. The term *hard of hearing* is used to refer to individuals with mild to moderate hearing loss. Because aspects of this study address hearing function and other audiological notions related to cognitive and language development as opposed to cultural elements, the noncapitalized term *deaf* will be used throughout.

Deafness is a condition that interferes with the auditory processing of sound and therefore with the development of spoken language. Language competency can significantly affect children's development of social and cognitive skills, and this is particularly true for deaf children, who consistently lag behind their hearing pears in most areas of academic achievement (Schick, de Villiers, de Villiers, & Hoffmeister, 2007). During the past 10 years, the universal screening of hearing in newborns, along with the development of digital hearing aids and cochlear implants, has had a measureable impact on the progress of children with hearing loss

(Busa et al., 2007; Harris, 2015; Spencer & Marschark, 2010). Current research notes considerable improvements for some deaf children in receptive and expressive spoken language following early identification, early intervention, and the use of new technologies in hearing amplification (Geers & Hayes, 2011; Geers, Nicholas, & Sedey, 2003; Harris et al., 2013). Some improvements have also been observed in literacy (Geers & Hayes, 2011). Nevertheless, the development of reading and writing skills remains a major challenge for most deaf children because they still may not have full access to spoken language (Kyle & Harris, 2010), even with cochlear implants (Connor & Zwolan, 2004) or hearing aids (Arehart, Sousa, Baca, & Kates, 2013; Banerjee, 2011). As noted in the research, individual trajectories vary significantly (Arfé, Dockrell, & Berninger, 2014; Geers, 2003; Geers & Hayes, 2011; Harris & Moreno, 2004; Kyle & Harris, 2010) for both cochlear-implant and hearing-aid users.

Signed language. For deaf children who do not benefit enough from amplification alone, an approach to communication involving sign language or sign-supported speech may be more appropriate. In this study, the term *sign language* is used to refer to the manual representation of language, relying on the use of signed vocabulary and syntax to represent concepts. The sign language used by the deaf community in the United States, ASL, not only has its own vocabulary but also its own grammar and is completely distinct from spoken English. A separate system, sign-supported speech, involves voicing, as in spoken English, while simultaneously signing a form of manually coded English. The syntax and pragmatics of English are used, with some signs being borrowed from ASL and others invented by educators of the deaf (Akamatsu & Stewart, 1998). The term *sign-supported speech* is often used interchangeably with simultaneous communication (SIMCOM), which is the term used in this study.

Differences between ASL and SIMCOM. It is important to differentiate SIMCOM from ASL, a natural language produced on the hands with signs that correspond roughly to words in a spoken language. The sequence in which signs are produced communicates syntactic information, just as in spoken languages. Facial expressions and body movements also are used to convey syntactic information. For example, asking a question in spoken English could be indicated by a rising pitch in voice, transformed word order, or use of an auxiliary verb, whereas in ASL a question is indicated by rising eyebrows, widening eyes, and a forward body tilt.

Another feature of ASL is its use of space. For example, when telling a story in ASL, the signer would introduce characters and then assign each to spatial locations around the body. These characters are then referred to with a point gesture, rather than repetition of the character's name.

A third important feature of ASL is its use of simultaneous elements as opposed to the temporal aspects of spoken language production. Basic signs can be inflected by accompanying body movements instead of using additional words. For example, the English sentence, "*You give her the book*," would be indicated using the sign for BOOK and a single motion across the torso. Because sign-language syntax is spatial rather than temporal, it is not possible to coherently speak a language like English while signing (Bellugi & Fischer, 1972).

Lastly, and also related to spatial elements of sign language production, is the fact that ASL does not have equivalent signs for many function words in English, such as pronouns (e.g., *he*, *she*, *it*), determiners (e.g., *this*, *that*, *a*, *an*, *the*), prepositions (e.g., *in*, *on*, *under*), or certain auxiliary verbs (e.g., *am*, *are*, *has*, *could*). These groups of words have little lexical meaning on their own and are mostly used to express grammatical relationships with other words in a sentence. In ASL, internal morphological changes to a sign (changes to movement or handshape) and referencing gestures are used to indicate this linguistic information.

SIMCOM, on the other hand, is best understood as a signed code for English (Meier, 1991; Wilbur, 1987). Signs, mostly borrowed from ASL, are arranged in English word order, together with artificial signs created to represent the function words and inflectional morphemes of English (Stewart, 1993; Stokoe, 1975). To use the example noted above, the English sentence, "*You give her the book*," would be conveyed by five different signs (one for each word), presented one after another in temporal sequence accompanied by speech. SIMCOM incorporates signs but not embedded in the visuospatial grammar of a true signed language. Instead there is a one-to-one match for spoken English. In this way SIMCOM is considered to be more of a sign system than a language (Akamatsu & Stewart, 1998).

Sign language and literacy. Because ASL uses handshapes and body movements instead of sound, receivers use their eyes instead of their ears to understand what is being said. Furthermore, because all linguistic information must be received through the eyes, the language is carefully structured to fit the needs and capabilities of the eyes and is especially suited for those who rely on the visual modality (Stokoe, 1975). Because sign languages bypass the impaired auditory channel, proficient deaf signers may have more extensive sign-language skills than nonsigning deaf individuals. However, this does not in itself support the process of reading because the written script is based on English, not ASL. Whereas hearing children (and oral deaf children) first learn English as a spoken language and then transfer skills and knowledge from spoken English to its written form, ASL users must acquire a new orthographic code and also a different language because there is no written equivalent of ASL (Musselman, 2000).

It is widely acknowledged that many deaf children have difficulties in their literacy development due to challenges accessing the spoken language upon which reading is based (Lederberg et al., 2013; Mayer, 2007; Nicholas & Geers, 2003). Sign-supported speech systems were specifically developed to address this problem. SIMCOM attempts to represent the syntactic structure of spoken English in a manual form while also delivering the speech signal. The intention is that deaf children can learn the structure and phonology of the English language not only through amplified sound and speechreading patterns of spoken English, but also through manual patterns of signed English (Akamatsu & Stewart, 1998; Akamatsu, Stewart, & Mayer, 2002).

Rationale for and concerns about SIMCOM. When sign-supported speech systems were developed in the 1970s, the anticipation was that SIMCOM would serve two purposes by providing a spoken signal for those children who benefitted from amplification and a signed, visual signal for those who did not. The basis in English word order was also meant to facilitate acquisition of reading and writing skills (Bornstein, 1973; Coryell & Holcomb, 1997; Lederberg et al., 2013). The specific intention of SIMCOM is that the words that are signed and the words that are spoken occur simultaneously, following typical English word order, and this exact combination of visual and auditory modalities is used to justify its suitability in providing access to elements of both spoken and signed languages (Coryell & Holcomb, 1997). Combining the modes was expected to have a synergistic effect (Akamatsu & Stewart, 1998). In practice, though, the very nature of the two modes (spoken and manual) often causes users to alter their messages to accommodate one mode or the other, causing a compromise in the message as a whole (Luetke-Stahlman, 1988; Wilcox, 1989). SIMCOM users, usually hearing teachers, will either slow their speech in order to sign every word or eliminate important function words, morphemes, and inflections in attempts to maintain signing speed and voice rate (Luetke-Stahlman, 1988; Marmor, & Petitto, 1979; Maxwell & Doyle, 1996). The artificial nature of SIMCOM (contrary to a natural language) in combining two languages is criticized by some researchers as unnatural and stilted and believed to lead to an impoverished or incomplete language system for many children who are deaf or hard of hearing (Baker, 1978; Johnson, Liddell, & Erting, 1989; Marmor & Petitto, 1979). SIMCOM, they point out, is actually a hybrid of two languages in that it combines parts of spoken-language structure and parts of signed-language structure.

Marmor and Petitto (1979) suggest therefore that SIMCOM does not possess the full grammar of either of the two languages from which it is derived. Furthermore, they note that languages are not typically described by modality and are not expressed simultaneously. Critics note that it is impossible to accurately model two languages when they are mixed. As previously noted, when ASL, with its visuospatial grammar, is combined with English (an auditory, vocal, linear, sequential language), speech can be slowed. The quality of ASL is also altered. Linguistic principles of English and ASL are violated. In linguistic terms, whether a language is spoken or signed, it must be governed by rules. It is argued that the rules governing both spoken language and signed language are compromised when they are used simultaneously.

SIMCOM and working-memory load. It has been suggested that SIMCOM is more than mere simultaneous production of a language in two modalities and that it actually imposes unique and complex processing demands on its users (Baker, 1978; Maxwell, 1990). This notion invites valid questions. Can one actually speak and sign every aspect of a language at the same time without one mode having a dominant or negative effect on the other? What about the processing demands for the receiver? Is it possible for a receiver to successfully integrate simultaneously produced speech and sign-signal sequences without experiencing cognitive overload?

The working-memory capacity of profoundly deaf children is smaller than that of hearing children (Burkholder & Pisoni, 2003; Pisoni & Cleary, 2003; Pisoni & Geers, 2000). Language comprehension requires working memory skills. Deaf children who use cochlear implants or digital hearing aids may have access to some sounds, but these sounds may still be distorted (Arfé, Rossi, & Sicoli, 2015; David & Hirshman, 1998). By expecting deaf children to simultaneously "listen to" degraded sound signals, while watching signed messages within complicated syntax, are we creating a cognitive load that is too high for comprehension processing? This experiment attempts to answer these questions.

Statement of the Problem

Many deaf children in the United States are educated in environments where SIMCOM is the primary mode of instruction (Gallaudet Research Institute, 2011). SIMCOM incorporates the use of spoken language and sign language presented simultaneously. This requires the receiver to process auditory and visual linguistic information at the same time, possibly leading to cognitive overload and, therefore, reduced comprehension. Individuals have limited capacity to retain and process information. One proposed explanation for this observation is that SIMCOM may result in competition between speech and manual communication for limited attention and processing resources in working memory, both of which are assumed to play major roles in language comprehension (Baddeley, Gathercole, & Papagno, 1998). Little research has been conducted on deaf children's comprehension of simultaneous communication, and even less has been done regarding the effects of presentation mode under the increased sound awareness provided by cochlear implants and digital hearing aids. It is suggested here that while attempting to process sound and sign at the same time, the sound signal may actually be a distraction. This study compares comprehension of language and working-memory function under two conditions (SIMCOM and sign only) to investigate the effects of mode of communication.

Need for the Research Study

A few research studies have been conducted on the use of bimodal communication systems in the classrooms of deaf learners, particularly teachers' attempts to deliver a coherent signed representation of English (Akamatsu et al., 2002; Marmour & Petitto, 1979; Mayer & Lowenbraun, 1990; Strong & Charlson, 1987). However, even fewer research studies have empirically explored how deaf students respond to these different communication modes (Hatfield, Caccamise, & Siple, 1978; Oullette & Sendelbaugh, 1982; Power, Hyde, & Leigh, 2008; Stewart, 1987), particularly SIMCOM and sign only, which are the focus of the current study. Research on the effects of communication mode on deaf children's learning has the potential to improve instructional practice and language policy for those students. The manner in which learners distribute their visual and auditory attention resources during a learning task is of interest to educators. Research on deaf students' ability to integrate simultaneously presented auditory and visual language also has the potential to increase our understanding of working memory and human information processing. In SIMCOM, is visual and auditory information synergized, or do learners have to shift their attention between the two sources? Does one of the sources serve as a distraction? Noting the limited and conflicting research in the area of SIMCOM, Hamilton (2011) has called for further research and reconsideration of the use of SIMCOM. This study responds to that call. This study also aims at investigating SIMCOM in relation to cognitive-load theory, a theory of instructional design stating that the quality of learning will be increased if consideration is given to the role and limitations of working memory (Sweller, 1988).

Purpose of the Study

This study used a story-recall task and a within-subject design to compare deaf children's comprehension of stories presented in SIMCOM with their comprehension of stories presented in ASL. The purpose of this study was threefold. The first aim was to note any effects of age, gender, reading ability, home language, PTA, or use of hearing-assistive technology (hearing aids or cochlear implants) on deaf children's story-recall performance. The second aim was to explore the effects of mode of communication on deaf children's story-recall performance. The third aim was to investigate whether the mode of participants' responses was influenced by the mode of presentation. The dependent variable in the study was the score on the story-recall task used as a measure of working memory. The independent variables were the two modes of presentation (SIMCOM and sign only). Covariates (age, gender, reading ability, home language, and use of hearing-assistive devices) were explored to note any effect on the dependent variable.

Research Questions

This study is guided by the following research questions:

1. Are there factors that affect the relationship between communication modes and story-retell scores? Specifically, will gender, age, PTA, standardized reading scores, home language, or type of hearing-assistive technology correlate with retell scores?

2. Does communication mode affect story-recall scores for deaf students? Specifically, is there a difference in story-retell scores when the story is presented in SIMCOM versus sign only?
3. Does the mode of presentation affect the mode of response? Specifically, will participants choose and maintain one mode of response regardless of the mode of presentation, or will they match the mode of response to the mode of the presentation? Is there a difference in scores among participants who respond using sign only or SIMCOM or for participants who switch modalities?

Significance of the Study

This study questions whether current assumptions about the efficacy of communication modes used with deaf learners are consistent with available research and thus has the potential to guide communication policy in schools for the deaf. According to theories of instructional design (Sweller, 1988), learning happens best when teaching methods are in line with human cognitive architecture. The use of SIMCOM has theoretical implications related to attention, memory, and cognitive load. Overload occurs when working memory has to process too much information too fast, which may be the case when deaf learners are presented with sign and speech signals all at once for extended language-based tasks. This study offers some empirical evidence that can be used to understand the learning needs of deaf children and create more effective learning environments for them.

Nature of the Study

This section reviews the rationale for the chosen theoretical framework through the lens of the dependent variable, the story-recall task. It reviews the ways in which the dependent measure has been explored in other studies with other populations and identifies other variables it has been used to evaluate. This section closes with a brief review of the study design and data-analysis procedures.

The theoretical underpinnings for this study are framed by cognitive information-processing and its proposed three-component memory system. *Story recall* is defined here as the process of generating a narrative from memory that represents a previously experienced verbal representation of an activity or event (Adams, Smith, Pasupathi, & Vitolo, 2002). Retelling a story immediately after hearing it involves verbal working memory that stores verbatim information for a brief period (Baddeley, 1998); long-term episodic and semantic memory (Tulving, 1972); and language-comprehension ability to processes phonological, morphosyntactic, semantic, and pragmatic aspects of language (Poulsen, Kintsch, Kintsch, & Premack, 1979). Because participants had to both store and manipulate information over a brief period, working memory is particularly referenced (Dodwell & Bavin 2008; Swanson & Berninger, 1996).

In this study, participants were presented with two sets of stories under two conditions. In one condition they were required to watch, process, and then reconstruct stories from a sign-only presentation; in the other condition, they were required to simultaneously watch and listen to, process, and then reconstruct spoken language as well as sign language (SIMCOM). In this way, the study also investigates cognitive load, described by Mayer (2001) as the cognitive complexity a task presents to an individual and the total amount of mental activity imposed on working memory during the internal processing of that task. It is assumed here that the SIMCOM condition induces more cognitive load than does the sign-only condition because the SIMCOM condition not only requires attention to competing signals but also imposes an increased temporal, sequential load on the message that is not present in the sign-only condition.

Story-recall performance has been studied in various populations, including children with attention-deficit/hyperactivity disorder (Lorch et al., 1999), learning disabilities (Copmann & Griffith, 1994; Griffith, Ripich, & Dastoli, 1986; Ripich & Griffith, 1988), intellectual disabilities such as Down syndrome (Bacon & Rubin, 1983; Loveland, McEvoy, Tunali, & Kelley, 1990; Luftig & Greeson, 1983; Tager–Flusberg & Sullivan, 1995), and language impairment (Merritt & Liles, 1987; Paul & Smith, 1993; Purcell & Liles, 1992). To the author's knowledge, only two published story-recall studies have evaluated the effects of communication mode in deaf children (Stewart, 1987; Tevenal & Villanueva, 2009).

Several variables have been found to affect story recall in typically developing children, including previous knowledge of story schema, existence/nonexistence of causality within the story, constructive memory related to a child's prior knowledge (Greenhoot, 2000), and language comprehension. Most of that research has been done in typically developing children (Davidson & Hoe, 1993; Hudson & Nelson, 1983). Other factors that have been shown to influence story recall include age (Gathercole & Baddeley, 2014), reading ability (Gathercole & Baddeley, 2014), home language (Hammer et al., 2012), and possibly gender (Pauls, Petermann, & Lepach, 2013). Although story-recall ability has not been widely studied in children with hearing loss, its nature as a language task is also assumed to be strongly associated with level of hearing loss and use of hearing-assistive technology (Lederberg et al., 2013). Thus, potential factors that may correlate with retell scores in this study include gender, age, PTA, standardized reading scores, home language, and type of hearing-assistive technology.

To explore the relationship between communication modes and recall ability, a within-subject, posttest-only design was used, where each participant's performance is measured by the score obtained after each experimental condition (SIMCOM/sign only). The dependent variable was the score on the retell task, and the independent variable was the communication mode (SIMCOM/sign only). This research design was chosen because it takes into account that the scores will be correlated, and it effectively equates the participants under the two conditions (modes) so that individual difference, the single largest contributing factor to error variance, is eliminated. In this design, participants serve as their own control on the variables of age, gender, home language, PTA, and type of hearing-assistive device. The rationale for the design is explored in greater detail in Chapter 2.

For research question 1, correlations between SIMCOM and sign-only scores with students' ages, standardized reading scores (Stanford Achievement Test, Verbal–Hearing Impaired; SAT-HI) and PTA were examined using the Pearson correlation test. Independent sample *t* tests were conducted to examine whether SIMCOM and sign-only scores were associated with gender or use of cochlear implants or hearing aids. One-way ANOVA was conducted to examine the relationship between SIMCOM and sign-only scores with home languages (Spanish, Chinese, Russian, English, or ASL). For research question 2, a repeated-measures ANCOVA was used to determine whether a statistically significant difference exists between the mean retell scores under the sign-only condition and those under the SIMCOM condition. For research question 3, a categorical coding scheme was developed to code responses, and qualitative comments are offered. A one-way ANCOVA was conducted to examine differences in SIMCOM recall scores as a function of response-mode category, while controlling for SAT-HI scores.

Organization of the Study

Chapter 1 presented the introduction, background, statement of the problem, need for the research study, purpose of the study, research questions and hypotheses, significance and nature of the study. Chapter 2 contains an in-depth review of related literature and research. The methodology and procedures used to gather data for the study are presented in Chapter 3. The results of analyses and findings from the study are contained in Chapter 4, and Chapter 5 contains a summary of the study results, conclusions drawn from the findings, limitations of the study, and recommendations for further research.

Chapter 2

Literature Review

The purpose of this study was to examine the effects of communication mode on the story-recall abilities of a sample of deaf children. A within-subject design was used to compare participants' story-recall scores when the story was presented in a sign-only mode with those when the story was presented in a SIMCOM mode to note which mode produced better results. The theoretical framework guiding this study is Baddeley's (1998) model of working memory, supplemented by concepts from cognitive-load theory (Sweller, 1988). The literature review is organized into three major sections. The first section describes the concept of working memory as a limited-capacity system, reviews studies of working-memory functioning in deaf individuals, and explores the role of verbal working memory in language acquisition and processing. This section also presents the rationale for the use of a story-recall task to measure working memory in deaf children. The second section addresses issues of cognitive load as may be experienced in simultaneous-communication exchanges along with potentially related research. The third section examines previous research related to use of simultaneous communication in educational settings with particular focus on redundancy effects, split-attention effects, and dual processing of stimuli. The results of the literature review formed the basis of the current experiment, which is presented in Chapter 3.

Working Memory

The theoretical framework for this study is the model of working memory originally developed by Baddeley and Hitch (1974) and then extended by Baddeley (2000). It defines working memory as a multicomponent, limited-capacity system responsible for temporary storage and manipulation of incoming information over short periods to facilitate other cognitive tasks (Baddeley, 1998). Within this model a central executive works to control attention while coordinating three subordinate systems and integrating information that enters the system through them. The phonological loop processes auditory-linguistic information, and the visuospatial sketchchpad processes visual/spatial information. The third subsystem, the episodic buffer, is thought to temporarily integrate incoming stimuli (information heard and information seen) with long-term memory, producing a single, complex representation or episode. This component has been far less researched than the others (Baddeley, 2000, 2007). Working-memory functioning in deaf children has been studied with implications at each stage and component of the memory system. These are described next.

Working memory for speech stimuli. The phonological loop, referred to as verbal working memory, consists of a storage area and an articulatory rehearsal process that maintains speech traces that deteriorate rapidly (Baddeley, 2000). In the phonological store, information is held temporarily in a speech-based form, where it is either recognized or forgotten (Baddeley et al., 1998). If the stimulus is recognized, it is either assigned meaning and used for the task at hand, or stored in long-term memory. Although capacity of the phonological loop is typically assessed by serial recall tasks involving arbitrary verbal elements such as digits and words, verbal working memory is closely associated with cognitive skills that play a role in language development, such as phonological awareness, word learning, and sentence processing (Baddeley et al., 1998). Verbal working memory is what allows babies to learn the speech sounds, lexicon, syntax, and prosody of their native language. With deafness, the auditory channel for receiving vocal information is compromised. The signal received may be incomplete, or the sound may be distorted. Studies of performance on verbal tasks in deaf children who use cochlear implants or hearing aids show that they have difficulties in phonological-loop functioning. Deaf children appear to have slower subvocal rehearsal and less developed rehearsal strategies (Burkholder & Pisoni, 2003; Pisoni & Cleary, 2003). This limits the child's ability to maintain active verbal information in working memory (Geers, Brenner, & Tobey, 2011; Pisoni & Cleary, 2003). The researchers associate these deficits with deaf children's reduced speech perception, reduced articulation speed, lower expressive and receptive syntactic skills, and overall weak reading skills (Burkholder & Pisoni, 2003; Harris et al., 2013; Pisoni & Cleary, 2003).

Working memory for signs. Some deaf individuals, particularly those who are able to benefit from hearing-assistive technology, use a speech-based code for certain verbal memory tasks (Burkholder & Pisoni, 2003; Pisoni & Cleary, 2003), but prelingually deaf individuals who use ASL or other forms of signed communication are noted to use a sign-based code for short-term encoding of linguistic information (Wilson & Emmorey, 1997, 1998, 2003). It was once thought that deaf signers relied on the visuospatial sketchpad for linguistic memory. However, in terms of memory and cognition, signed language is verbal and at the same time visuospatial. Thus, it is not easily explained in terms of modality-specific models of cognition.

In studies of deaf signers' immediate recall of signs, Wilson and Emmorey (1997, 1998, 2003) found that working memory for sign language displayed parallel effects of phonological similarity and word length (Wilson & Emmorey, 1997, 1998) associated with the phonological loop. They proposed a sign-based phonological loop (sign loop) in deaf signers, analogous to hearing speakers' speech-based phonological loop. The sign-based phonological loop, they claim, comprises two components: a phonological store to hold sign-based phonological stimuli (e.g., handshape, hand orientation, location, movement) and a manual articulatory rehearsal mechanism that refreshes information in the phonological store (Wilson & Emmorey, 2000). Regardless of whether or not a sign loop exists, the organization of working memory for sign language does not seem to support temporal information in the same way as working memory for speech (Colombo, Arfé, & Bronte, 2012; Hamilton, 2011; Harris & Moreno, 2004; Wilson, Bettger, Niculae, & Klima, 1997).

Multiple studies have compared deaf signers with hearing speakers in terms of linguistic memory span and nonlinguistic spatial memory span. It is well documented that in tasks of digit, word, and letter span, deaf signers' signed-language memory span is significantly shorter than speakers' spoken-language span (Bavelier, Newport, Hall, Supalla, & Boutla, 2008; Boutla, Supalla, Newport, & Bavelier, 2004). Explanations that have been offered for the discrepancy between sign and speech capacity are that signs take longer to articulate than speech (Wilson et al., 1997; Wilson & Emmorey, 2006); speech-based encoding leads to a larger serial memory span than does sign-based encoding (Hall & Bavelier, 2011); visually encoded information decays faster than speech-like information (Boutla et al., 2004); and visual encoding is less effective than auditory encoding in maintaining serial-order information (Bavelier et al., 2008; Boutla et al., 2004).

Each of the above explanations for the difference between deaf and hearing children's working memory span is particularly significant in an examination of simultaneous communication where speech and sign are used concurrently. One of the concerns in the practice of SIMCOM is the different rates of speech and signing articulation. For example, Bellugi and Fischer (1972) calculated the rate of speech articulation alone as approximately twice the rate of signing articulation alone. When speech and signing are produced simultaneously, the rate of speech articulation averages 1.65 times faster than that of signing.

Consequently, the production of SIMCOM requires producing simultaneous sign and speech, which might lead people to delete or incorrectly code signs and, in turn, represent English inadequately.

Baker (1978) empirically compared the communication rate of SIMCOM with that of sign only. Fourteen adult signers (10 deaf, 4 hearing) participated in the study. Participants were videotaped in pairs when conversing on two prearranged topics, one in SIMCOM and one in sign only. The research found that, when using SIMCOM, hearing signers maintained a higher speaking rate than did the deaf signers, but with a decreased signing rate that substantially deleted signed information, whereas deaf signers had a slower speaking rate but either maintained or increased their signing rate with considerably fewer omissions of signed information.

Numerous subsequent studies (e.g., Huntington & Watton, 1984; Strong & Charlson, 1987; Swisher, 1984) confirmed the considerable number of sign omissions and/or reduced speech made by hearing people (mainly teachers or parents) and suggested the cause as the cognitive requirement of continuous thinking about the content of the conversation and how to encode thoughts into different channels, while simultaneously expressing them into these two channels—that is, cognitive and productive overload. If SIMCOM is difficult for hearing teachers to produce, imagine the processing demands on the receivers. Taking into account that deaf children exhibit many differences/deficits in verbal working memory, how might these deficits influence their language processing and comprehension experiences? This area is explored next.

Working memory and language comprehension. In learning any language, whether spoken or signed, a principal task is to distinguish the distinct symbols of the language from the stream of sound or signs presented (Felser & Clahsen, 2009; Hirsh-Pasek & Golinkoff, 1996). An utterance is experienced temporally as a sequence of phonemes forms a word, and a sequence of words or signs forms a sentence. Language comprehension requires maintenance of words and signs received earlier as new words/signs are still arriving. Thus, language comprehension must involve a temporary storage of the linguistic information. In language comprehension, whether spoken or signed, the phonological loop maintains incoming linguistic information active in memory for the time necessary to accumulate all the elements of the message while the central executive system maintains attention to the stimulus. Another role of the central executive is that of distributing memory resources when task demands increase or when attentional and memory resources must be distributed among different tasks, for example, rehearsing words and organizing words in sentences or transcribing a sentence while holding its elements in memory (Acheson & MacDonald, 2009; Baddeley, 2007).

This central executive component of working memory uses executive functions and is typically assessed by more complex working-memory tasks, such as listening- or reading-span tasks or a story-recall task, as was used in this study. These tasks involve the processing of sentences as well as the temporary storage of single words/signs (Conway et al., 2005). The central executive enables the working-memory system to selectively attend to some stimuli and ignore others. The central executive component is particularly important when one is engaged in a task that requires both attention to and coordination of visual and auditory stimuli, as is the case with SIMCOM (Baddeley, 1998). How does the central executive function during a SIMCOM experience? Does the central executive work to integrate the two incoming modalities, or does one modality act as a distractor? Can one modality serve as the primary mode of input while the secondary mode acts as a supplement? Language production is also dependent on working memory (Dodwell & Bavin, 2008; Swanson & Berninger, 1996), particularly in a story-recall task, where the participant must hold elements of the original story in mind while constructing the retell. These questions are explored in this experiment.

Assessing working memory. Working-memory capacity, or span, is measured in terms of ability to simultaneously store and process information and is a particularly important concept when it comes to language comprehension. Simple span tests, such as digit or list recall, mainly display storage functions in working memory and assess ability of general memory, but not comprehension of connected language. Verbal working memory significantly influences the language performance of children with hearing loss (Burkholder & Pisoni, 2003; Harris et al., 2013; Pisoni & Cleary, 2003). Yet previous studies have been limited mainly to exploring the contribution of working memory using simple language such as word/sign list recognition, receptive vocabulary, and sentence comprehension (Colombo et al., 2012; Harris et al., 2013; Pisoni & Cleary, 2003). Only a few studies have explored the role of deaf children's working memory in more complex verbal tasks, such as story recall (Stewart, 1987; Tevenal & Villanueva, 2009). The current study aims to fill this gap and examines the contribution of linguistic memory skills to deaf children's ability to pay attention to, comprehend, and then retell a story that is presented in two different modes.

Story recall requires significant linguistic abilities at the word, sentence, and connected-discourse levels (Dodwell & Bavin, 2008; Duinmeijer, de Jong, & Scheper, 2012; Swanson & Berninger, 1996). A story-recall task assesses the ability to hold new information in short-term memory, concentrate, and manipulate that information to produce a retell. A story-recall task can tap concentration, planning ability, cognitive flexibility, and sequencing skill, but may also be sensitive to the mode of presentation, which is what this study examines. In the SIMCOM mode, not only must the participants capture the information that is presented visually and auditorily, but they must also retain their own thoughts about the story in a manner that allows effective recall. This ability is challenged further in deaf children, who have less working-memory capacity. Use of multiple channels may increase the amount of information that the brain can process (van Merriënboer & Sweller, 2005), but the risk of cognitive overload remains. Too much information delivered in an ineffective manner can interfere with the brain's ability to successfully integrate information in a way that is usable. This idea is explored in the next section.

Overall working memory refers to the cognitive system responsible for temporary storage and processing of incoming information. Storage and processing functions share the same limited fund of resources during comprehension. Storage during language comprehension involves the ability to hold onto verbal information, whether signed or spoken, while also operating on the same information to understand the unfolding message. The working-memory model centers on the ultimate compromise between storage and processing of information when the amount of resources is surpassed by the demands of the task. If incoming language stimuli are grammatically complex or, as in this study, delivered through two modes simultaneously, some resources allocated to maintaining information in storage may be shifted to comprehension, leading to forgetting some or all of previously processed information.

Cognitive-Load Theory

Cognitive load is a theoretical construct describing the extent to which cognitive resources, especially working memory, are utilized during learning, problem solving, thinking, and reasoning (Mayer, 2001). As described previously, stimuli are received from the environment through the senses and pass into working memory, where they are either processed or discarded. The biggest limitation of working memory is its capacity to deal with only about 7 (±2) pieces of auditory information simultaneously and about 5 (±1) pieces of visual information simultaneously (Miller, 1956). If the capacity of working memory is exceeded while processing a quantity of information, some, if not all, of that information may be lost. The major factor that contributes to cognitive load is the number of elements that require attention. Generally speaking, as memory load increases, performance decreases (Denh, 2008).

Sweller et al. (Sweller, 2011; Sweller, van Merriënboer, & Paas, 1998) have developed a body of research literature and a theory about the role of cognitive load in learning and education, which has become known as the cognitive-load theory. The theory centers around the idea that the format of an instructional presentation has a direct effect on the performance of the learners and that the quality of instructional design will be increased if greater consideration is given to the role and limitations of working memory (Sweller, 2011).

Since the 1980s, educational researchers have applied cognitive load theory in their theoretical and empirical work on issues such as transfer of learning, memory, instructional design, and measurement of cognitive load. At the present time, cognitive-load theory has been applied primarily to multimedia learning and online instruction. This theory has rarely been applied to deaf education, and much of that work has focused on the use of captioned lectures and sign-language interpreters in the classroom (Yoon & Kim, 2011; Mather & Clark, 2012; Mayer, Lee & Peebles, 2014). To the author's knowledge, no studies have applied the principles of cognitive-load theory to explorations of communication mode in classrooms for deaf children.

Types of cognitive load. According to the literature, cognitive load can be subclassified into intrinsic, extraneous, and germane cognitive load (Mayer, 2001). Intrinsic cognitive load is an inherent quality of the material presented to a learner based on its difficulty. For example, for the average person, the cognitive load involved in listening to an explanation of nuclear physics will be much greater than that involved in listening to a short story about a trip to the zoo. In the current study, the intrinsic load was the conceptual content of the stories presented for recall (see Table 3.2). It included a specific lexicon and set of concepts relayed by the syntactic constructions. It was assumed in this study that participants would be familiar with most of the vocabulary in the stories, as well as the scenarios in which the vocabulary was embedded and, thus, the intrinsic cognitive load was considered to be low.

Extraneous cognitive load is generated by the manner in which information is presented to learners. This kind of load is under the control of those who design learning experiences. In the current study it is assumed that, in the sign-only condition, load will be lower than in the SIMCOM condition because the first condition calls for processing of a visual signal alone while the latter condition entails the processing of two stimuli simultaneously. It is hypothesized here that the need to simultaneously integrate two verbal modes, one visual and one auditory, will distract from learning because they may require listeners/receivers to split their attention. In cognitive-load theory, the higher the intrinsic and extraneous load, the less capacity remains in working memory for germane cognitive load, which is the third subcategory. Germane cognitive load constitutes the remaining available cognitive resources, or the cognitive load that participants need to process and comprehend material, form and/or automate schemata, and produce a response. In this study, germane cognitive load is needed to formulate the story recall, which is the measure of working memory.

Related research in cognitive load. Cognitive psychology distinguishes between focused attention (the processing of a single input) and divided attention (the simultaneous processing of multiple signals) (Clark, Nguyen, & Sweller, 2006). The manner in which instruction is designed can inadvertently increase cognitive load (Chandler & Sweller, 1992). In an experiment with hearing college students recruited from the Psychology Subject Pool at the University of California, Santa Barbara, Mayer, Heiser, and Lohn (2001) noted what Mayer referred to as a redundancy effect on learning. This effect refers to the phenomenon in instruction that occurs when identical information is given in two or more forms, such as pictures/animation, on-screen text, and audio. If one of these forms is redundant, eliminating the redundancy may enhance learning. The researchers divided 78 hearing participants into two groups, with one group watching an animation explaining the formation of lightning while also listening to narration of the explanation, and a second group watching the animation, with the narration accompanied by on-screen text. The group that received concurrent on-screen captions performed worse on tests of retention and transfer than did the group who received no on-screen text. The measures of retention and transfer were tests created by the researchers and consisted of five items; examinees had to write answers to questions related to the content of the presentation and how it might be applied in problem-solving situations. The researchers explained the redundancy effect as being consistent with a dual-channel theory (Paivio, 1986) as well as Baddeley's sensory-modality model (1998).

The dual-channel theory, as described initially by Paivio (1986) and later expanded by Clark and Paivio (1991), assumes that humans possess separate information-processing channels for visually represented material and auditorily presented material and that each channel has limited capacity. In the experiment by Mayer et al. (2001), one source of information—the on-screen text—was redundant with the spoken narrative. Adding on-screen text overloaded the visual information-processing channel, causing the learners to split their visual attention between two sources (the animation and the on-screen text). We can process two sources of information, but not when they are both verbal. Mayer et al. suggest that, although only hearing students were involved in their research, it is important to study multiple presentation modes in students with hearing loss, because this population may rely more on visual modes of processing.

When learners watch/listen to both written and spoken material, they must ensure that both forms are closely coordinated; otherwise, the information will be disjointed and thus unintelligible (Mayer, 2001). In order to coordinate the two sources of information, limited memory resources will be required and therefore will not be available for cognitive activities that are essential for learning. In contrast, if either the spoken or written text only is presented, the cognitive coordination of the two sources of information is not required, freeing limited cognitive resources for essential learning. In general, any redundant information, regardless of its form (diagram, text, auditory information, presence of equipment), usually requires working-memory resources to process, making these resources unavailable for the cognitive activities required for learning. Applied to the current study, in the SIMCOM condition, participants will receive redundant information in both sign and speech. Will they need to use cognitive resources to ensure that the information from both sources match, as the redundancy principle states, thus compromising the resources need to retain and reproduce the story in the recall task?

In another study on the use and impact of on-screen text, in a video recording of a training lecture where there the text was basically a transcription of the lecturer's speech, Kalyuga, Chandler, and Sweller (2004) found that hearing students learned less material when text appeared than they did when the instruction included only the speaker's voice. In that study, 25 hearing trade apprentices 16 to 19 years of age, all of whom were attending a vocational school in Australia, were randomly assigned to two groups corresponding to two instructional formats. One group was presented with auditory information only, and the second group received auditory presentation along with corresponding on-screen text. After the presentation the participants completed a performance test consisting of multiple-choice questions developed by the researchers and related to the content of the presentation. Test scores showed a significant difference between the two groups, with the group that received auditory information only scoring higher than the group that also received the visual on-screen text. They concluded that the simultaneous presentations of written and spoken text during the presentation imposed extraneous cognitive load and that presenting in one modality only would enhance learning.

In the study by Kalyuga et al. (2004), simultaneous presentation of identical messages in visual and auditory form required the learners to coordinate both sources—the printed subtitles as well as the incoming speech stimuli. Although this is not exactly the case in SIMCOM, parallels in the need to divide attention between a reading (visual) task and an auditory task may be drawn in that they are both verbal stimuli.

Diao, Chandler, and Sweller (2007) have also noted the negative effects of written/spoken text redundancy in second-language learning. When the same text is presented in different modalities, learners must process the sources of information simultaneously and build referential connections between them. Diao et al. suggested that for beginning second-language learners, the listening rate may lag behind the reading rate, resulting in poor auditory-visual correspondence. In SIMCOM, the rates of speech and sign production also have been implicated. Many other studies in educational design note how subtitles increase extraneous cognitive load (Brünken, Plass, & Leutner, 2003; Paas & van Merriënboer, 1993; Paas, van Merriënboer, & Adam, 1994).

To summarize, the redundancy effect occurs when additional information presented to learners results in negative rather than positive effects (Mayer, 2001). According to the cognitive-load theory, the fact that the information is present in more than one form means that the receiver not only has to manage attention distribution, but also has to assign some cognitive capacity to verification of the information between the different sources. This could result in cognitive overload. In SIMCOM the actual intent is that there is duplication of linguistic information presented through two modalities. As in the previously mentioned studies, the competition between the sources may also have a negative effect on comprehension due to potential cognitive overload. In SIMCOM, the same linguistic information is simultaneously presented in speech and in sign. Requiring learners to split their attention among two or more information sources requires learners to expend more effort using working memory to integrate information among sources to make sense of it. Learners must devote more cognitive sources to managing working memory than to learning the information.

The current study elaborates on this issue by investigating the use of speaking and signing simultaneously, possibly inducing the redundancy effect. Does the use of SIMCOM inadvertently create the redundancy effect?

Hearing and hearing-assistive technology. Hearing is a complex process that originates in the cochlea, a tiny shell-shaped organ located inside the temporal bone of the skull and comprised of thousands of microscopic sensory cells. In a typically hearing person, these sensory cells, also referred to as hair cells, respond to acoustic information in the environment and translate it into a neurological code that the brain interprets. Speech is a complex acoustic signal engaging with these sensory cells as it passes through the cochlea. When sensory cells are damaged and/or missing, incomplete and distorted sound arrives at the brain (Flexer, 2011). In these situations, the brain has to work harder to interpret the sound.

When a child with hearing loss still has some access to sound through the cochlea, hearing aids may be used to boost that access. A hearing aid is an electronic, battery-operated device that amplifies sound to improve listening comprehension. It collects sounds from the environment via a microphone, amplifies the sounds, and then directs the amplified signals into the user's ear through a tiny speaker. The working sensory cells in the cochlea then send the sound signals to the auditory nerve. Hearing aids work best if the hair cells in the cochlea are evenly distributed. Newer digital hearing aids work better than do the older analog models because they can isolate different frequencies and provide more or less amplification at a given pitch range, depending on what an individual's audiogram, or hearing profile, shows (Blake & Gordon, 2007; Hornsby, 2013). The problem occurs when there are simply not enough hair cells in the cochlea in a given frequency for the amplified sound to work. If no hair cells are available, no sound will be sent to the auditory nerve, regardless of the level of amplification.

For children with profound hearing loss (few to no working hair cells), cochlear implants may be considered. A cochlear implant consists of an internal and an external component. The internal component is surgically inserted under the skin behind the ear, and a narrow wire is threaded into the inner ear. The external component is connected to the internal component through the skin by means of an external magnetic disk. A microphone at the opening of the ear picks up sound from the environment and funnels it into the speech processor, which translates the acoustic signal into electrical impulses. These impulses are then transmitted directly to the auditory nerve via the transmitter electrode array implanted in the cochlea. The transmitter allows the full spectrum of frequencies to reach the auditory nerve. As long as the entire electrode array is inserted in the cochlea and the auditory nerve is healthy, sound can travel to the brain (Wilson & Dorman, 2009). The manner in which an individual brain handles the signals is more variable (Blake & Gordon, 2007; Kronenberger et al., 2013). If the brain can fully integrate the sound signals into understandable information, the implant is considered to be successful (Geers et al., 2011; Geers & Sedey, 2011)—but this outcome is not guaranteed.

Part of the success of an implant is related to how hard an individual has to work to make the brain learn how to understand the implant. Part depends on how much sound the individual was exposed to before the implantation and how well the brain understood that sound. Part of it depends on how old the individual is at the time of implantation (Boons et al., 2012; Holt & Svirsky, 2008). Those who seem to do best at making sense of implant signals are those who had the most hearing before becoming deaf and those who have had the shortest period of deafness before receiving an implant, including babies and toddlers. Even though they may not have had any hearing before implantation, their brains are so flexible (plastic) that they have less of a challenge learning to interpret the kinds of signals an implant produces. The older a child is at the time of implantation, the harder they have to work to make sense of sounds (Nicholas & Geers, 2013; Sarant, Harris, Bennet, & Bant, 2014; Sharma & Campbell, 2011).

The spectral and temporal information that individuals receive from each type of technology (hearing aid or cochlear implant) is different (acoustic vs. electrical). Although children who use hearing aids and those who use cochlear implants have distinctly different auditory experiences, both require more cognitive work than do hearing children when it comes to processing auditory information (Flexer, 2011; Stiles, McGregor & Bentler, 2011). For typically hearing children, decoding speech is not effortful because it happens automatically. When listening through a cochlear implant or hearing aid, the demand on one’s auditory and cognitive systems to understand speech can increase substantially. Decoding speech in the presence of hearing loss increases cognitive load, possibly making speech understanding less automatic. This would make learning more effortful for children with hearing loss, whether in an everyday environment or in a classroom setting. Deaf adults report that listening fatigue is common (Hornsby, Werfel, Camarata, & Bess, 2014; Stiles et al., 2011), but little research has been conducted on listening fatigue in deaf children (Hicks & Tharpe, 2002).

Hearing-assistive technology and cognitive load. This section of the literature review investigates the impact of hearing loss and current hearing-assistive technology on cognitive functioning in clinical studies. Although Edwards (2014) cites the need for more research in natural settings where users of hearing-assistive technology live, learn, and work, it is important to lay the experimental groundwork. According to Edwards (2014), it is only in the past 10 years that audiological research has begun to develop measures to determine the effect of digital hearing aids and multichannel cochlear implants on cognitive functioning. The auditory information conveyed by a damaged cochlea to the brain is not as clearly specified as the information conveyed by an intact cochlea, requiring increased processing in working memory as linguistic content is decoded (Lunner, Rudner, & Rönnberg, 2009).

In a landmark publication, McCoy et al. (2005) showed that a relationship exists between listening through hearing aids or cochlear implants and other aspects of cognition, particularly memory tasks. This study compared 24 adults (12 with typical hearing and 12 who used hearing aids) in a running-memory task. Both groups had almost perfect recall of the final words of the three-word sets, so the authors inferred that all three words had been correctly identified. Nevertheless, the hearing-aid users recalled significantly fewer of the nonfinal words than did the hearing group. This was true even though both groups were matched for age, education, and verbal ability. Numerous other studies confirm the findings that listening is more difficult through assistive-listening devices (Akeroyd, 2008; Lunner & Sundewall-Thorén, 2007; Souza & Sirow, 2012; Stenfelt, & Rönnberg, 2009). Cumulatively, these results were taken as support for the idea that hearing-aid use contributes to increased cognitive load. If hearing technology use alone contributes to increased load, how might the addition of a visual task further tax cognitive functioning? Studies that integrated both sensory capacities are reviewed next.

Tun, McCoy, and Wingfield (2009) used a dual-attention task to measure listening effort while engaging vision in a group of 48 adults (hearing as well as users of hearing aids). In a dual-attention task, participants were asked to listen to and recall speech materials as a primary task while also conducting a concurrent secondary task. Changes in secondary-task performance between single-task and dual-task conditions, or "cost," were then taken as an indicator of attentional resources assigned to the primary task. The hearing loss is assumed to impose an extra load on processing resources and thus should be reflected not only in the level of speech recall as a primary task, but also as an increase in secondary-task cost. In that study, participants were asked to use a computer mouse to track a randomly moving visual target, while they were also involved in a standard word-recall task. Reaction time on the visual task and ability to recall words were measured. Then the tasks were combined. The researchers noticed that reaction times for the visual task increased when the listening task was added and suggested that the results support the hypothesis that extra effort at the sensory-perceptual level attendant to hearing loss has negative consequences to downstream recall.

Hicks and Tharpe (2002) used a dual task in two groups of children 6 to 11 years of age (14 with mild to moderate hearing loss and 14 with typical hearing). The children were asked to repeat words presented through loudspeakers at 70 decibels (dB) while pressing a button when a probe light appeared. The words were presented in a quiet condition as well as in a simulated-noise condition. The children with hearing loss wore their personal hearing aids. At the end of the simulated-noise condition, the children were asked to rate the level of difficulty they experienced. Although no significant difference in difficulty ratings was found between the groups, the children with hearing loss showed consistently and significantly slower reaction times than did the children with typical hearing. In addition, the children with hearing loss had significantly lower word-recognition scores (primary task) in all conditions than did the children with typical hearing.

Hornsby (2013) also used a dual-task paradigm to assess word recognition, word recall, visual recall, and visual-reaction times to objectively quantify listening effort and fatigue. *Mental fatigue* was operationally defined as a decrement in performance over the duration of the experiment, which lasted approximately 1 hour. Subjective ratings of listening effort experienced during the experiment and ratings of fatigue and attentiveness immediately before and after the dual task were also obtained. The dual-task response times systematically increased over the duration of the speech task and were consistent with development of mental fatigue. Subjective ratings of fatigue and attentiveness also increased significantly after completion of the dual task. Results from subjective and select objective measures suggest that sustained speech-processing demands can lead to mental fatigue in persons with hearing loss.

Stiles (2014), a pediatric audiologist, also noted a relationship between working memory and audiovisual integration occurring in children with hearing loss that does not occur in children with typical hearing. Stiles suggests that children with hearing loss need to use the visual stream of speech more actively for comprehension as they listen, thus engaging with central executive processes like working memory differently than for children with typical hearing. When a sign signal is added, cognitive load is further increased. According to Stiles, researchers are only beginning to look at what implications audiovisual integration, including the use of sign and speech, has for the education and habilitation of children with hearing loss. The current study has the potential to contribute to these understandings.

Rönnberg, Rudner, Foo, and Lunner (2008) developed what they refer to as the "effortfulness hypothesis," described as the extra effort that a hearing-impaired listener must expend to achieve perceptual success. These researchers suggest that this extra effort comes at the cost of processing resources that might otherwise be available for encoding the speech/language content in memory. Subsequently, Rönnberg et al. developed a working-memory model for Ease of Language Understanding (ELU), which proposes that language understanding under taxing conditions is related to explicit cognitive capacity.

Although the studies by Rönnberg et al. primarily explored the relationship between aided speech recognition and cognitive capacity in experienced hearing-aid users, he called for an extension of this research in understanding the role of working-memory capacity in sign language under conditions like SIMCOM, which requires not only the effortful processing of speech but also the simultaneous visual processing of sign language (Rönnberg et al., 2013). Recalling the modality-specific differences relating to processing characteristics of the sensory modalities reviewed in Chapter 1 (i.e., working-memory storage capacity for signs is lower than equivalent storage for speech and there is less temporal organization for signs than for speech), this study proposes that SIMCOM will be specifically associated with increased explicit processing demands. The current study may contribute understandings toward Rönnberg's model.

Taken together, the previously mentioned studies and Rönnberg's ELU, decoding speech in the presence of hearing loss automatically increases cognitive load because an individual must work harder to process the kind of signal produced by the technology they use. This makes learning more effortful for children with hearing loss, whether in an everyday environment or in a classroom setting. In this study the SIMCOM condition not only requires children to process spoken language but also to process a sign-language signal at the same time. It is hypothesized that the effortful processing suggested by Rönnberg et al. (2008) is further taxed by the visual-sign signal.

Studies on the Influence of Speech-and-Gesture Integration on Comprehension Tasks

Some research has been conducted on speech-and-gesture integration, which has produced mixed results regarding the effects of the integration on comprehension. Some studies found that comprehension did not always improve when gestures were added to speech. For example, Krauss, Dushay, Chen, and Rauscher (1995) conducted three experiments to note the extent to which spontaneous gestures added to a spoken message enhance the communicative effectiveness of the message. The three experiments differed in the types of stimulus the speakers described: abstract graphic designs, novel synthesized sounds, or samples of tea. All three experiments used a two-phase procedure. In the first phase, participants were videotaped as they described a stimulus to a partner, who then tried to select it from a set of similar stimuli. Half of the dyads communicated face to face; the other dyads were in different rooms and communicated over an intercom. In the second phase, the videotaped descriptions were presented to new listeners, who tried to select the stimulus described. Half of these listeners both saw and heard the videotape; the others only heard the soundtrack. Communication accuracy, as measured by the rate at which listeners selected the correct stimulus, was low overall, $M = .555$; $SD = .089$, but better than by chance in all three experiments. However, accuracy was not enhanced in any of the tasks by allowing the listener to see the speaker's gestures. The results question whether hand gestures have a communicative function and, if so, how much semantic information they provide.

Lozano and Tversky (2006) investigated the roles of gestures and speech in explanations of procedure with a group of thirty-seven Stanford University undergraduates. Communicators explained how to assemble a simple piece of furniture in three conditions: using speech alone, speech with gestures, or gestures alone. Gestures used for explaining included pointing to indicate parts or sections of parts and action to demonstrate assembly. The gesturing-only communicators were noted to include many actions that made information explicit and modeled critical steps in the procedure. The speaking-only communicators used only words to convey similar information and the speaking-gesturing communicators implemented far fewer gestures than did the gesturing-only group, as measured by a coding of action steps visible in the videotape. The participants who were presented with gestures alone learned assembly better, making fewer assembly errors than did those who were presented with speech only or with speech and gestures. The authors interpreted the results to mean that visual attention to action information was crucial for good assembly performance. Gestures both highlighted and exemplified action information, and the more exposure participants had to gestures for this purpose, the better they performed the assembly task. In noting the significance of gestures to communication and a commonality between gestures and sign language, the researchers noted how, in providing descriptions of environments, both signers and speakers used their hands to draw an imaginary map of space, indicating markers or signposts within the sketched space or using their hands to indicate a route through the space (Emmorey, Tversky, & Taylor, 2000).

With regard to combining modes, still other research has provided evidence that an integrated speech-gesture system was more comprehensive than it would be if content were derived from a visual or auditory modality alone. For example, in a study conducted by Beattie and Shovelton (1999), ten participants watched video clips of people describing a cartoon using speech plus gestures, speech alone, or gestures alone. When asked questions about objects and actions in the cartoon, the participants were more accurate under the speech-plus-gestures condition than under the speech-only condition. Although this study was limited by the small sample, similar studies on narrative retellings (Goldin-Meadow & Sandhofer, 1999; McNeill, Cassell, & McCullough, 1994) confirmed that even when the information was presented in speech-and-gesture conflict, listeners generally were able to integrate features of visual and auditory signals to create a unified account of the speaker's message.

Furthermore, based on quantitative analyses of visual fixations during a video-based task, Silverman, Bennetto, Campana, and Tanenhaus (2010) found that, compared to speech alone, iconic gestures overlapping with coexpressive speech hindered comprehension in 19 adolescents with high-functioning autism, although they facilitated comprehension in 20 typical controls matched for age, gender, verbal IQ, and socioeconomic status. In that study, gesture comprehension was assessed by analyzing visual fixations during a video-based task. Participants' eye movements were recorded while they watched videos of a person describing one of four shapes shown on a computer screen, using speech-and-gesture or speech-only descriptions. Participants clicked on the shape that the speaker described. Analyses of eye movements showed that the control participants fixated visually on the correct target more quickly when gestures were present than when presented with speech only, but that was not the case for individuals with autism. Gestures seemed to facilitate comprehension in typical individuals, whereas it hindered comprehension in those with autism.

Collectively, research on the influence of bimodal signals on cognitive tasks has produced mixed results. Some research shows that gestures and speech comprise a cohesive system, whereas other research finds a less synergistic relationship between the two conditions. Although debate about this issue continues, the next section explores the intentional combination of speech and sign under the assumption that the integration of the two systems will support overall language development in deaf children.

Review of the Literature for SIMCOM

Studies of acquisition of English grammar in SIMCOM environments. Several studies of children who are exposed to SIMCOM are centered around whether and how it is used before and after cochlear implantation and whether and how it does or does not interfere with speech development (Burkholder & Pisoni, 2003; Geers & Hayes, 2011; Geers & Seday (2011); Harris, 2015; Holt & Svirsky, 2008; Nicholas & Geers, 2003; Pisoni & Cleary, 2003; Pisoni & Geers, 2000; Spencer, Tye-Murray, & Tomblin, 1998). These studies do not directly compare cognitive functioning related to communication mode, but their findings do contribute to the current study. Studies that relate specifically to the current experiment are reviewed next.

With regard to syntactic development of English, Spencer et al. (1998) reported that deaf students using cochlear implants in SIMCOM language environments showed integration across modality in that they acquired English grammatical morphemes resulting in improved syntactic development. Evidence showed that the students produced those morphemes primarily through speech, but continued to sign (and also to often speak) content words. As an example, a child may have signed "*My dad work on farm*" but said "*My dad works on a farm*." This pattern demonstrates that, with access to sufficient auditory information, students were able to synthesize visual and auditory input and produce morphemes in the sensory modality to which they are best suited. The study by Spencer et al. may be used in support of SIMCOM because one of the original purposes of SIMCOM was to deliver the English morpheme system that was not available through sign language alone. This general idea that better knowledge of syntax has been observed in some classrooms in which teachers used SIMCOM consistently is noteworthy, but grammatical morpheme use continues to present special difficulties, even when children have some access to spoken English, as found in numerous other studies (Arfé et al., 2014; Arfé et al., 2015; Akamatsu, Stewart, & Becker, 2000; Connor & Zwolan, 2004; Geers, 2003; Nicholas & Geers, 2003, 2013).

Akamatsu et al. (2000) found that English syntactic development, although delayed, seems to improve with age and SIMCOM experience. For example, they found evidence of continuing improvement in morphosyntax (e.g., articles, plurals) during late elementary and even middle-school years. The authors explored the face-to-face English competence of five students who were participating in a larger study of teachers' use of English-based signing. Using case studies, the authors reported on the students' development of English-based signing at the beginning and end of their involvement in this 4-year study. Grammatical forms that were similar in English and ASL were initially more readily produced when tested for in English, and showed consistently higher attainment levels across all the students, than were grammatical forms that were different in English and ASL. The authors found emerging English forms that could be documented between prompted and imitated utterances and within blocks of test items examining the same grammatical constructions. The authors concluded that teachers' concerted efforts to use English-based signing as a language of instruction enhanced deaf students' English acquisition. Such signing, they noted, helped build a bridge between native sign language and the development of English skills necessary for literacy.

Alternatively, perceiving signs and spoken words simultaneously may interfere with spoken-word processing. Kirk, Pisoni, and Miyamoto (2000) examined the effects of age at implantation, communication mode, and lexical difficulty on spoken-word recognition by children with 22-channel cochlear implants. Participants were selected from a pool of children who were part of a longitudinal study concerning benefits of cochlear-implant use, although the total number of participants in the study was not reported. All participants had prelingual deafness and used a cochlear implant for more than 6 months. They were divided into two groups based on their age at implantation. The first group received their implant by age 2 and had an average age of about 5 years at testing. The second group received their implant after age 6 and had an average age of 9 years at testing. The first group was educated in listening and spoken-language environments where no sign language was used. The second group was educated in total-communication environments (SIMCOM). Spoken-word recognition tests and lexical-discrimination tests were administered orally, and participants' imitative responses were scored as the percentage of words correctly identified. The researchers reported that the performance of the earlier-implanted, orally educated group was significantly higher than that of the later-implanted group whose education included signs and speech.

A limitation of that study was that stimuli were only presented in one mode, so it is not surprising that participants who were used to the addition of a visual signal performed less well than did those who had been trained to rely only on the auditory signal. The authors suggest that the combined use of speech and sign might require children to distribute their attention over two visual sources of information (i.e., manual-visual and audiovisual). Such division of attention could create competition between limited processing resources in working memory and result in less efficient speech processing. They noted that at the time of publication, this possibility had not yet been empirically tested. The current study also addresses their suggestion.

Comprehension of information in SIMCOM vs. other modes. An extensive search was conducted using the following online databases and search engines: Blackwell Synergy, EBSCO, ERIC, Google Scholar, JSTOR, PsycInfo, PubMed, PubPsych, Ovid, and MEDLINE. Search terms included: simultaneous communication, SIMCOM, total communication, communication mode, deaf, deaf education, American Sign Language, ASL, signed English, sign systems, manually coded English, contact signing, methods of communication, multimodal communication, and sign-supported speech. Studies conducted after 1972 were included because that was the year in which the first signed English system was invented (Scheetz, 2001).

Six research articles were found to directly compare the comprehension of simultaneously communicated information with the comprehension of information using other modes of communication. These studies had varying objectives, sample populations, and experimental designs, and all had varying results. Three of the studies only examined either reception or recall of single words or word lists, one of which used hearing infants receiving a degraded signal to simulate hearing loss. Of the three remaining studies, one used simple sentences as the stimulus. Only the final two studies used short stories, as was done in the current study. All of these studies are reviewed next for the contribution they make to, or their relationship with, factors in the current study.

Studies of simultaneous perception of speech and signs at the word level. Crittenden, Ritterman, and Wolcox (1986), citing the controversy over communication modality to be used in schools for the deaf, investigated performance on a test of receptive vocabulary as a function of presentation mode with 52 profoundly deaf children 6 to 12 years of age. They used the Total Communication Receptive Vocabulary Test (Scherer, 1981), in which examinees individually view videotape and point to a picture on a four-picture plate that most closely corresponds to the videotaped stimulus. This test, standardized for the deaf and hard of hearing, yields a raw score, which can be converted to an age equivalent. The participants, who attended a residential school for the deaf where the official mode of communication was SIMCOM, were randomly assigned to one of five communication groups (sign only [ASL], sign with lip movements and no voice [signed English], sign with lip movements and voice [SIMCOM], voice with lip movements [speaker's face visible], or voice only [speaker's face not visible]). The researchers reported that after adjusting for age, participants achieved significantly higher scores in the three conditions that used sign language, whether or not it was accompanied by voice, than in the two oral conditions. Mean scores were 69.36 for ASL, 70.77 for signed English, and 66.50 for SIMCOM, whereas the mean scores for the aural groups were 29.9 with lip movements 20.33 without lip movements. Because no significant differences were noted between the sign-only (ASL) and signed-English groups, with or without voicing, the researchers concluded that for this population, aural communication alone did not provide enough significant information to communicate the message. A major limitation of this study was the use of a vocabulary test, which does not take into account any communication elements other than lexical items to assess communication mode. Another questionable aspect of the study was that many of the children who participated had transferred to the school after unsuccessful experiences in oral-only educational programs. Thus, the results should not be surprising.

Although the above study did not show a significant difference between sign-only or sign combined with speech, there is some evidence that exposing deaf children to words and signs simultaneously might enhance spoken-word processing. For instance, Hamilton and Holzman (1989) found that the method of encoding varied with task demands and with participant characteristics. The study included 58 participants with six different levels of spoken-language and sign-language experience and fluency. All participants were 18 years of age or older and were attending or had graduated from a college program. They comprised six groups: (1) hearing speakers (nonsigners), (2) hearing speakers who had also signed for at least two years, (3) hearing speakers who were born to deaf parents and considered ASL their first language and spoken English their second language, (4) deaf individuals who lost their hearing after the age of six and considered English their first language but had learned to sign also, (5) deaf individuals who were born deaf but had developed spoken language, and (6) deaf individuals who were born deaf and did not use any spoken language.

Phonologically similar, cherologically similar (similar handshape), and control word lists were presented using speech only, sign only, or through both modalities simultaneously. Participants' recall mode indicated that participants encoded flexibly, and that the code being used was influenced by the manner in which the stimulus was presented. Participants with both sign and speech experience recalled simultaneous presentations better than did those presented orally or through sign alone, which the researchers took to signify the occurrence of enhanced encoding as a function of individual linguistic experience. One's total linguistic experience or the mode the participant was most familiar with or most accustomed to appeared to determine recall accuracy following different types of encoding, rather than determining the encoding basis used. Limitations of this study included the use of only college-educated adults and the use of word lists instead of more complex language stimuli.

To examine the hypothesis that competition might exist between speech and manual communication for limited attention and processing resources in infants with hearing loss, Ting, Bergeson, and Miyamoto (2012) studied hearing infants' ability to segment word forms from continuous speech under the influence of a degraded auditory signal. The degraded auditory signal, produced by inducing noise while listening, was meant to simulate hearing loss and produce the effect of listening through a hearing aid or cochlear implant. The researchers cited the landmark study by Jusczyk and Aslin (1995), which found that 7.5-month-old hearing infants can recognize familiar words in fluent speech, even if they had not yet attached meaning to those words, and that this ability to recognize word forms in fluent speech is an essential antecedent to word learning. In the original experiment, Jusczyk and Aslin observed that infants familiarized with the words *cup* and *dog* listened significantly longer to passages containing those two words during a test phase than they did to passages containing the novel words *bike* and *feet*. Alternately, infants familiarized with the words *bike* and *feet* listened significantly longer to passages containing those words than they did to passages containing the novel words *cup* and *dog*.

In an attempt to apply this finding to the use of SIMCOM, Ting et al. (2012) hypothesized that infants would have more difficulty segmenting words from fluent speech if they were first familiarized with the words presented in both speech and sign than they would if first familiarized with the words presented in speech only. They wanted to note the effects of early sign and speech input on infants who already had a compromised hearing system, but because they were unable to recruit enough infants with confirmed hearing loss, they used hearing infants and attempted to simulate the hearing loss by adding background noise to the auditory input aspect of the test phase.

Utilizing an infant-controlled, visual-preference procedure, the researchers tested twenty 8.5-month-old normal-hearing infants. Infants were familiarized with repetitions of words in either the speech-and-sign (n = 10) or the speech-only (n = 10) condition. Infants were then presented with four 6-sentence passages using the infant-controlled visual preference procedure. Every sentence in two of the passages contained the words presented in the familiarization phase, whereas none of the sentences in the other two passages contained familiar words. It was predicted that the infants who were familiarized with words presented in the speech-and-sign condition would have more difficulty segmenting those words from fluent speech due to competition for a limited amount of working-memory capacity and information-processing skills.

Results showed that infants exposed to the speech-and-sign condition looked at familiar words for 15.3 seconds and at nonfamiliar word for 15.6 seconds, $t(9) = -0.130$, $p = .45$. Infants exposed to the speech-only condition looked at familiar words for 20.9 seconds and at nonfamiliar words for 15.9 seconds. This difference was statistically significant, $t(9) = 2.076$, $p = .03$. Because the infants looked at familiar words longer in the speech-only condition (20.9 seconds) than in the SIMCOM condition (15.3 seconds), it was concluded that infants' ability to segment words from degraded speech is negatively affected when the words are initially presented in simultaneous speech and sign. The researchers suggest that a decreased ability to segment words from fluent speech may contribute toward the poorer performance of pediatric cochlear-implant recipients in total-communication (SIMCOM) settings on a wide range of spoken-language outcome measures.

The results of that study suggest that a decreased ability to segment words from fluent speech may be a contributing factor toward the poorer performance of deaf children in SIMCOM environments. However, it should be kept in mind that only typically hearing infants were tested and that an attempt was made to simulate a degraded auditory signal by presenting the words in background noise. It is uncertain whether similar findings would be replicated in children with hearing aids or cochlear implants, whose audiovisual speech perception skills are influenced by hearing loss and for whom auditory experience plays a role in audiovisual speech perception. Furthermore, the researchers were unable to assess whether infants' visual attention was divided between the speaker's face and the hand gestures. Examining infants' visual attention with an eye-tracker system, they noted, might provide further insight into differences in visual attention to speakers in speech-only versus SIMCOM environments.

Studies of SIMCOM at the complex language level. Another study that set out to measure reception of language under sign-only and SIMCOM conditions was conducted by Pudlas (1987). Pudlas utilized a within-subject design with a group of 106 deaf students 7 to 18 years of age who were presented with 12 sentences via each of five presentation modes: speechreading only (no audition component), speechreading plus audition, sign only, sign plus audition and speechreading (SIMCOM), or audition only (no speechreading component). The students were all recruited from local school districts in British Columbia or from the provincial school for the deaf, but all were enrolled in classrooms where SIMCOM was the method of communication used for instruction. Four-, five- and six-word sentences were created by the researcher, controlling for length, phrase structure, syntax, vocabulary, and content, and presented to the students through a videotaped recording. Participants were instructed to attend to the monitor and then to write the sentence on an answer form. The dependent variable was the number of words received and correctly recorded in the appropriate space in an answer booklet. Guessing was encouraged and spelling errors were accepted as long as the correct words appeared in the correct blanks on the answer sheet. A significant difference between the conditions, with or without the use of signs, was observed as noted in the following mean scores: sign-only = 31.5, SIMCOM = 33.15, speech plus lip-reading = 7.5, lip-reading only = 3.77, and speech only = 3.10, with the SIMCOM mode scoring slightly higher than the sign-only mode. The fact that performance did not significantly improve when signs were added to the spoken information is attributed by Pudlas as evidence of processing limitations when the two modes were presented simultaneously.

To assess the effects of language ability in different modalities for deaf participants, Stewart (1987) examined the comprehension of deaf students on stories presented in ASL and signed English in three modalities: sign only, sign plus lip movements but no voice, and SIMCOM. The experimental design used a repeated-measures approach. Three different ghost stories were videotaped once in ASL, once in the sign-only mode following English word order (signed English, no voice, no lip movement), once with sign plus lip movement (signed English, no voice), and once in SIMCOM (sign plus lip movement plus voice), for a total of twelve stories.

Thirty-four middle- and high-school students (mean age = 16.9 years) with severe to profound hearing loss (PTA = 83–113 dB) participated in the study. All participants had their previous 5 years of education in a total-communication program using signed English and speech. The participants were randomly assigned to watch either the signed English version of the three stories in different modalities or the ASL version of the three stories. Each story was presented randomly so that each participant watched three stories only once in various modalities. After watching each story, the participants were asked to immediately retell as much of the story as possible in any mode that they preferred. Goodman and Burke's (1972) Miscue Analysis Procedure for Retelling Stories was used to analyze the amount of information reproduced, and the maximum score for each story was 100.

Results of the study revealed that deaf students reproduced more information when stories were presented in ASL than when they were presented in signed English without speech signals. Interestingly, when SIMCOM was used, the difference in scores was not significantly different from that for the ASL presentations. In signed English, the addition of speech improved the comprehension of stories, which showed an advantage for SIMCOM. Stewart (1987) concluded that little benefit in comprehension would be gained through the additional cues derived from speechreading and audition in SIMCOM when knowledge of ASL was adequate. He added that reasons for there not being a more statistically significant effect of ASL were related to the fact that students had only been exposed to ASL informally outside of school contexts. These findings are important because, although they do not show a negative effect on comprehension for SIMCOM, Stewart seemed to maintain a bias toward ASL or sign-only methods.

The only other experiment that examined the effects of SIMCOM on the degree of correct information received was conducted by Tevenal and Villanueva (2009). Noting that previous research showed that SIMCOM did not produce complete messages (Baker, 1978; Johnson et al., 1989; Marmor & Petitto, 1979; Schiavetti, Whitehead, Whitehead, & Metz, 1998), their stated objective was to determine whether deaf, hard-of-hearing, and hearing participants received complete or equivalent messages from SIMCOM presentations. The researchers used direct feedback from the participants as the indicator of message equivalence. Eighty-nine undergraduate and graduate students from Gallaudet University participated in the study (46 deaf, 8 hard of hearing, and 35 hearing). The ages ranged from 18 to 57 years (mean age = 25 years). All the participants watched nine video clips, each of which lasted less than 30 seconds. Each clip presented a hearing person who simultaneously spoke and signed specific information expressed in complete sentences. Three of the clips were taken from a U.S. History classroom lecture at the college; the remaining six clips were presentations from public events, which also occurred at Gallaudet University.

After each of the nine clips was shown, participants were presented with printed questions on a PowerPoint slide and asked to write the answers to those questions in an individual answer booklet. The questions, created by the researchers, were based on the content delivered in the just-viewed video clips. After viewing all the clips and answering all the questions, the participants were asked to write general comments describing how well they understood the clips. The answers were scored for the percentage of correct answers, and distinct differences in comprehension based on hearing status were revealed in the final scores. The group of hearing participants scored the highest number of correct answers, with a mean score of 84%. The mean score was 36.25% for the hard-of-hearing group and 29.33% for the deaf group. The score for the hearing participants was 47.75% higher than that for the hard-of-hearing group and 54.67% higher than that for the deaf group.

The researchers interpreted the results to indicate that not all the participants had the same access to the information presented. SIMCOM did provide equivalent messages to the deaf and hard-of-hearing groups, but many confounding variables (e.g., no control on the written

English skills and/or the sign-language skills of the participants) weakened the study. For example, it is well documented that average students with severe to profound hearing loss leaving the educational system in the United States read at the beginning of the fourth-grade level (Trezek, Wang, & Paul, 2010). Furthermore, in most cases, the challenges to deaf students' reading comprehension are not specific to print, but are paralleled by similar weakness in understanding sign language—that is, individuals who are deaf or hard of hearing cannot fully comprehend sign-based presentations without required bona fide sign-language skills (Marschark et al., 2009). The comparison between hearing and deaf or hard-of-hearing participants in the study also complicated the results.

In summary, few studies have empirically investigated the influence of bilingual-bimodal features of SIMCOM on cognitive tasks. Only two studies have been identified since SIMCOM became popular in the 1970s, and the more relevant study is more than 25 years old. Neither study revealed a significant difference in favor of one mode or another. More research is needed in this area.

Research Questions

This study is guided by the following research questions:

1. Are there other factors that affect the relationship between communication modes and retell scores? Specifically, will gender, age, PTA, standardized reading scores, home language, or type of hearing-assistive technology (hearing aid or cochlear implant) correlate with retell scores?

2. Does communication mode affect story-recall scores for deaf students? Specifically, is there a difference in story retell scores when the story is presented in SIMCOM versus sign only?
3. Will mode of presentation affect mode of response? Specifically, will participants choose and maintain one mode of response regardless of the mode of presentation, or will they match the mode of response to the mode of the presentation? Is there a difference in scores among participants who respond using sign only or SIMCOM only or for participants who switch modalities?

Hypotheses

Research question 1. It is hypothesized that there will be some relationship between students' gender, age, PTA, standardized reading scores, home language, and type of hearing-assistive technology (hearing aid or cochlear implant). Hypothesized positive and negative correlations are described below.

Gender. There will not be a statistically significant relationship between gender and story-retell score. Although there is a higher incidence of attention-deficit/hyperactivity disorder in boys, not enough evidence is available to unequivocally note differences in working-memory performance between boys and girls (Cattaneo, Postma, & Vecchi, 2006; Silverman & Eals, 1992; Thorell & Rydell, 2008).

Age. There will be a statistically significant relationship between age and story-retell score. Older participants will have higher retell scores than younger participants, because there is a documented relationship between age and working memory. An age-related improvement has been reported in the performance of working-memory tasks in both deaf and hearing individuals (Akamatsu et al., 2000; Gathercole, Pickering, Ambridge, & Wearing, 2004; Luciana & Nelson, 1998). The neural processes and brain structures that subserve working memory continue to develop throughout childhood, and developmental changes in brain regions are believed to parallel cognitive development (Casey, Giedd, & Thomas., 2000; Dempster, 1992; Luna et al., 2001).

PTA. There will be a statistically significant relationship between PTA and story-retell score. PTA is the average of hearing thresholds measured at 500, 1000, and 2000 Hz. In clinical audiology, the PTA is a method of validating the accuracy of hearing thresholds (American Speech–Language–Hearing Association, 2005). The quietest level at which a person can understand two-syllable words is typically similar to the PTA. Participants with lower PTAs will have higher retells scores under the SIMCOM condition. Lower PTAs would indicate more hearing and thus more access to spoken English through the auditory channel. Alternately, participants with lower PTAs and thus more hearing ability may perceive the spoken signal as a distraction, increasing memory load, and score lower in the SIMCOM mode. Some research shows that amount of hearing influences the development of working memory. The working-memory capacity of profoundly deaf individuals and later-implanted children is smaller than that of hearing children (Burkholder & Pisoni, 2003; Pisoni & Cleary, 2003; Pisoni & Geers, 2000), but even some residual audibility in early childhood is enough to support development of verbal working memory (Stiles et al., 2011).

Standardized reading scores. There will be a statistically significant relationship between standardized reading scores and story-retell scores. Participants with higher standardized reading scores will have higher retell scores. Working-memory performance is highly predictive of academic achievement in reading, and several studies have demonstrated a relationship between working memory and reading comprehension (Oakhill & Cain, 2007; Engle, Carullo, & Collins, 1991; Perfetti, Landi, & Oakhill, 2005).

Home language. There will be a statistically significant relationship between home language and story-retell score. Participants exposed to English at home will have higher retell scores because more exposure to English should indicate more knowledge of English. Little research has been conducted on the demographic characteristics of children with hearing loss who are exposed to nondominant languages or are multilingual (Crowe, McLeod, & Ting, 2012). Some studies have examined the development of one language in children exposed to oral multilingual environments. Thomas, El-Kashlan, and Zwolan (2008) found that children with cochlear implants who lived in oral mono- and multilingual homes had similar levels of English-language proficiency. Alternately, Teschendorf, Janeschik, Bagus, Lang, and Arweiler-Harbeck (2011) found that deaf children from multilingual home environments showed less proficiency in the dominant language than did their peers from monolingual home environments.

Hearing-assistive technology. There will not be a statistically significant relationship between hearing-assistive technology and story-retell score. Although cochlear implants and hearing aids serve the same purpose, they are different devices with different capabilities benefitting different individuals in different ways. Because performance can vary so widely, it is difficult to make predictions for individual users (Burkholder & Pisoni, 2003; Pisoni & Cleary, 2003; Pisoni & Geers, 2000; Stiles et al., 2011). Both cochlear implants and hearing aids are considered to contribute to effortful processing of speech stimuli, and listeners using hearing-assistive technology must allocate more resources to the task of initially perceiving the speech input, leaving fewer resources for subsequent recall (Lunner et al., 2009).

Research question 2. It is hypothesized that there will be a difference between communication-mode input and story-retell scores such that scores will be higher under the sign-only condition than under the SIMCOM condition. Children who are profoundly deaf demonstrate weaker working-memory capacity (Burkholder & Pisoni, 2003; Hamilton, 2011; Pisoni & Geers, 2000). The need to split attention across two incoming language stimuli (signed and spoken) presented simultaneously will further tax working memory, thereby increasing cognitive load and diminishing resources needed for comprehension and retell production.

Research question 3. Participants' response mode will vary. Although the evidence in this area is extremely limited, Stewart et al. showed that both ASL- and English-dominant bilinguals translated English stories to ASL in retelling (Stewart, 1987; Stewart & Kluwin, 2001; Stewart & Clarke, 2003).

Chapter 3

Methodology

The purpose of this study was to examine the effect of unimodal (sign-only) and bimodal (SIMCOM) communication on story-recall scores for a sample of deaf children. The story-recall task was used as a measure of working memory. This chapter describes the research design and addresses the appropriateness of the design for the study. Potential strengths and limitations of the design are presented. Next, the chapter reviews the setting and participants, instrumentation, pilot testing, and research procedures, and describes data collection and analysis methods.

Research Design and Rationale

A within-subject, posttest-only design was selected for this study, where each participant's performance was measured by the score obtained on a story-recall task after each experimental condition (SIMCOM/sign only). The dependent variable was the score on the retell task, and the independent variable was the communication mode (SIMCOM/sign only). This research design was chosen because it takes into account that the scores achieved will be correlated and it effectively equates the participants under the two conditions so that individual difference, the single largest contributing factor to error variance, is eliminated. In this design, participants serve as their own control on the variables of communication mode, age, gender, home language, standardized reading score, PTA, and type of hearing-assistive device.

The rationale for the proposed research design is supported by Greenwald's (1976) examination of within-subject designs. According to Greenwald, an advantage of within-subject designs is that it provides for the ability to control for individual differences in overall levels of performance by comparing the scores of a participant in one condition with the scores of the same participant in other conditions. This is significant in that participants will invariably differ from one another, regardless of the condition. Individual differences are clearly evident when dealing with issues of working memory (Cowan, 2001; Just & Carpenter, 1992; Wilken & Ma, 2004). A within-subject design sets up each participant as his or her own control. Thus, this design is insensitive to individual differences and more likely to reveal differences caused by the independent variable. That is, the within-subject design guarantees equivalent groups before the experiment is started. Greenwald (1976) noted that this typically increases power or ability to detect an effect of the independent variable.

Additional proponents of the research design include Charness, Gneezy, and Kuhn (2012), who address the application of within-subject designs specifically within the field of psychology and educational research, and Heppner, Wampold, and Kivlighan (2008), who note that the within-subject design offers a powerful but underused means for identifying causal relationships. Kressley and Knopf (2006) addressed the application of within-subject designs specifically to research in memory, as did Godden and Baddeley (1975), who used the design to study working memory with divers in underwater environments. Gais, Lucas, and Born (2006) used a within-subject design in a recall task that studied learning after sleep. Biederman, Ryder, Davey, and Gibson (1991) used a within-subject design in an experiment involving memory and developmentally delayed children.

Greenwald (1976) and others also note a set of interrelated limitations of the within-subject design—namely, practice and order effects. Also known as carryover effects, these effects imply that participation in one condition may affect performance in other conditions, thus creating a confounding, extraneous variable that varies with the independent variable. In this study, participants' performance may have changed across the two conditions simply because of repeated testing and not because of the change in the independent variable (communication mode). These practice effects are a threat to internal validity, particularly when the different conditions of the independent variable are presented in the same order to all participants. Counterbalancing strategies, whereby different participants receive different orders of the conditions, were used in this experiment to address this limitation and will be described as they were applied in the Procedure section. The within-subject design with counterbalancing controlling for threats to internal validity is considered a strong experimental design (Johnson & Christensen, 2000).

Participants

With prior approval from the Institutional Review Board at Teachers College, Columbia University, this study used convenience sampling. Participants included 36 children (19 females, 17 males) with severe to profound hearing loss, who attended a state-funded school for the deaf in a large city in the Northeastern part of the United States (grades 5–8). They ranged in age from 11.3 to 14.8 years, $M = 12.9$ years, $SD = .99$. The school adheres to the total-communication philosophy wherein teachers are expected to sign and speak simultaneously (i.e., SIMCOM) at all times. Demographic information obtained from the school and from parent reports indicated that of the 36 participants, 16 (44.44%) were black (African American, Caribbean American, African), 13 (36.11%) were Hispanic, 4 (11.11%) were Asian, and 3 (8.33%) were white. Languages used at home included Spanish (7 [19.44%]), English (26 [72.22%]), Chinese (1 [2.78%]), Russian (1 [2.78%]), and ASL (1 [2.78%]). Participants' unaided PTA in the better ear indicated that all students had severe to profound hearing loss (72–

120 dB). Within the group, 17 (47.22%) of the participants used cochlear implants and 19 (52.78%) used hearing aids. None of the participants were reported to have additional handicapping conditions. The demographic characteristics of the participants are presented in Table 3.1.

After gaining consent to participate from parents/guardians, demographic information for student participants (i.e., age, gender, ethnicity, degree of hearing, documented presence of additional disabilities, home language) was requested from the school. Thirty-eight students were eligible for participation and given consent letters. Thirty-six of these students returned the signed consent letter from their parents/guardians who agreed to provide or permit access to demographic information and allow participation in the study.

The Research Team

The research team consisted of a professor from the Deaf Education program at Teachers College, Columbia University, and an instructor (the author) who had worked as a middle-school teacher at the recruiting site for 12 years. Five research assistants contributed to the study: four female, hearing graduate students from the same program, one of whom was a freelance ASL interpreter; and one deaf male graduate student, who was a fluent signer and a student-teacher at the school site, and therefore familiar with the students participating in this study.

Sources of Data

The data used in this study included demographic data from school records, a story-recall measure, and transcripts of participant responses from the story-recall task.

Measures

For research question 1: Demographic data that included participants' age, gender, PTA, home language, standardized reading scores, and type of hearing-assistive technology used (hearing aid or cochlear implant) were collected from school records. These data was used to analyze effects on the dependent measure, which was the score on the story-recall task. In these records:

- Deafness was measured by PTA.
- Standardized reading scores were measured using the *Stanford Achievement Test–Hearing Impaired–Verbal* (SAT-HI) (1996).
- Age, gender, home language, and type of hearing-assistive technology were updated regularly through school contact with families.

For research question 2: The students' performance on *The Woodcock-Johnson Tests of Achievement* (WJ III ACH) (Woodcock, McGrew, & Mather, 2001) subtest Story Recall was used in the study. The normative sample used to develop the WJ III ACH involved a geographically and demographically diverse group of 8,935 individuals, ranging in age from 2 to 102 years. Individuals were randomly selected within a stratified sampling design that controlled for 10 specific community and individual variables and 13 socioeconomic-status variables. The sample consisted of 1,143 preschool subjects; 4,784 kindergarten through twelfth-grade subjects; 1,165 college and university subjects; and 1,843 adult subjects. The Story Recall subtest has a median reliability of .87 among individuals 5 to 19 years of age.

Two sets of quantitative data (retell score on stories presented in SIMCOM and retell score on stories presented in sign only) were collected as the primary data. The primary dependent measure was the score on the story-recall in each mode. A story-recall measure was used to assess comprehension of stories under the two conditions as well as an indirect measure of cognitive load. Story recall requires an individual to pay close attention to and then recall the meaningful parts of presented narratives. It is considered to be a reliable measure of verbal working memory (Williams, Goldstein, & Minshew, 2006), because the task requires the participant to listen to and recall passages of gradually increasing length and complexity. Some items in the passages must be recalled verbatim and others may be paraphrased. Points are awarded for specific elements that are recalled, and participants' scores are computed as the number of essential elements correctly recalled for each of the stories. The maximum score in each condition was 38.

For research question 3: A categorical coding scheme was developed whereby a number was assigned to each response from each participant. The dependent variable was the response mode coded as category 1 if the participant responded using sign only, category 2 if the participant responded using SIMCOM, and category 3 if the participant responded by matching the mode of response to the mode of presentation.

Materials

Two sets of videotaped short stories were used for the recall task. The first set (stories 1–6) was taken directly from the WJ III ACH Story Recall subtest (Woodcock et al., 2001). These stories were presented in SIMCOM. The second set (stories A–F) was an alternative form created by the research team to include different content but linguistic structures and syntactic elements similar to those presented in the first set. These stories were presented using sign only. The two sets of stories representing the two experimental conditions began as simple propositions and became increasingly more complex. For each condition, the first story consisted of two simple sentences, whereas the last consisted of four sentences, with some including embedded clauses (see Table 3.2).

For consistency, it was decided that one signer would be videotaped presenting all 12 stories. This would ensure that all participants saw the material in exactly the same way. The signer chosen was the coordinator of services for Deaf and Hard of Hearing students at Teachers College, Columbia University, who was a certified interpreter and a child of deaf adults. This person met with the research team on numerous occasions to discuss the project before the taping took place. The research team and the signer worked collaboratively in order to translate the frozen text of the twelve English stories into either SIMCOM (sign and speech in English word order) or sign only (sign language with no voice component).

For the SIMCOM component, the signer used conceptually accurate signs along with voicing in English word order to relay the stories. In order to maintain the goal of conceptual accuracy, however, some words were spoken but not signed, such as "*to*" as in "likes to catch butterflies," or "*in*" and "*the*" as in "ride in the car" (in this case the sign for ride includes the action of getting in the car, so separate signs for *in* and *the* are not produced). The two research team members who had experience in the classroom with the student participants for this study assisted the team in developing a translation that was most similar to the format in which the teachers at this school for the deaf sign in the classroom with these students.

For the sign-only component, basic ASL syntax and features were used. ASL has a somewhat flexible sentence structure and a variety of forms, depending on what is being communicated, as is the case in other languages. Typically, ASL sentences follow a topic-comment structure similar to the subject-predicate structure in English. However, the topic of the sentence can be either its subject or its object, depending on the focus of the message. For example, Story A (*Steve likes to play games*) would be signed BOY STEVE GAMES LIKE PLAY. A nonmanual marker indicating "games" as the topic of the sentence would be the use of raised eyebrows while signing GAMES.

Pilot

Two students from the school (one male and one female), who were considered by the teachers as representative of the students, participated in a pilot study to examine the overall design of the procedure, the usefulness of the scripted protocol, and the general comprehensibility of the 12 stories. Signing speed, idiosyncratic use of individual signs, and clarity of lip movements were factors that affected the message being delivered; accordingly, modifications were made in the production and delivery of the test items. For example, the initial sign used for HALLOWEEN was not familiar to the students in the pilot, so it was replaced by a more local variant.

Data-Collection Procedures

The graduate research assistants in the Deaf Education program at Teachers College, Columbia University, administered the research protocol. To explain the procedure before the individual assessments, all participants were gathered in one classroom where one of the researchers used a scripted protocol to describe what would take place. One practice item for each communication mode (SIMCOM and sign only) was presented, and participants were given the opportunity to ask questions and clarify understandings of the process. Participants were then called into one of four classrooms individually where a TV monitor, a video camera, and two chairs (one for the student participant and one for the researcher) were arranged. To alleviate any anxiety the students might have on performing, especially in front of strangers, a school staff member was also in the room with each student. Four female researchers, all of whom were fluent signers, individually administered the experiment simultaneously in four separate classrooms following a scripted protocol. The protocol consisted of the following instructions: “You are going to see/hear a story. Then you are going to tell the story back to me. Watch/listen very carefully.” Immediately after the story was presented, the examiner asked the student to retell the story to her. At the end of each retell the examiner asked, “Is that all?” “Is there anything more you can remember?”

Counterbalancing was used to reduce the influence of order effects and practice effects. Participants were randomly assigned to watch either SIMCOM stories first or sign-only stories first. The stories were presented through video, one by one, and after each presentation, participants responded with their recalls. The researchers did not repeat any stories, but encouraged participants to offer whatever they could remember. The participants were instructed to respond in whatever communication mode they felt comfortable using. For each participant, the performance of the story-recall task lasted approximately 15 to 20 minutes. The entire procedure was videotaped for analysis.

Transcription and scoring for the dependent measure. The same four researchers who administered the tests were divided into two pairs to translate the participants’ videotaped story recalls into English, capturing both the speech and signing that the participants used (sign language without voice was translated into English first). Neither pair of researchers translated responses from participants they administered: one conducted the initial translation and coding, a second one double-checked the transcriptions against each participants’ videotaped recall, and a third researcher (the author) joined the discussion if any ambiguity occurred. The two researchers within each pair then scored the participants' responses individually based on the transcripts. The participants' total scores were obtained by adding every correctly identified element in each modality. Interrater agreement was 96% for the first pair of transcribers/scorers and 94% for the second pair.

After each participant's free recall was transcribed it was scored using the scoring method provided by the Examiners Manual (Mather & Woodcock, 2007). Segments of the stories are separated by slashes (/). Each segment contains content words (nouns, adjectives, adverbs, pronouns, prepositions with semantic load), which are scored. Some sections also contain noncontent words (conjunctions, articles, helping verbs, prepositions without semantic load), which are not scored. The participants' recalls were compared with the semantic units from the original stories, and a score of 0/1 (not recalled/recalled) was assigned for each segment. Participants were given one point for each correctly identified element in their responses. Words in bold were considered essential elements and had to be present to receive credit. Other elements could be synonyms or paraphrased. Variations of verbs (e.g., "like" for "likes," "swim" for "swimming") and minor omissions (e.g., "monkey" for "monkey's") were permissible. The content words did not have to be recalled in the order in which they were presented. Although we followed these scoring criteria, we did make one modification related to proper nouns, specifically names. In sign language, names are either fingerspelled or initialized. Because the original names used in the WJ III ACH may have been unfamiliar to the participants, we assigned 1 point for a complete name if it was fingerspelled or spoken correctly or .5 if it was misspelled or incorrectly spoken. We also awarded .5 if the response referred to the subject as "boy" or "girl" but did not provide a name. Points were totaled to achieve a final recall score.

Coding for research question 3. Once the propositional scoring was completed, the videotapes were reviewed again to code the communication mode the students used in their response. Of interest was whether the participants responded in the same mode as that used in the presentation or in a different mode, and whether or not there was a pattern or consistency in response modes. To note this, each set of participant responses was assigned to one of three response classes: category 1 if the participant responded using sign only, category 2 if the participant responded using SIMCOM, or category 3 if the participant matched the mode of response to the mode of presentation. The same procedure as above was used for reliability. Interrater reliability was 92% for the first pair of scorers and 94% for the second pair.

Data-Analysis Procedures

IBM SPSS Statistics for Macintosh, Version 22.0, was used to analyze the data, and all statistical analyses were conducted at the .05 level of significance.

Research question 1. Are there other factors that affect the relationship between communication modes and retell scores? Specifically, will PTA, standardized reading scores (SAT-HI), age, gender, ethnicity, home language, or type of hearing-assistive technology (hearing aid or cochlear implant) correlate with retell scores? For research question 1, correlations between SIMCOM and sign-only scores with students' ages, standardized reading scores, and PTA were examined using the Pearson correlation test. Independent sample *t* tests were conducted to examine whether SIMCOM and sign-only scores were associated with gender or the use of cochlear implants or hearing aids. One-way ANOVA was conducted to examine the relationship between SIMCOM and sign-only with home languages (Spanish, Chinese, Russian, English, or ASL).

Research question 2. Does communication mode affect story-recall scores for deaf students? Specifically, is there a difference in story-retell scores when the story is presented in SIMCOM versus sign only? A repeated-measures ANCOVA was used to determine whether there was a statistically significant difference between the mean retell scores under the sign-only condition and those under the SIMCOM condition.

Research question 3a. Does mode of presentation affect mode of response? The number of students who responded in sign only, SIMCOM only, or matched their response mode to the presentation mode was counted and converted into a percentage. These data are presented descriptively.

Research question 3b. Is there a difference in scores among participants who respond using sign only, in SIMCOM only, or for participants who switch modality? A one-way ANCOVA was conducted to examine differences in SIMCOM recall scores as a function of response mode category, while controlling for SAT scores.

Summary

This chapter described the method for exploring the effect of communication mode on the story-retell scores for a group of deaf children using a within-subject design. The historical use and validity of this design for detecting a treatment is supported through the literature review presented in Chapter 2 and the previous discussion. Participants, materials, and data collection and analysis procedures were described. Potential strengths and limitations of the proposed research design were presented along with steps taken to maximize reliability and minimize potential threats to internal validity. In conclusion, this chapter demonstrated that the present within-subject design allows for identification of empirical evidence regarding the effect of communication mode on the story-retell scores of the participants.

Table 3.1

Demographics for the Sample Group

Participant Code	Age	Gender	Home Language	PTA	CI/HA	SAT	Ethnicity
A1	13.3	F	Spanish	115	CI	1.2	Hispanic
A2	13.4	F	English	93	CI	1.5	Black
B1	14.3	M	English	92	HA	1.4	Hispanic
B2	14.7	M	English	115	CI	1.5	Russian
B3	14.2	M	English	108	CI	1.5	Black
B4	14.8	M	English	112	CI	1.8	Black
B5	14.2	F	English	112	CI	2.5	Black
B6	14.4	F	English	118	CI	1.2	Black
C1	14	M	English	108	HA	1.9	Black
C2	12.9	M	Chinese	107	CI	2.3	Chinese
C3	13.2	F	ASL	107	HA	2.0	Black
C4	13.2	F	English	120	CI	3.1	Yemeni
D1	13.9	M	English	72	HA	2.0	Black
D2	13.7	M	English	102	HA	1.4	Black
D3	13.2	F	English	120	HA	2.2	Hispanic
D4	13.6	F	English	103	HA	2.1	Black
E1	11.8	M	English	118	CI	1.9	Hispanic
E2	11.7	M	Spanish	115	CI	1.9	Hispanic
E3	11.6	F	English	120	CI	1.8	Hispanic
E4	12.1	M	Spanish	112	CI	1.6	Hispanic
E5	11.4	F	English	115	CI	2.0	Bangladeshi
F1	11.3	M	Russian	95	CI	1.2	Russian
F2	12.1	M	Spanish	112	HA	1.3	Hispanic
F3	11.5	F	English	115	HA	1.5	Chinese
F4	11.5	F	English	120	CI	1.4	Hispanic
F5	11.5	F	English	108	CI	1.4	Black
G1	12.2	M	English	105	HA	1.4	Polish
G2	12.5	F	English	112	HA	1.2	Hispanic
G3	13.4	F	English	105	HA	1.6	Black
G4	12.9	M	English	112	HA	1.4	Black
G5	12.3	F	Spanish	112	HA	1.3	Hispanic
H1	13.3	M	English	120	HA	1.2	Black
H2	12.2	M	Spanish	107	HA	1.7	Hispanic
H3	12.5	F	English	100	HA	1.2	Black
H4	12.8	F	English	94	HA	0.1	Black
H5	12.7	F	Spanish	87	HA	1.4	Hispanic

Note. PTA = Pure-tone average, CI = cochlear implant, HA = hearing aid, SAT = Stanford Achievement Test.

Table 3.2

Measurements of Story Recall

Stories 1–6	Stories A–F
1. /**Julie**/ likes to catch **butterflies.**/ Then she lets them go./	A. /**Steve**/ likes to play **games**./ He always wins./
2. /**Mary**/ has a dog./ He loves to ride/ in the car,/ but he hates to take a bath./	B. /**Bob**/ has a book./ It is about a snake/ in the jungle, / who eats only leaves./
3. /**Amy**/ and her dad/ were out fishing/ in a boat./ Her dad said, "Don't talk/ or the fish will swim away."/	C. /**Tom**/ and his sister/ were swimming/ in the ocean./ His sister said, "I am cold,/ we need to get out of the water."/
4. /A little/ **spider**/ wanted to cross the street,/ but he was afraid/ because there were so many cars./ So he hopped on/ a boy's/ **shoe**/ and made it safely across./	D. /An old/ **monkey**/ wanted to eat a banana,/ but he could not reach it/ because the bananas were too high./ So he stepped on/ another monkey's/ **shoulder**/ and got the banana./
5. /**Rick**/ got some **glow-in-the-dark**/ **stars**/ for his **sixth** birthday./ He wanted to put them on his **bedroom**/ **ceiling**./	E. /**Maya**/ wore a **yellow-and-white**/ **dress**/ for **Halloween**./ But she forgot her **sparkling**/ **crown**./
6. /The **dinosaur**/ at the **museum**/ was over **20 feet**/ tall./ Many people came to see it./ Some small/ children/ were scared./ They thought it was **real**./	F. /The **elephant**/ at the **zoo**/ had a **3-month-old**/ baby./ The baby was cute./ His big/ ears/ could move./ People thought it was **funny**./

Stories 1–6 were taken from the Story Recall subtest of *The Woodcock-Johnson III Tests of Achievement*, form A. Stories A–F were developed by the research team using some elements from WJ III ACH, form B. Words in bold are considered essential elements of the study.

Chapter 4

Results

This chapter provides a description of the data-analysis procedures and results. First, analyses were conducted to examine the effects of age, gender, PTA, standardized reading scores, home language, and type of hearing-assistive technology used on students' recall scores to determine whether any such variables were potential covariates. Next, a test of the primary within-subject hypothesis is presented, in which I examined the difference between students' recall in the two conditions (SIMCOM and sign only) while controlling for potential covariates. Lastly, results of analyses are presented in which I examined whether the participants' model of response is related to their recall scores.

The study used a within-subject design to investigate the effect of communication mode on story-recall scores in 36 deaf children 11 to 14 years of age. The primary dependent variable was the score on the story-recall task. The primary measure of story recall was the number of correct propositions produced in the retelling protocols. The independent variables were the two communication modes: SIMCOM and sign only. Other independent variables were participants' age, gender, PTA, standardized reading score, home language, and type of hearing-assistive technology.

Preliminary Data Analysis

Before testing the study hypothesis, the data were examined for outliers and missing data. No outliers were found, as assessed by inspection of a box plot. The assumption of normality was not violated, as assessed using the Shapiro Wilk test ($p = .937$). Alpha for all tests of significance was set at the .05 level (two-tailed).

Primary Data Analysis

Research question 1: What factors are associated with children's recall?

Age. A Pearson correlation test was conducted to determine whether there was a relationship between participants' ages and recall scores. No significant correlation was found between age and SIMCOM scores, $r(35) = .28$, $p = .09$, or between age and sign-only scores, $r(35) = .28$, $p = 0.99$ (see Table 4.1).

Table 4.1

Correlations among Demographic and Other Control Variables and Independent Study Variables

Variable	SIMCOM	Sign Only	SAT	Age	PTA
SIMCOM	1				
Sign only	.81*	1			
SAT	.58*	.62*	1		
Age	.28	.29	.13	1	
PTA	.18	.20	.22	–.19	1

Note. $N = 36$; SIMCOM = simultaneous communication; SAT = Stanford Achievement Test; PTA = pure-tone average.
$^{*}p < .01$.

Gender. An independent samples *t* test was conducted to determine the effects of gender, if any, on retell scores. The data indicated no significant difference in scores between male and female participants in either the SIMCOM condition, males: $M = 21.85$, $SD = 6.44$; females, $M =$

20.68, *SD* = 7.01; *t*(34) = –.52, *p* = .61, or the sign-only condition, males: *M* = 27.76, *SD* = 5.65; females: *M* = 26.42, *SD* = 6.14; *t*(34) = –.68, *p* = .50 (see Table 4.2).

Table 4.2

Descriptive Statistics and t *Test for Effect of Gender*

	Females (*n* = 19)		Males (*n* = 17)				
Mode	*M*	*SD*	*M*	*SD*	*df*	*t*	*p*
SIMCOM	20.68	7.01	21.85	6.44	34	–.51	.60
Sign only	26.42	6.14	27.76	5.65	34	–.68	.50

Note. SIMCOM = simultaneous communication.

Home language. A one-way ANOVA was conducted to examine whether differences existed between participants' recall scores based on their home languages. No significant differences in retell scores were found based on the participants' home language in either condition, SIMCOM: *F*(4, 31) = 2.35, *p* = .075; sign only: *F*(4, 31) = 1.38, *p* = .26 (see Table 4.3 for descriptive data and Table 4.4 for analysis).

Table 4.3

Descriptive Statistics for Home Language

Mode	Language	*N*	*M*	*SD*
SIMCOM	English	25	21.44	6.28
	Spanish	8	18.75	5.99
	Chinese	1	33.00	
	ASL	1	32.00	
	Russian	1	13.50	
	Total	36	21.36	6.68
Sign only	English	25	27.12	6.14
	Spanish	8	26.56	4.12
	Chinese	1	32.00	
	ASL	1	34.50	
	Russian	1	17.00	
	Total	36	27.05	5.87

Note. SIMCOM = simultaneous communication; ASL = American Sign Language.

Table 4.4

One-Way ANOVA for Effect of Home Language

Mode	Source	*df*	*SS*	*MS*	*F*	*p*
SIMCOM	Between groups	4	364.58	91.14	2.4	.07
	Within groups	31	1198.66	38.66		
	Total	35	1563.24			
Sign only	Between groups	4	183.03	45.75	1.4	.26
	Within groups	31	1025.35	33.07		
	Total	35	1208.38			

Note. SIMCOM = simultaneous communication.

PTA. In order to note the effects of residual hearing on recall scores, if any, a Pearson correlation test was performed. No significant correlation was found between PTA and SIMCOM scores, $r(35) = .18$, $p = .29$, or between PTA and sign-only scores, $r(35) = .20$, $p < .23$ (see Table 4.1).

Standardized reading scores. A Pearson correlation test was conducted to determine the relationship between SAT scores and retell scores. A strong positive correlation was noted between SAT and SIMCOM scores, $r(35) = .58$, $p < .001$, and between SAT and sign-only scores, $r(35) = .62$, $p < .001$. Participants with higher reading scores performed better in both conditions than did participants with lower reading scores. Based on this significant finding, SAT score was included as a covariate in the subsequent within-subject analyses to determine differences between presentation conditions (see Table 4.1).

Hearing-assistive technology. An independent samples *t* test was conducted to determine the effect of type of hearing-assistive technology, if any, on participants' retell scores. No significant difference was found between scores for cochlear-implant users versus hearing-aid users in either the SIMCOM or sign-only condition. Results for cochlear-implant users in SIMCOM were $M = 23.17$, $SD = 6.21$, and results for hearing-aid users in SIMCOM were $M = 19.50$, $SD = 6.76$, $t(34) = 1.69$, $p = .10$. Scores for cochlear-implant users in the sign-only condition were $M = 28.55$, $SD = 5.14$, and scores for hearing-aid users in the sign-only condition were $M = 25.71$, $SD = 6.28$, $t(34) = 1.47$, $p = .15$. Thus, the type of hearing-assistive technology did not significantly influence performance in either condition (see Table 4.5).

Table 4.5

Descriptive Statistics and t *Test for Effect of Hearing-Assistive Technology*

	Cochlear Implant (n = 17)		Hearing Aid (n = 19)				
Mode	*M*	*SD*	*M*	*SD*	*df*	*t*	*p*
SIMCOM	23.17	6.21	19.50	6.76	34	1.69	.10
Sign only	28.55	5.14	25.71	6.28	34	1.47	.15

Note. SIMCOM = simultaneous communication.

Research question 2: Are there differences in story recall as a function of presentation mode? A repeated-measures ANCOVA was used to determine whether there was a statistically significant mean difference between the retell scores under the sign-only condition and those under the SIMCOM condition, while controlling for SAT scores. Results revealed a statistically significant within-subject effect, $F(1,34) = 8.36$, $p = .007$ (see Table 4.6). Participants attained higher retell scores during the sign-only condition, $M = 27.05$, $SD = .77$, than they did during the SIMCOM condition, $M = 21.23$, $SD = .91$ (see Table 4.7). To test whether the magnitude of the mean difference was of practical significance, an effect size was calculated using the partial eta-squared value, which yielded $\eta^2 = .19$. According to Cohen's (1988) guidelines, a value of .197 is large. The significance of the mean difference in this study suggests that higher scores for the sign-only condition are unlikely due to chance, and that an effect of communication mode on recall scores actually exists.

Table 4.6

ANCOVA Summary

Source	Sum of Squares	*df*	Mean Square	*F*	*p*	Partial Eta Squared
Mode	66.40	1	66.40	8.36	.007	.197
Mode SAT	.994	1	.99	.12	.726	.004
Error	270.04	34	7.94			

Note. SAT = Stanford Achievement Test.

Table 4.7

Descriptive Statistics for ANCOVA

Mode	*M*	*SD*
SIMCOM	21.23	.91
Sign only	27.05	.77

Note. Means are evaluated at the following value of the control variable: standardized reading score = 1.61. SIMCOM = simultaneous communication.

Research question 3: How does presentation mode influence response mode? Each participant's response mode at the time of recall was classified in one of three categories: use of SIMCOM only, use of sign only, or matched response to presentation mode (i.e., SIMCOM used to respond to SIMCOM presentation, sign only used to respond to sign-only presentation). Most participants responded with sign only regardless of the presentation mode (22/36 [61.1%]). Fewer responded consistently in SIMCOM (11/36 [30.6%]). Only 3 participants (8.3%) matched their response mode to the mode of presentation. A one-way ANCOVA was conducted to examine differences in SIMCOM recall scores as a function of response mode category, while controlling for SAT scores. Results revealed no significant difference in recall scores based on response mode in the SIMCOM condition, $F(2, 35) = 1.22$, $p = .30$. Similarly, the results of a second one-way ANCOVA on sign-only scores, controlling for SAT scores, revealed no significant difference in recall scores based on response mode in the sign-only condition, $F(2, 35) = 1.13$, $p = .33$ (see Table 4.8).

Table 4.8

Descriptive Data for Response Mode

Mode	Response Mode	*N*	*M*	*SD*
Sign only				
	Sign only	22	26.17	.99
	SIMCOM	11	28.00	1.46
	Matched	3	29.65	2.73
SIMCOM				
	Sign only	22	20.09	1.17
	SIMCOM	11	23.37	1.72
	Matched	3	21.75	3.22

Note: Results are estimates, controlling for standardized reading scores. SIMCOM = simultaneous communication.

Chapter 5

Discussion

Overview

Simultaneous communication, or SIMCOM, is a regularly used mode of communication for instruction in schools for the deaf in the United States (Gallaudet Research Institute, 2011). Simultaneous communication is the use of spoken language and sign language presented simultaneously, following English word order and grammar rules. The development of English-language skills to improve literacy outcomes for deaf children was one of the major goals in the creation of this system after sign language was reintroduced in schools for deaf children in the early 1970s (Hyde & Power, 1991). SIMCOM was meant to provide auditory access to spoken language, thus maintaining and supporting residual hearing, as well as visual access for the parts of the language that could not be heard. Although this mode has been used in schools and classes for deaf students since the 1970s, its effectiveness has not been reflected in increased literacy rates for most deaf students (Lederberg et al., 2013; Mayer, 2007; Nicholas & Geers, 2003; Wang, Trezek, Luckner, & Paul, 2008). Many studies of SIMCOM have reported on hearing teachers' ability to deliver instruction in this mode in the classroom (Hyde & Power, 1991; Mayer & Lowenbraun, 1990; Strong, & Charlson, 1987), but fewer have explored its impact on deaf children's comprehension (Stewart, 1987; Tevenal & Villanueva, 2009).

The purpose of this dissertation was to examine the effects of SIMCOM and sign-only communication modes on deaf children's story-recall performance while taking into account any effects of age, gender, reading ability, home language, PTA, or use of hearing-assistive technology (hearing aids or cochlear implants). It also intended to investigate the relationship between mode of presentation and mode of response. This study was structured around three specific questions: (1) Does age, gender, reading ability, home language, or use of hearing-assistive technology interact with mode of communication? (2) What are the effects of mode of communication, if any, on story-recall scores? (3) Is mode of student response related to mode of presentation, and does mode of response correlate with higher or lower scores?

Results of this investigation indicated that significant differences in recall scores do indeed exist between the sign-only and SIMCOM modes of communication, with the sign-only condition scoring higher. With regard to the secondary variables investigated in this sample, only reading ability had a significant effect on the dependent variable. Finally, the preferred mode of communication for most participants was sign only, although several also used SIMCOM. For the remainder of this chapter, results related to each research question will be discussed. Educational implications will then be addressed, followed by study limitations. Finally, possible avenues for future research are offered.

Summary of the Results

Research question 1. In this study, age, gender, home language, PTA, and type of hearing-assistive technology did not significantly influence performance in either condition. Only standardized reading scores were found to correlate with performance in both conditions. These results are in line with the hypotheses listed in Chapter 2 for gender, reading ability, and type of hearing-assistive device, but not for age, PTA, or home language. The fact that recall scores did not increase significantly for older participants, for participants with more hearing, or for participants whose home language was English is perhaps related to the larger language-learning challenges faced by deaf children reflected in the persistent plateau in linguistic development that has characterized the field of deaf education since its inception (Lederberg et al., 2013). Variables that this study could not control for include age at identification, age at first hearing-aid fitting or implantation, quantity and quality of early intervention, and early caregivers acceptance of their child's deafness and their ability to commit resources. It has been well established that a critical period exists for language development during which the nervous system is particularly sensitive to the effects of sensory stimuli (Krashen, 1973; Newport, 1990; Smith, 2014). The observation that hearing babies engage in vocal babbling and deaf babies exposed to sign language engage in manual babbling, both at about 7 months of age, suggests that, regardless of modality, it is early experience that shapes language behavior and ultimately this will be a deciding factor in development (Seal & DePaolis, 2014)**.**

Research question 2. The results supported the hypothesis that recall scores would be higher for the sign-only condition. These findings thus suggest that the working-memory system performs differentially in different recall contexts, and that, in the present study, the sign-only condition presented the more optimal context for a more complete propositional recall for these participants. The results of the present study lend support to the idea that use of two channels (sign plus speech) to deliver the same linguistic information taxes working memory, leading to decreased recall ability. From a cognitive overload perspective, the addition of a mode of communication necessarily affects the attention distribution, because the system must make decisions about which mode to pay attention to or how to rapidly switch attention between modes. This situation seems to reinforce the idea that although humans can process language and visual information at the same time, we do not process two simultaneous language stimuli easily.

The results may also represent an application of Mayer's (2001) cognitive theory of multimedia learning. This model includes many of the principles involved in the previous research ideas of Baddeley (2000), Paivio (1986), and Sweller (1994) in its exploration of dual channels for incoming visual and auditory information, selective attention to one system using prior knowledge as a guide, and application of cognitive resources for using the stimuli to build schema and make decisions. Under the simultaneous-communication condition, speech and sign—although attempting to relay the same information—actually specify different gestural and articulatory events with signs manipulated to conform to the parameters of speech. Information from the two sensory channels cannot be integrated quickly in the same way, as it is when an experienced listener simultaneously sees the speaker's lips and hears speech or when an experienced receiver of signs sees a visually coordinated message. Thus, little facilitation or enhancement is gained from the combination of visual and auditory input; if anything, substantial competition and even inhibition effects resulting from two divergent input signals may occur.

The outcomes of the current experiment counter the results of the studies by Pudlas (1987) and Stewart (1987), which did not find a significant advantage for sign-only input versus SIMCOM, while supporting the results of the study by Tevenal and Villanueva (2009), which concluded that SIMCOM did not provide an equivalent message to all receivers in their study.

Research question 3. Although most participants responded in the sign-only mode, several voiced responses accompanied by sign. However, it is difficult to draw conclusions about these results. Responses categorized as sign only included the use of ASL syntax, nonmanual markers, body movements, and sign space. Although the mode remained manual, there was evidence of language mixing in this group. For example, some participants never voiced but included some signed-English signs and English grammar within their responses. A few participants included English prepositions (*in, on*), copular verb forms (*is, was*), and conjunctions (*or, for*) in their recalls of stories presented in ASL. Noteworthy is that the presentations did not include sign equivalences for these English grammatical features. This is evidence that, for some participants, the structure of ASL was internally translated and recalled syntactically in English. This again raises questions about mode versus language.

Other participants mixed modes in that they voiced while signing more ASL-like syntax. It became difficult at some points to categorize utterances with a language label (ASL or English) as opposed to categorizing for mode. Although not the purpose of this study, these results invite interesting exploration into second-language and bilingual-language acquisition. Throughout the participants' responses there are numerous instances where individuals did more than recall the stories in the same language as the presenter; many inserted their own knowledge of language with regard to syntax, semantics, and pragmatics. For example, in a practice story about the fictional character Harry Potter, where Harry Potter's name was fingerspelled, the participant recalled the story using the sign for Harry Potter (a wand motion) instead of the fingerspelled presentation. In another instance, while recalling a story presented in ASL (story C, see Table 3.2) , a participant voiced the present progressive morpheme *ing* in the verb "swimming," the article *the* preceding the sign for "ocean," and the particle verb *am* for the phrase "I am cold." None of these are present in signed ASL. These are examples of participants inserting their own understanding of one language into the recall of another. In code-switching studies, the dominant language is often called the matrix language, into which elements from the embedded language are inserted (Yim & Bialystok, 2012). Which language for these students is considered dominant when taking mode into account? The transcriptions of participants' responses for this study are fertile ground for continued exploration in this area.

Implications

The current findings, if replicated, have significant educational implications. First, they serve to support the intuition of many teachers and educational professionals who have suggested that deaf students struggle with SIMCOM. Although this study should not be taken as a call for schools and programs to adopt a sign-only policy, it does alert educators to the idea that one mode may support struggling language learners better than two modes. This study did not explore a voice-only mode, which is appropriate for many deaf children who are identified early, amplified early, and who are successful at developing listening and spoken language (Nicholas & Geers, 2013). Although there is longstanding controversy over communication methods in deaf education, perhaps in the early stages of language development it is the separation of modes rather than the exclusion of one over the other that matters most in language and concept development. This is an area where the field of deaf education may benefit from collaboration with the field of bilingual education.

The findings of this study, although limited to a small and specific sample group, may also provide some insight on possible ways to improve educational designs for deaf children. Keeping in mind understandings about how information processing occurs can help educators reduce cognitive load in specific learning situations. Helping learners manage load can result in more productive learning (Clark et al., 2006). The idea that in the SIMCOM condition participants may have had to split attention between two sources of information underscores the impact of instructional design on cognition, specifically on a learner's working memory. Eliminating the physical and temporal separation of incoming linguistic stimuli may result in better learning for these children.

Communication is a cornerstone of learning and a key feature of collaborative experiences. Successful classrooms depend on communication among all participants, and teachers who understand this aspect of pedagogy seek to build communicative experiences into the design of their curriculum. One of a teacher's roles is to design continuously learning environments. Classroom learning depends on students understanding the medium of teaching. The present study raises awareness of educators to the issues of working memory in the classroom. With a cognitive load that is too high, one runs the risk of the student not being able to follow the presentation. In the future, it might be possible to refine the predictions for classroom learning by combining cognitive-load theory with theories of cognitive development, which make some specific predictions about how much capacity is present at a particular age in childhood (Halford, Cowan, & Andrews, 2007). Hamilton (2011, p. 417), in his study of memory skills in deaf learners, asks the question, "Is recall and comprehension of SIMCOM superior to sign-only communication in the classroom during presentation of information more complex than word lists?" This study may answer his question for the particular sample studied. His next question, "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?" remains and is an area open to future study.

Limitations

This study has limitations that could be addressed in future work. First, it does not resolve the question of access to English for the purposes of literacy. Although this study found that participants were better able to understand sign language only, this should not be seen as a call for a sign-only policy in deaf education, but rather as a call to continue to explore the language-learning needs of deaf children and how best to support the development of language needed for academic success.

A second limitation is possibly the use of PTA as a measure of hearing. Although PTA is useful for indicating the quietest levels at which a child can hear, it does not directly indicate the child's access to speech. Another measure, the Speech Intelligibility Index (SII), is more highly correlated with the intelligibility of speech and is perhaps a better indicator of a child's access to speech in conversation (American National Standards Institute, 1997). An additional benefit of the SII is that it can take into account the effects of a child's hearing aid or cochlear implant on conversational speech. This measure is not yet widely used in school audiological evaluations and, thus, that information was not available for the participants in this study. Because scores did not differ greatly based on the amount of residual hearing, this indicator may not have been consequential.

A third limitation is that deaf children represent a low-incidence population; thus, conducting a strong group research design is challenging. Some aspects of the chosen research design limit interpretations. Although an experimental design with random assignment to comparison groups was used, the sample size was relatively small compared with that used in typical research. Given the diversity of deaf children, generalization from small sample sizes must be made with caution.

Lastly, this study may have benefitted from inclusion of a subjective measure of cognitive load or participant input regarding which mode was more comprehensible and why. Traditional audiological measures, such as pure-tone threshold testing and measures of speech recognition, provide valuable information about auditory function and processing abilities. For example, measures of speech recognition indicate how much an individual understands when speech is presented in noise at a conversational level. However, these measures do not indicate how much effort was exerted to achieve that level of understanding. It is logical that as listening conditions decline understanding of speech becomes more difficult and listening effort increases (Mackersie & Cones, 2011; Zekveld, Kramer, & Festen, 2011). Regardless of condition level, there will always be individual variation in both subjective and objective measures of listening effort (Picou, Ricketts, & Hornsby, 2011). Asking for participant perceptions would have provided interesting data to explore related to the recall scores.

Future Directions

Although the measurement of cognitive load in the context of classrooms for deaf children still requires careful experimental research, this study provides a starting point. The logical next step in this research would be to do a more comprehensive study on the influence of language history and the unexplored factors (age at identification, age at amplification or implantation, quantity and quality of early intervention) on cognitive load under different modes of communication.

Another exciting application would be to compare how the brain processes one versus two simultaneous modes of communication through neuroimaging. The brain is a sequential processor, and large fractions of a second are consumed every time the brain switches tasks (Friederici, 2011). It is possible that the brain views one mode or the other as a distraction when both are presented simultaneously. According to Posner, Rothbart, Sheese, and Voelker (2014), we never pay full attention to one thing. The brain has a hard time doing two independent tasks that require conscious thought. Despite our desires to multitask and the belief that it is even possible to do so, what the brain is actually doing is switching back and forth so quickly that it just appears to be processing simultaneously. One reason for the brain to switch among tasks is that similar tasks compete to use the same part of the brain. Central executive processes in the frontal lobes of the brain allow individuals to exert some sort of voluntary control over behavior. The central executive system also helps us achieve a goal by ignoring distractions. If one is performing a task where one wants to read a newspaper on a train and ignore voices and the sounds of the train, the frontal region of the brain may configure the brain to prioritize visual information and reduce auditory information. How might this relate to the communication mode and the deaf child, and how might images of the brain involved in SIMCOM affect our understandings?

In conclusion, this study found that the ability of deaf students to comprehend and recall stories was affected by mode of communication. These results provide support for the idea that simultaneously received speech and sign messages may compromise comprehension by competing for limited attentional resources. In this study, attempts at comprehension of SIMCOM may be evidence of the redundancy principle (Sweller, 1988), which states that attention is split when the same information is presented in multiple modalities. Continued research on deaf students' ability to integrate simultaneously presented auditory and visual language is suggested.

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