Phonological Encoding in Aided Augmentative and Alternative Communication

by

Elena Dukhovny

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Committee in charge:

Professor Gloria Soto, Co-chair

Professor Anne Cunningham, Co-chair

Professor Susanne Gahl

Professor Martine Smith

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Abstract

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Short-term memory for words is typically described in terms of phonological storage and rehearsal. However, research has shown that task demands, such as alternative means of output, may alter characteristics of short-term word storage. Alternative / Augmentative Communication (AAC) via high-technology Speech Generating Devices (SGDs), typically used by people with profound communication impairments, involves production of words via device-specific motor sequences. No study, however, has systematically considered potential effects of SGD-based production on short-term memory for words.

In the current study, modality of short-term word storage was evaluated in a group of adult typical speakers trained to use SGDs, as well as a small group of authentic long-term users of SGDs. Results indicated that neurotypical subjects continued to store word lists phonologically when using SGDs, while authentic users of SGDs demonstrated phonological encoding more strongly during recall of high frequency ‘core’ words than during recall of lower frequency ‘fringe’ words. Thus, phonological encoding appears to remain a robust means of short-term word storage across output modalities.

Dedications

To Alexander, Galina, Irina, and especially to Mark, our inimitable ‘grandpa-on-duty.’
To Alex
To Benny and Levi
To Mendel

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Chapter 1: Introduction

In North America, about eight to 12 people per 1000 experience severe communication impairments that require alternative and augmentative communication (AAC) methods to supplement existing speech or replace speech that is not functional (Castrogiovanni, 2008). AAC is a clinical intervention that attempts to compensate either temporarily or permanently for the impairment and disability patterns of individuals with severe communication disorders, including disorders of spoken and written communication. AAC interventions are typically multimodal, involving various aided and unaided forms of representation such as traditional orthography, drawings, photographs, gestures, manual signs, and other types of visual symbols. While *unaided AAC* options, such as sign language, rely on the user's body to convey messages, a*ided AAC* requires the use of tools or equipment in addition to the user's body. According to the American Speech, Language and Hearing Association (ASHA), aided communication methods can range from paper and pencil to communication books or boards to electronic devices with touch screens (also known as “dynamic screens”) that allow the user to access thousands of picture symbols, letters and/or written words to produce voice output and/or graphic output (ASHA, 2011). Because electronic devices speak a preprogrammed word or phrase when a symbol is accessed, they are known as speech generating devices (SGDs) or voice output communication aids (VOCAs). An ever-increasing variety of complex touch-screen SGDs is available for purchase (Beukelman et al., 2011). However, empirical research on SGDs is still in its infancy.

For neurotypical speakers, the production of speech, in addition to serving an immediate communicative function, may play a role in short-term phonological storage (D. J. Murray, 1968; Peterson & Johnson, 1971). Short-term phonological storage, also known as phonological working memory (WM) or verbal working memory, is the brief temporary storage and manipulation of verbal information (Baddeley, 2003). In order to learn new words, we need to briefly store a novel string of speech sounds while we attach meaning to it. The ability to briefly store phonological forms is therefore considered crucial for vocabulary acquisition (Gathercole & Baddeley, 1989, 1990). Although phonological WM has traditionally been modeled as a system distinct from speaking, emerging research has suggested that short-term storage of phonological forms may rely in part on the mechanisms of spoken production (Achelson & MacDonald, 2009). Production of speech may also play a long-term role in the acquisition of the phonological structures of a language by helping to establish language-specific phonotactic constraints (Warker, Xu, Dell, & Fisher, 2009). For those whose communication impairments begin at birth, aided AAC tools need not only to provide a means of expressive communication, but also to fulfill the role that typical production plays in supporting language acquisition (Bedrosian, 1997). This includes supporting the creation of phonotactic constraints and providing representations for language storage.

In existing research, people who need aided AAC to communicate due to severe speech impairments (SSI) have been found to have relatively poor phonological working memory and poor associated skills such as vocabulary and literacy levels (Foley & Pollatsek, 1999; Larsson, Dahlgren Sandberg, & Smith, 2009; Vandervelden & Siegel, 1999, 2001) In the search for causes and treatments of vocabulary and literacy deficits in this population, a number of studies have addressed environmental factors, such as markedly reduced access to language and limited literacy instruction for children with severe to profound communication needs (Beukelman & Mirenda, 2005, p. 333). In addition to environmental factors, some attention has been given to direct effects of lack of functional speech on phonological storage (Larsson & Dahlgren Sandberg, 2008). No study, however, has systematically considered potential effects of aided communication tools on verbal memory. This is a significant omission, since people with no functional speech may be introduced to aided communication at a very young age (Cress & Marvin, 2003) and aided language production is known to differ from spoken language production in several systematic ways that have the potential to affect traditional phonological means of word storage (Hjelmquist, 1999). To discuss potential effects of aided production on word storage, this chapter introduces influential models of spoken production, phonological working memory and aided production. These are presented in more detail in Chapter Two.

Typical production and working memory

Typical production of words, from selection of a concept to the physical act of speaking, has been separated into sequential levels of encoding: lexical selection, morphological and phonological encoding, phonetic encoding and finally, articulation (Levelt, Roelofs, & Meyer, 1999). Meaning is selected first, followed by grammatical characteristics. Once a word is selected and its grammatical characteristics are specified, the phonological form of that word is retrieved from the long-term phonological store. This step is known as phonological encoding. It is followed by phonetic encoding, which involves the translation of the phonological form into a series of gestures to prepare for final articulation of a word. These last two steps have been grouped as the phonological / articulatory domain and are necessary prerequisites to the last step of production, which is articulation. That is, every time an individual speaks a word, he must access the phonological form of that word from long-term memory, prepare it to be articulated by filling in details such as intonation and then translate it to a series of motor movements (Levelt, et al., 1999). In addition to being required for spoken production, the last stages of word production also play a role in maintaining information in phonological working memory, described next.

According to Baddeley (2003), the primary proponent of an influential working memory model, phonological working memory is part of a larger, multi-component, working memory system that also includes a visuo-spatial sketchpad, responsible for brief storage of visual and spatial information, the episodic buffer, which integrates information between short-term and long-term memory systems, and a central executive, which directs the three lower systems. Phonological working memory, known in this model as the “phonological loop,” is described as distinct from long-term phonological memory, playing a unique role in brief storage of verbal information. It is assumed to have a phonological store, where phonological forms can be held briefly, and an accompanying phonological rehearsal function. Phonological rehearsal refreshes the forms currently in short-term storage, thus extending storage time, via strategically controlled covert (or overt) repetition. Covert speech is also used to encode visually presented items, such as pictures and written words, into phonological form (Baddeley, 2003). Items presented auditorily get immediate access to the phonological store and do not need to be re-coded.

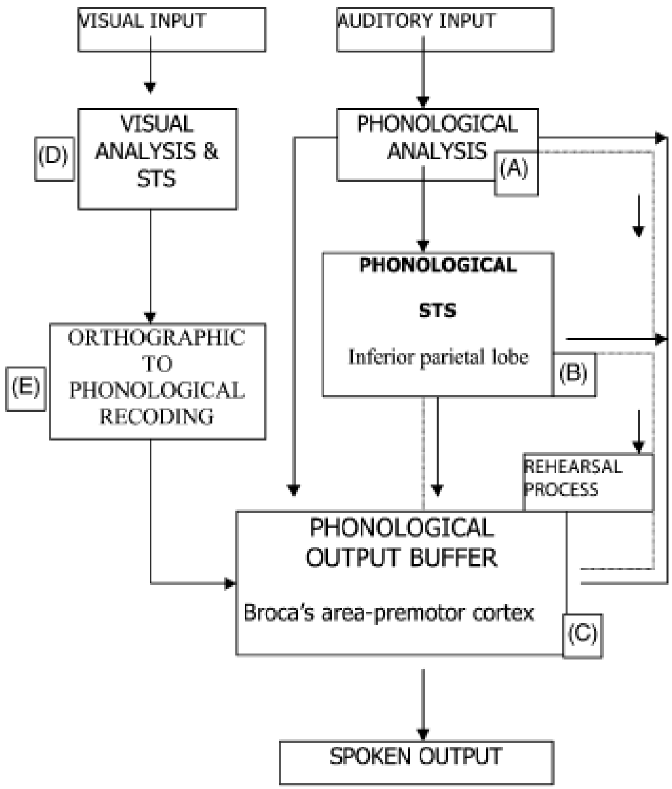


Figure 1: A proposed model of the phonological loop (Baddeley, 2003, p. 93)

The phonological working memory model has been researched extensively, largely through the related paradigms of word repetition and list recall (Baddeley, 2003). Two effects have been observed in short-term list recall that support the overwhelmingly phonological nature of short-term word storage: the phonological similarity effect and the word length effect (Baddeley & Hitch, 1994). Under the *phonological similarity effect*, there is an increased difficulty in short-term recall of phonologically similar items as compared to phonologically dissimilar items, so that, for example, "mad, cat, man…" is recalled less accurately than "mad, dog, pin..." The effect is used to support the phonological nature of word representation in short-term storage. The *word length effect* describes the pattern whereby success in short-term list recall decreases as word length increases, so that, for example, "university, refrigerator, hippopotamus…" is recalled less accurately than "wit, sum, pad..." The word length effect supports the presence of an online phonological rehearsal process, because shorter words are presumed to be rehearsed and produced at a higher rate, "leading to a greater span." (Baddeley, 2007, pp. 8-9).

An additional pattern, the *articulatory suppression effect*, has demonstrated an overlap in phonological rehearsal and speech production. When subjects are asked to speak a distractor word to themselves while remembering word lists, the word length effect disappears, indicating that the rehearsal mechanism was occupied with preparing a word for production (Baddeley, Lewis, & Vallar, 1984). Speaking distractor words at the time of list presentation also disrupts recall of visually presented stimuli (see Gathercole & Baddeley, 1993, p. 9; D. J. Murray, 1968), though not auditorily presented stimuli. The effects of articulatory suppression suggest overlap in the processes of phonological short-term recall and speech production. Particularly, the suppression of the word length effect suggests that phonological rehearsal relies at least in part on the same mechanisms as speaking.

Aided language production and phonological WM

While phonological storage appears to be a highly preferred storage modality for words, some studies have shown that short-term recall of language can also be conducted outside of the phonological domain (Hitch, Halliday, Schaafstal, & Heffernan, 1991; Pa, Wilson, Pickell, Bellugi, & Hickok, 2008; Reisberg, Rappaport, & O'Shaughnessy, 1984; Wilson & Fox, 2007), depending on the particular demands of the task. For example, in one study, subjects were trained to store lists of numbers via a sequence of finger movements, rather than phonologically (Reisberg, et al., 1984). Aided communication presents a dichotomy between input modality (spoken) and output modality (device-based), providing a unique opportunity to address effects of production on short-terms storage.

Aided language production differs from speaking in modality, organization, unit size and motor acts required for retrieval. Modality is the most obvious difference between aided AAC and speaking. Aided communication systems use some form of graphic representation of meaning, in contrast to oral language, where meaning is represented with sound. Graphic representations, typically laid out in grids of same-sized frames called ‘icons’, are often placed in semantic categories (e.g. “transportation” or “food”), syntactic categories (e.g. verbs or adjectives) and/or episodic categories (e.g. words necessary for a medical appointment) (Schlosser, 1997). Additional strategies initially help users remember where the necessary icons are located. Some strategies are based on word meanings and semantic association. For example, Unity, a system of language organization used with the Prentke Romich brand of voice output devices, uses semantic elaboration (i.e., story-telling) strategies to match a concrete picture with an abstract concept (Oxley & Norris, 2000) and semantic compaction to allow the use of “short sequences of a small number of multi-meaning icons to form words, phrases, and sentences” (Prentke Romich, 2011).

Other strategies are based on the visuo-spatial nature of the AAC system. For example, groups of icons can be color-coded for easier visual access (Thistle & Wilkinson, 2008). A few strategies make limited use of the phonological or grapheme structure of words, such as alphabetizing items within a semantic category or providing a “sounds like” feature that allows the user to find words by phonological similarity. The phonological form of a word, however, is secondary to an item’s visuo-spatial and semantic characteristics.

Another contrast between aided communication and spoken language is in the unit size of representations. While, in spoken language, words can be broken down further into syllables and phonemes, individual graphics on aided communication systems typically represent whole words or semantic, syntactic or episodic categories. Frequently, for the sake of communication rate, individual graphics represent whole phrases or sentences (Beukelman & Mirenda, 2005, p. 28). It takes a user of an aided AAC system anywhere from one to about eight access steps to access a morpheme. The number of steps necessary to produce a word is not directly correlated with the number of phonemes in the spoken version of that word. Thus, aided communicators who access graphic equivalents of whole words have limited need and limited opportunity to plan the phonological forms of words for the sake of aided production. This is particularly true for pre-literate users of aided AAC and is in stark contrast to speaking individuals, who must always attend to phonological structure of words before speaking them.

Nevertheless, just as natural speakers must plan the phoneme sequence of a word for spoken production, users of aided communication must know the system-specific sequences that represent words in aided production. While organizational strategies may initially help users learn the locations of words on complex aided communication systems, constant explicit visual searching of an AAC system presents a significant extra cognitive load on the user. In order to minimize this extra cognitive load, researchers and manufacturers of complex speech generating devices have begun to explore development of motor encoding for SGD-driven production. Akin to oral motor encoding for speaking (AAC and Autism, 2011), device-specific encoding involves creating and training to automaticity a unique motor sequence for each lexical item. The suggestion is that, when trained to automaticity, device-based motor sequences imitate planning for production in oral language. This suggestion has limited empirical but significant anecdotal support (Bidstrup & Sharp, personal communication, Nov. 2010). Because, as described above, spoken language production appears to interact with phonological storage, it is imperative to explore motor planning for the use of SGDs , including any effects that storage of these device-based motor sequences may have on existing phonological and phonetic encoding for production and storage.

Current study

The mismatch between visuo-spatial motor planning for SGD-based production and phonetic encoding for natural speech suggests that preparing for device-driven production may complement or displace phonological planning for production. Because preparing for spoken production is a process also involved in phonological storage, changing production modality from spoken to aided production may then affect characteristics of short-term word storage. The purpose of this study was to examine the relationship between modality of word production and memory for words. Characteristics of word storage have been traditionally measured through phonological similarity and word length effects in list recall. The current study compared memory for lists that were recalled via SGD to each other and to those recalled via spoken response, looking for presence and comparative size of phonological similarity and word length effects across conditions.

A description of the effects of SGD-based output on phonological memory has extensive theoretical and practical implications. A finding of decreased phonological encoding with SGD-driven responses would support a significant role for production in short-term storage. In addition, a description of effects of SGD-based output on phonological encoding could provide insight into the effects of SGD use on word learning by aided communicators, opening the way for theoretically driven studies of intervention and device design. Chapter Two expands on the relationships between word production and word storage.

Chapter 2: Background

The capacity for short-term recall and manipulation of words and non-words, known as phonological working memory (WM), is considered a key marker of early word learning (Gathercole, Willis, Emslie, & Baddeley, 1993) and a predictor of literacy development (Alloway et al., 2005), with stronger performance on working memory tasks linked to better vocabulary and phonological processing. A prominent model, introduced in Chapter One, has described phonological WM as part of a self-contained working memory system. This model is based on findings of specific performance patterns in list recall, including the word length effect, the phonological similarity effect and the effect of articulatory suppression (Baddeley, 2003), all described in Chapter One. Additional research has suggested that phonological WM is affected by several factors that are not fully accounted for in Baddeley's traditional WM model. Specifically, characteristics of short term recall reflect long-term language learning across the lifespan (Gathercole, Frankish, Pickering, & Peaker, 1999) and are immediately affected by ongoing task demands (Reisberg, et al., 1984). There is also some overlap between performance patterns in short-term recall and spoken language production. Language production via speech-generating device (SGD) presents a unique opportunity to examine aspects of the production/WM relationship, focusing on short-term and long-term effects of production on phonological storage. This chapter suggests that the presence of another means of production, particularly in the absence of spoken production, has the potential to affect short-term storage modality. To do this, the chapter begins with a brief description of phonological WM development, followed by evidence from typical spoken language production linking production processes to phonological WM performance. The next section approaches production effects on phonological storage over the lifespan by addressing WM performance in populations with profound developmental speech disorders. This is followed by evidence that short-term encoding modality can be altered by ongoing task demands. The last section considers the case of SGD-based language production and its implications for phonological WM.

WM Development

The primary research tool used to describe phonological working memory has been the list recall paradigm, including recall of digits (Dahlgren Sandberg, 2001), words (Hitch, et al., 1991; Hitch, Halliday, Schaafstal, & Schraagen, 1988), non-words (Gathercole, Frankish, et al., 1999) and letters (Conrad & Hull, 1964; Foley & Pollatsek, 1999). To study list recall, lists have been presented orally (Jarrold, Baddeley, & Hewes, 2000), as pictures (Hitch, et al., 1991; Hitch, et al., 1988) and in writing (Conrad & Hull, 1964) and subjects have been asked to provide responses by speaking (Hitch, et al., 1991; Hitch, et al., 1988), writing (Baddeley, Chincotta, Stafford, & Turk, 2002; Conrad & Hull, 1964), picking cards out of matching sets (Conrad, 1971) and judging the correctness of provided lists (Baddeley, et al., 2002; Gathercole, Service, Hitch, Adams, & Martin, 1999), as well as by pointing (Larsson & Dahlgren Sandberg, 2008; Larsson, et al., 2009). Phonological WM has been tested using the list recall paradigm across a variety of ages, from adults to children as young as 4 years old (Hitch, et al., 1991; Hitch, et al., 1988). Studies have found that the number of spoken words recalled increases from about three items at four years old to about seven items in adulthood (Gathercole & Baddeley, 1993, p. 25). In other words, short-term phonological storage becomes more efficient with age, reaching adult capacity around age 14. The other major age-related change in phonological WM is an increase in types of stimuli that trigger phonological storage and rehearsal.

Stimulus lists for recall can be spoken or presented visually. Spoken presentation of stimuli triggers phonological similarity and word length effects several years before visual presentation triggers these same effects. When presented with spoken lists, children begin to demonstrate phonological similarity and word length effects as young as four years old (Hitch, Halliday, Dodd, & Littler, 1989; Hitch, et al., 1991; Hulme, Silvester, Smith, & Muir, 1986). With picture lists, phonological similarity and word length effects first appear at about seven years old (Hitch, et al., 1989; Hitch, et al., 1988), though they can be triggered earlier if pictures are explicitly named at presentation (see Gathercole & Baddeley, 1993, pp. 28-29; Hitch, et al., 1991). Thus, children initially appear to need external support to recode visually presented items into phonological form for short-term storage. Starting after the age of seven, and through adulthood, short-term storage becomes overwhelmingly phonological for both aurally and visually presented stimuli.

In adulthood, typical speakers consistently demonstrate phonological similarity and word length effects when given both spoken and picture lists, except under conditions of articulatory suppression (Baddeley, et al., 1984; Gathercole & Baddeley, 1993, p. 9). Specifically, visually presented lists do not trigger similarity or length effects in adults when articulatory suppression is required during item presentation (D. J. Murray, 1968). As described in Chapter One, articulatory suppression during storage also eliminates the word length effect. Articulatory suppression has this effect on recall because both the re-coding of pictures into sound strings and the following rehearsal of phonological forms are done with covert speech (subvocalization). Covert speech develops through later preschool and early school years in typical children (Conrad, 1971) and plays a significant role in phonological working memory performance. The disruption of memory tasks by concurrent articulation strongly suggests a relationship between working memory and speech production, where people rely on the subvocalization component of production for re-coding and rehearsal during short-term phonological storage.

Typical Production and WM

Baddeley's 'phonological loop' model acknowledges the close relationship between covert speech and phonological rehearsal (Baddeley, 2007, p. 36). Other research suggests that spoken production is more than just a tool utilized for phonological rehearsal, but part of a complex system of influences that build our implicit understanding of the phonological structure of language.

All users of spoken languages learn the phonotactics of language, that is, the legality and prevalence of particular phoneme sequences. Phonotactic constraints are acquired by hearing language, but also at least in part through experience with spoken production (Dell, Reed, Adams, & Meyer, 2000; Warker, et al., 2009). In turn, knowledge of the phonotactics of language is useful in both remembering and producing new phonological forms. For example, in a common task used to assess phonological short-term memory, non-words with common sound sequences are repeated more quickly than those with less likely sound combinations (Vitevitch, Luce, Charles-Luce, & Kemmerer, 1997). Although the dominant direction of influence between phonological storage and production is still debated (Achelson & MacDonald, 2009), a close relationship between speaking and storage is suggested by many similarities in patterns of short term recall and spontaneous production. This includes similar types of errors (Achelson & MacDonald, 2009), and similar rates of errors in spontaneous speech and short-term list recall. Error rates in both short-term recall and spoken production reflect long-term knowledge of language phonotactics, such as better recall and faster production of high frequency than low frequency words, as well as better recall and faster production of words that sound like many other words (Gathercole, Frankish, et al., 1999; Roodenrys, Hulme, Lethbridge, Hinton, & Nimmo, 2002). In addition, spontaneous articulation rates are positively correlated with short-term phonological memory (Kail, 1997; Peeters, Verhoeven, & de Moor, 2009).

This and other similarities suggest significant overlap between the mechanisms of phonological short-term storage and spoken production, where, at minimum, spoken production affects knowledge of the phonological structure of language and underlies phonological rehearsal. Further similarities between response patterns in spontaneous spoken language and list recall have even led some to the conclusion that short-term recall of words, rather than existing as a distinct system, is conducted exclusively through long-term storage and production mechanisms (Achelson & MacDonald, 2009). Whether speech production and short-term storage reflect the same underlying process, as suggested by Achelson and MacDonald, or rely on distinct, but mutually influential, mechanisms, as presented in the phonological loop model of short-term memory (Baddeley, 2003), our ability to store and retrieve phonological forms appears to be influenced by speaking, through long-term phonological knowledge developed in part through speaking and through the reliance of phonological rehearsal on production mechanisms. The lifespan role of language production experience is also indirectly supported by a range of studies on short-term recall in developmentally non-verbal populations. These show that lifetime lack of speaking experience correlates with lower overall performance on short-term phonological storage and manipulation tasks.

Phonological WM and Atypical Production (Non-verbal Populations)

Production disorders.

Motor speech impairments severe enough to prevent individuals from producing functional spoken output may arise from one of two disorders: apraxia and dysarthria. Apraxia is "a neurogenic speech disorder resulting from impairment of the *capacity to program sensorimotor commands* for the positioning and movement of muscles…" (Duffy, 1995, pp. 4-5); that is, a disorder of motor planning. A diagnosis of verbal apraxia indicates severely affected motor plans for speech. Dysarthria, on the other hand, is "a collective name for a group of speech disorders resulting from disturbances in *muscular control over the speech mechanism* due to damage of the central or peripheral nervous system. It designates problems in oral communication due to paralysis, weakness, or incoordination of the speech musculature" (Duffy, 1995, pp. 4-5); that is, a disorder of motor execution. A diagnosis of anarthria suggests a deficit of the speech musculature that is so profound as to cause complete lack of functional speech.

Both apraxia and anarthria may be acquired or developmental. Apraxia affects motor planning for speaking. There has been a small number of studies demonstrating that acquired apraxia includes not only difficulty with speaking, but lack of word length effects in recall by apraxic subjects, suggesting that apraxia also affects phonological rehearsal for storage (Martins & Ortiz, 2009). This has been taken to indicate a reliance of short-term recall on the planning mechanisms of spoken production. Anarthria is notable for the fact that, while articulation is profoundly affected, phonological encoding for speech remains intact; that is, people can and do produce covert speech (Bishop & Robson, 1989). Developmental anarthria is a condition that frequently results from a primary diagnosis of cerebral palsy. It is the disorder most commonly addressed in studies of developmentally non-verbal populations (Owens, Metz, & Farinella, 2011, pp. 354-356). People with developmental anarthria can and do use phonological forms for short-term storage, demonstrating that overt spoken output is not necessary for phonological short-term memory (Bishop & Robson, 1989). However, phonological short-term storage in this population appears to be significantly less efficient than that of typical speaking adults, as described below.

Short-term phonological memory development in populations with SSI.

Several studies have explored phonological WM performance by people with no functional speech. In addition to the list recall paradigm described above, studies of people with profound speech impairments have also used rhyming tasks to assess phonological working memory, because rhyming requires brief maintenance of phonological forms, but has no literacy prerequisites. Rhyming tasks typically require the subject to determine whether two words rhyme or to pick a non-rhyming word out of a group (e.g. Pufpaff, 2005). Just like stimuli for list recall, stimulus words for rhyming tasks can be presented auditorily or visually. Because visually presented stimuli, but not auditorily presented stimuli, require re-coding into phonological form, differences in rhyming performance on picture vs. spoken stimuli presumably tap directly into phonological re-coding skills.

Beukelman and Mirenda, in a review of language development with AAC, report that "…although at least some individuals with [profound speech impairments] are able to analyze and manipulate phonologic information successfully, they score well below control participants on research tasks [involving manipulation of phonological information]" (Beukelman & Mirenda, 2005, p. 329). Seeking to describe patterns of development of phonological rehearsal in children with no functional speech, Murray (J. Murray, 2001 in J. Murray & Goldbart, 2009), compared children with anarthria to typical children. She found that, at the age of five, the anarthric children were "following a similar, yet delayed, pattern of memory rehearsal development" to typically developing children. Dahlgren Sandberg (2001) found that a group of school-aged children with SSI performed significantly worse on a digit span task than a group of typical children matched on chronological and mental age, suggesting that for people with SSI, deficits in phonological working memory persist into the early years of elementary school. Results of this study should be used cautiously, because groups in the study were not matched on response modality and linguistic age. To replicate the results in a more tightly controlled setting, however, Larsson, et al, (2009) compared fifteen non-verbal school-age children with SSI due to cerebral palsy to fifteen children with natural speech and no disabilities, matched for mental and linguistic age. Both groups completed a forward digit span and a backward digit span task, providing responses by pointing to numbers. In this follow-up study, the non-speaking group performed significantly worse than the comparison group on forward digit span, but significantly better than the comparison group on backward digit span, which is typically considered a more complex task. While these outcomes seem contradictory, backward digit span results were very poor across subjects, suggesting floor effects in both groups. Forward digit span results did not show floor effects and group differences in forward digit span performance indicated that children with SSI tend to be less successful with phonological WM tasks than typically developing speaking children.

In one of several studies focused primarily on literacy skills in children with no functional speech, Vandervelden and Siegel (1999) compared rhyming in three groups: non-speaking children, speaking children with speech impairments and typical speakers matched for reading level. The non-speaking group performed significantly below controls in rhyme judgment tasks. Additionally, they demonstrated more difference in picture-cued vs. speech-cued performance than both the typical group and the speech-impaired controls, suggesting that they were having disproportionate difficulty recoding picture stimuli into phonological form.

Card and Dodd (2006) gave a selection of phonemic awareness tasks, including rhyme judgment, to three groups of children similar to those in Vandervelden & Siegel (1999). The groups were matched for non-verbal intelligence and included speaking children with CP, non-speaking children with CP and typical speakers. Unlike Vandervelden & Siegel's experiments, most of Card & Dodd's tasks evoked similar performance across groups, including judging rhyme from spoken stimuli. However, given visually presented stimuli, speaking children with CP performed significantly better than non-speaking children with CP, again suggesting an impairment in phonological encoding in the non-speaking group. Results across studies of non-speaking children, therefore, suggest that, while they show a range of phonological encoding abilities, they typically fall below those of matched speaking subjects. This pattern appears to continue into adulthood.

Foley and Pollatsek (1999) looked for use of phonological coding in adult subjects with developmental anarthria and dysarthria. To do this, they administered traditional list recall tasks with response adaptations for non-speaking participants. The authors evaluated the level of phonological similarity effects through recall of consonant lists, where some consonant lists were phonologically similar (e.g. 'b, p, g") and others were not (e.g. "b, j, f"). They also looked for word length effects in word recall. Consonant lists were visually presented and word lists were auditorily presented. Subjects demonstrated recall by selecting cards with pre-printed responses or typing answers into their SGDs.

Foley and Pollatsek described several patterns that emerged from the results of this study. Two of their six anarthric participants demonstrated significant phonological similarity effects and one demonstrated significant word length effects, demonstrating that absence of functional speech from birth does not in itself preclude phonological encoding for recall. However, most of Foley and Pollatsek's anarthric participants did not demonstrate significant phonological similarity or word length effects and group-wide effect sizes in the anarthric group did not reach significance. These results pointed towards overall decreased phonological encoding and rehearsal in the anarthric group. Overall, studies of short-term recall in non-speaking subjects suggest that, although anarthric subjects can and do use covert speech, lack of functional overt speech correlates with less success in short-term list recall.

A direct effect of anarthria on phonological storage has been proposed, suggesting that, during short-term storage, lack of articulation "affects construction and storage of phonological units and leads to indistinct phonological representations that easily fade" (Larsson & Dahlgren Sandberg, 2008). Though Larsson & Dahlgren Sandberg did not propose a specific mechanism to account for the effect of non-functional speech on short-term phonological storage, one explanation of poor short-term storage by people with SSI involves phonological rehearsal. Although overt articulation is not necessary for phonological storage, lack of speaking practice also means lifelong lack of feedback from articulation and reduced opportunity for subvocalization. Given the fact that subvocalization appears to underlie phonological rehearsal, chronic lack of practice in subvocalization can mean less efficient phonological rehearsal.

In addition to ineffective rehearsal, non-functional speech may affect the quality of the phonological long-term store, as suggested in one study of lexical decision by people with anarthria. Smith (2001) tested lexical decision (recognizing words vs. non-words) and phoneme identification in a group of anarthric adults, compared to typical children matched on reading ability. Lexical decision, like rhyming, requires that the subject briefly store a phonological form as they are making a lexicality judgment. Smith found that adults with anarthria performed significantly worse than the control group on both kinds of tasks. Additionally, they demonstrated different error patterns, accepting false words as real even when they included sequences of phonemes that were illegal in English phonology. According to Smith, these results suggest that lack of experience with spoken production appears to have a discernible effect on knowledge of phonotactic constraints.

Studies of populations with SSI demonstrate that lifelong lack of spoken experience is correlated with decreased efficiency of phonological storage. Instead of speaking experience, those with SSI who use an aided communication system acquire experience with a different production modality. Several studies suggest that, depending on task demands, other modalities can be designated for language storage. Moreover, these modalities exhibit many of the same characteristics as those widely attributed to the phonological loop (Reisberg, et al., 1984).

Task Influences on Short-term Encoding

For natural speakers, sound-based encoding appears to be the most efficient modality of short-term storage (Reisberg, et al., 1984). Encoding sound strings for speaking is an over-learned process, typically supported by a massive long-term store of phonological forms and benefitting from thousands of speaking trials per day starting at a very young age, making speech-based encoding the most extensively practiced way to store and output information. Having a practiced (automated) means of storage and production significantly reduces the cognitive load of a recall task and thus improves performance (Grabowski, 2010). While phonological encoding is most typical, a range of studies demonstrates that storage modality can be adapted to task requirements.

Complete lack of sound-based input causes a complete restructuring of language storage in deaf users of formal sign languages, who store sign representations in ways that are very similar to phonological representations in hearing speakers. This is demonstrated by sign-based short-term memory effects equivalent to phonological effects. Sign-based effects include effects of similar sign structure (akin to the phonological similarity effect), and the effect of suppression through irrelevant signing (akin to the articulatory suppression effect; see Pa, et al., 2008). Even in hearing natural speakers, phonological encoding is not ubiquitous. This is particularly true in childhood, as demonstrated in recall studies of picture lists with young children (Hitch, et al., 1991). For users of spoken language, phonological encoding becomes the predominant encoding modality in the early years of school. Even those with a lifetime of spoken experience, however, can be trained to encode in non-phonological ways for short-term recall.

In an attempt to alter short-term storage modality, a group of typical subjects was trained to remember digit lists via a sequence of pre-learned finger movements that the authors called a “finger loop,” drawing a parallel with the “phonological loop” component of Baddeley’s model (Reisberg, et al., 1984). After subjects were trained to use the finger loop for recall, they were presented with numbers on a screen and asked to complete a series of digit span tasks, with the hypothesis that subjects would use their fingers, not their covert speech, to store digit lists. To determine whether subjects stored lists as a series of finger movements, authors also presented a “finger suppression” task, where subjects were required to drum their fingers on a table or perform short finger movement sequences while remembering number lists. An effect was achieved similar to that of articulatory suppression: recall became less successful when subjects drummed their fingers on a table. This indicated that drumming had interfered with finger-based rehearsal and that subjects had, in fact, been storing number lists via sequences of finger movements. In addition, effects of articulatory suppression were not observed in the finger storage condition, suggesting that subjects had shifted storage strategy completely from phonological to “finger loop” storage.

In a similar experiment, designed to create a short-term storage loop in yet another modality, Wilson and Fox (2007) demonstrated that a learning “loop” can be created outside of the phonological modality, triggered by task demands. In a study of short-term recall of non-linguistic stimuli, they asked subjects to remember sequences of gestures. Just as phonological similarity, word length and articulatory suppression typically impede recall of word lists, in this study, gesture similarity, length of gesture sequence and suppression via gesture all impeded recall of gesture lists. Thus, memory for non-linguistic gesture strings was subject to procedural effects very similar to those obtained in phonological encoding, demonstrating that short-term storage "loops" can be created across a range of modalities. Moreover, consistent use of an additional modality can build up long-term effects beyond immediate encoding.

One common type of language output used consistently throughout the lifespan is typing. In one study, fluent typists were found to demonstrate effects on letter recognition and storage that appeared to stem from motor memory for typed output. Yang, et al (2009), presented expert typists with two consecutive sets of two-letter combinations and asked them to recognize which pairs in the second set had also been presented in the first set. Although there was no typing involved in this particular experiment, fluent typists were more likely to produce a "false positive," that is, to wrongly label a letter pair as "previously seen," if the pair was easier to type, suggesting that existing typing motor plans influenced letter recognition.

There is, then, a fair amount of circumstantial evidence suggesting that short-term recall typically relies at least in part on mechanisms in spoken language production, but may adapt as necessary to task demands. SGD-based production shifts task demands of production and recall in several significant ways, discussed in Chapter One and reviewed briefly below. SGD-based recall, then, may encourage the formation of an "SGD loop" for short-term recall. Because SGD use is promoted as a lifespan activity, akin to typing, lifespan effects of this SGD loop should also be observed in lifelong users.

SGDs and Phonological Encoding

Models of SGD-based production.

SGD-based production involves access to items on a grid, initially learned through visuo-spatial and semantic cues and, presumably, eventually stored as a motor program for finger (or thumb, knuckle, or other access point) activity. The disparities between spoken and aided production, described in Chapter One, have raised theoretical questions about the psycholinguistic processes underlying SGD-based production. An unaddressed question in SGD-based production has concerned the point at which production planning enters the phase of SGD-based encoding.

As noted in Chapter One, typical spoken production involves phonological encoding (the activation of the phonological form of a selected word), followed by phonetic encoding (the adaptation of the abstract phonological form to a production context and planning of speech gestures) (Levelt, et al., 1999). Typical SGD production must, as its last step, involve a set of SGD-specific movements. Two possible production pathways both lead to the SGD-specific movements (Smith, 2006). In one model of SGD-based production, following lexical selection, aided communicators may proceed through phonological and phonetic encoding, just as typical speakers do, and only then "recode an underlying speech-based message into graphic symbols." (Smith, 2006). In other words, in this model, aided communicators first subvocalize their message, then translate it into a set of device-specific movements that access target locations on a board or screen. In the alternative model, aided communicators may follow lexical selection directly with device-specific encoding. In this case, those using an SGD may be omitting phonetic encoding, and possibly even phonological encoding, of the selected lexical item (Smith, 2006). However, there is little empirical knowledge about the aided production process.

Anecdotal reports on SGD-based production.

Research challenges.

Empirical research on psycholinguistic characteristics of aided production has been difficult, for several logistical reasons. Long-term AAC system use is always secondary to severe speech impairments which are, in turn, secondary to a wide range of neurological disorders and injury. In addition to the underlying speech impairments, the evolving nature of both aided AAC tools and intervention methods in recent years has meant that many people with SSI have gone through multiple aided AAC systems, complicating evaluation of long-term effects of aided communication.

The motor planning component of aided communication appears to be most relevant to a narrow range of systems. In order for consistent motor plans to form, it seems that several criteria need to be met. First, to facilitate the creation of a motor plan, the aided AAC tool must allow for the creation of words via access sequences with varying numbers of steps, whereas many low-cost devices typically speak a message only after a single access step (e.g., Meyer Johnson, n.d.). Second, the system or device needs to be used frequently and regularly to provide the necessary amount of practice for the creation of automated motor plans, whereas devices are frequently abandoned or used sporadically (Angelo, 2000). Most of the scarce evidence on language production via SGD has been anecdotal. Some of the studies on populations with SSI (described above) have included some subjects who used SGDs, but these have had very limited information on length and fluency of subjects' SGD use. Anecdotal reports, however, do suggest that SGD-based communicators use SGD-based encoding for at least some production. Anecdotal reports also suggest that word characteristics may affect the fluency and type of SGD-based output.

User reports of production patterns.

Many reports of automated SGD use come from personal stories and videos (Faso, personal communication, 01/2011) Fluent SGD-based communicators describe and demonstrate their use of SGDs as a process akin to "blind" typing. That is, many long-time SGD users do not demonstrate any searching behaviors while accessing icon sequences on their devices, or do not look at their device at all while they produce device-based output. This suggests the existence of fluent motor plans for SGD-based production. A pattern anecdotally observed with users of SGDs is that SGD-based communicators are more likely to use automatic motor plans for high frequency words, which consist of closed class items such as pronouns, articles and auxiliary verbs (Sharp, Bidstrup, personal communication, 11/2010). These are also known as 'core' words (The Bridge School, 2008). With less frequent items, which are known as 'fringe' vocabulary and include mostly situation-specific open class words, such as nouns, verbs and adjectives, SGD-based communicators are said to be more likely to use searching behaviors, to attempt a close substitute of the target word or, in the case of literate users, attempt to spell the target word, even when an icon sequence may be available. If, as anecdotally reported, authentic aided communicators are using SGD-based motor plans more consistently for high frequency words, any effects of SGD-based motor plans on storage may be more pronounced in recall of high frequency words. For users of SGDs, core and fringe vocabulary typically differ along several dimensions, including frequency of use of the spoken form in the SGD user's environment, frequency of access to the SGD-based sequence by the SGD user and ease of graphic representation. For the purposes of this paper, items of the type that are traditionally used in list recall tasks, aligning most closely with the 'fringe vocabulary' category, will be labeled 'picturable objects,' while the items most likely to generate an SGD-based motor plan, selected from core vocabulary of SGD users, will be labeled 'high frequency words.'

Focus on SGD-based motor planning.

The development of automatic motor plans for SGD-based production has been one of the signature components of a language intervention program run by the Prentke Romich company, a large manufacturer of dynamic screen SGDs. "Language Acquisition through Motor Planning," or LAMP, is a fairly recent intervention that claims to support the language development of early users of SGDs. The LAMP program includes a range of features that are outside the scope of this paper, such as strategies to motivate children. Relevant to this study, however, is the focus on automaticity in device-based language production (AAC and Autism, 2011). To promote automaticity in device use, the LAMP program is rooted in consistency of icon locations across the lifespan and extensive practice with frequently occurring icon sequences. The initial training program for beginning SGD users is the basis for SGD training presented to neurotypical subjects in the current study (see Chapter Three for more details). This program includes training screens where several icons at a time are activated for practice. New vocabulary is presented with brief narratives that assist in the initial encoding of icon sequences, and automaticity is trained through repeated exposure to several icon sequences at a time on a partly empty training screen.

The creation of SGD-based production plans that serve the same function as spoken motor plans has the potential to affect both immediate and lifespan language encoding strategies. Among immediate effects, to match task demands invoked by use of the SGD, people may use an SGD-specific modality for short-term storage. Among lifespan effects, because authentic aided communicators are typically hearing and receive the vast majority of their language input in spoken form, relationships must form between the store of SGD-based motor plans and the long-term phonological store. This study begins to address the nature of SGD-based encoding by addressing SGD effects on short-term phonological storage.

Present Study

To explore effects of SGD-based production on short-term encoding, this study used classic list recall tasks traditionally utilized in working memory research. In typical speakers, short-term storage modality can be affected by immediate task demands (Reisberg, et al., 1984; Wilson & Fox, 2007). Does a switch in task demands from spoken output to SGD-based output, affect the modality of short-term storage? The current study hypothesized that use of SGD-based output would activate SGD-specific, rather than phonological, short-term encoding, thereby eliminating or strongly reducing phonological similarity and word length effects.

The research question was addressed in two complementary studies. In Study One, a large group of neurotypical adults was trained in limited use of an SGD. Subjects then participated in classic working memory tasks by providing spoken and SGD-based response. The purpose of Study One was to determine modality of encoding by comparing phonological similarity and word length effects observed during spoken recall with those observed during SGD-based recall. In Study Two, four authentic, long-term users of SGDs completed phonological memory tasks using their SGDs. The aim of Study Two was to describe modality of storage preferred by aided communicators by looking for the presence of phonological similarity and word length effects. Study Two included separate assessments of high frequency words and lower frequency picturable objects.

Because anecdotal reports suggested that SGD production patterns may be different for lower-frequency picturable objects vs. for high frequency words, an additional aim of Study Two was to address anecdotal reports of differences in SGD-based production. Does SGD-based output differ for lower frequency picturable objects vs. higher frequency words? The current study hypothesized that automatic use of access sequences would be observed more often in the recall of high frequency words than in the recall of lower frequency picturable objects.

Chapter 3: Methods

Study One: Neurotypical Subjects

This study compared short-term memory of neurotypical adults for pictured lists of picturable objects under conditions of either spoken or SGD-based response.

Subjects.

Twenty four neurotypical adults (18 y.o. or older) were recruited using a local Internet advertising website (Craigslist) and campus mailing lists at SFSU. Consent for participation in the study was obtained following the guidelines of Institutional Review Boards at SFSU and UCB. All subjects had started speaking English before age 10, spoke unaccented English and received at least a high school education. Five subjects spoke additional languages, including Vietnamese, Spanish, Croatian, Cambodian and Cantonese. Of subjects who began the study, one was discontinued because she did not meet criterion for the initial training task. Other subjects completed all tasks successfully. Of the twenty three remaining subjects, nine were men and fourteen were women. The average age of subjects was 33.

Table 1: *Subject Characteristics, Neurotypical Subjects*

Number of subjects: 23	**Average subject age**: 33	**Education level:**	**Gender:**	**Languages spoken:**
		Some college: 8	M: 9	English-only: 14
		B.A. or higher: 15	F: 14	English and another: 5

Materials.

***Stimuli*.**

Three sets of eight black-and-white line drawings of common objects were selected from the IPNP database of nameable objects (Szekely et al., 2004) to be used in recall tasks (tasks are described in "Design," below). To assure consistently identical labeling across subjects, all stimulus words were selected to be highly familiar, highly picturable items with unique verbal labels. All three sets were matched for average word frequency (Brysbaert & New, 2009) and for length of access sequence on SGD using independent-sample t-tests (see Table 4). In addition, Sets One and Two were matched for number of phonemes (Coltheart, 1981). In Set One (short, phonologically dissimilar), items had one-syllable, phonologically dissimilar names (teeth, sun, kite, cake, leg, wood, fox, mask). In Set Two (short, phonologically similar), items had one-syllable names that were phonologically similar, following descriptions of phonological similarity described in prior literature (cat, hat, bag, fan, pan, hand, gas, ant; Baddeley, et al., 2002; Foley & Pollatsek, 1999; Hitch, et al., 1991; Jarrold, et al., 2000). In Set Three (long), the items had three-syllable names (butterfly, elephant, hamburger, radio, submarine, camera, potato, umbrella).

Table 2: *Word Sets, Picturable Objects*

Set	Word List
Set One (short-dissimilar)	*Teeth, sun, kite, cake, leg, wood, fox, mask*
Set Two (short-similar)	*Cat, hat, bag, fan, pan, hand, gas, ant*
Set Three (long)	*Butterfly, elephant, hamburger, radio, submarine, camera, potato, umbrella*

Table 3: *Set Characteristics, Picturable Objects*

	Average Word Frequency*	Average number of phonemes	Average length of access sequence (Unity-Seq., 60- location)
Set One	36.22	3.25	3.25
Set Two	78.10	3.13	3.13
Set Three	23.09	6.63	3.13

*SubtlexUS word frequency is # appearances per million words.

Table 4: *Set Comparisons, Picturable Objects*

	Word frequency	Number of phonemes	Length of access sequence
Set One vs. Set Two	0.21^	0.55	0.72
Set One vs. Set Three	0.34	<0.01*	0.66

^Listed are p-values based on independent-sample Student's t-test; p> 0.05 indicates no significant differences between sets

SGD.

Responses for SGD-based tasks were provided via a Vantage Lite speech generating device with the Unity language compaction system (PRC website). It is a 3 lb., 6 oz touch-screen device with dimensions 8.7"w x 9.2"h x 1.6"d and a 8.4" in. touch screen.

Figure 2: *Vantage Lite Speech Generating Device*

Design.

Subjects were given three recall tasks: Task 1 (recall of short, dissimilar words), Task 2 (recall of short, phonologically similar words) and Task 3 (recall of long words), to be completed with spoken response and with SGD-based response. Output modality (spoken vs. SGD) and word characteristic (similar vs. dissimilar and short vs. long) were manipulated as within-subjects factors. Order of task presentation was counter-balanced both for output modality and word characteristic. Each recall task consisted of six lists to recall. Each of the six lists in a task had six items (Hitch, et al., 1991). Items for each trial list were selected at random from the matching set of eight words described above (Hitch, et al., 1991; Hitch, et al., 1988) using a random number generator function in Microsoft Excel 2007. Items were never repeated within lists. Each block of six lists was presented twice; once in the spoken response condition and once, to a different subject, in the SGD response condition.

Procedure.

Subjects were tested individually in a single session that lasted approximately one hour. Word lists for each task were presented on a 14-inch computer monitor using PowerPoint 2007. Each task was completed using spoken response and using SGD-based response.

In the SGD response condition, subjects were pre-trained to produce item labels on the SGD before each task began. During SGD training, the experimenter demonstrated the access sequence for each item label on a screen where pictures were suppressed in all locations except the eight target locations ("training screen"). Modeling of the sequence was combined with a one-sentence narrative to facilitate initial access to the sequence ("About the Unity Language," 2011). After the demonstration, each subject repeated each access sequence five times on the same training screen, then twice on the full screen, with all locations showing (please see Appendices for Training Protocols). Pretraining continued until all eight items in a set were independently accessed twice on a full screen without errors. Thus, subjects practiced the SGD access sequence for each item either seven, nine or eleven times. In the spoken response condition, subjects were asked to name each drawing. On the small number of occasions when the label that a subject provided was not the intended label, the subject was told "Today we will use ____."

In each task, after all items were labeled, two practice lists of three items each were presented for recall. Presentation rate was one item every second (Baddeley, et al., 2002; Larsson & Dahlgren Sandberg, 2008). In the SGD condition, subjects were instructed not to speak words aloud, to wait until the whole list was presented (indicated by a blank screen and a beep) and then recall all items in the same order as they were presented. In the spoken condition, subjects were instructed to wait until the whole list was presented (indicated by a blank screen and a beep) and then recall all items in the same order as they were presented. After two spoken practice lists, six lists were presented for immediate recall. Subjects were encouraged to guess if they were unsure. After completing recall of six lists, subjects repeated the procedure with the next stimulus set.

Coding and data analysis.

Following Larssen & Sandberg (2008), Hitch, et al., (1988), and Hitch, et al., (1991) and Foley & Pollatsek (1999), items in each list were scored as correct if they were recalled or immediately self-corrected in their correct ordered place in the sequence.

Study Two: Authentic Aided Communicators

This study described the short-term memory of adult aided communicators during recall of picturable objects and, separately, during recall of high frequency words.

Subjects.

Four adults who used speech-generating devices (SGDs) as a primary method of communication secondary to profound developmental speech and physical impairment (cerebral palsy) were recruited through targeted e-mail and word-of-mouth within the AAC community in a large metropolitan area on the U.S. West Coast. Consent for participation in the study was obtained following the guidelines of IRBs at SFSU and UCB. The subjects included three women and one man, with the average age of the subjects being 25. All subjects used wheelchairs for mobility and had their devices mounted on their wheelchairs directly in front of them. English was the native language of all four subjects, and one subject also understood Vietnamese. All received at least a high school education and did not have diagnoses of mental retardation, according to their AAC consultant. All subjects had used their current SGD for at least two years and accessed it via direct selection for a range of independent activities, including conversation with familiar and unfamiliar partners. All had SGDs equipped with the Unity language organization system ("About the Unity Language," 2011), described in Chapter One. All subjects understood the tasks, followed directions consistently and independently answered follow-up questions about the tasks.

***Subject 1*:**

Subject AB is a 28-year-old woman who has been using her current device, a Delta Talker, for ten years. The Delta Talker is a static screen speech generating device with 128 locations in an 8 by 16 grid, organized according to the Unity language system. The Unity system includes a spelling option and the device includes a message output window where the written version of any produced message appears. AB does not have functional use of her hands and accesses her device with an optical pointer attached to the right side of her glasses. She produces language on her device through a combination of icon sequences and spelling. Using her SGD, AB communicates with familiar and unfamiliar partners and gives presentations to groups. Additionally, she uses the SGD for media access, including daily e-mail and social networking.

***Subject 2*.**

Subject CD is a 22-year-old man who has been using his current device, an Eco, for two years. The Eco is a dynamic screen speech generating device with a range of grid size options. CD uses a 144-icon interface in a 16 by 9 grid, organized according to the Unity language system, integrated with additional software called WordPower. WordPower presents high-frequency words and word parts (e.g. “to, the, -ed”) on single icons for one-step access on an SGD starter screen. CD uses the version of WordPower that provides written words, rather than line drawings (Inman, n.d.). WordPower also supports word prediction for spelling-based communication. CD does not have functional use of his hands and uses a head pointer (reflective dot in the center of his forehead) to access his device. He produces language on the device through a combination of icon sequences and spelling. Using his SGD, CD communicates with familiar and unfamiliar partners. Additionally, he uses the SGD for media access, including e-mail and social networking, and has used it to participate in community college coursework.

Figure 3: *Word Power Vocabulary Design*

Subject 3.

Subject EF is a 31-year-old woman who has been using her device, a Delta Talker, since high school. EF does not have functional use of her hands and accesses her device with an optical pointer attached to the right side of her glasses. She produces language on her device through a combination of icon sequences and spelling, with icon sequences used almost exclusively for high-frequency closed-class words and spelling used almost exclusively for all other words. Using her SGD, EF communicates with familiar and unfamiliar partners. She also uses the SGD for daily e-mail and social networking. Additionally, EF reports reading for pleasure on a daily basis.

Subject 4.

GH is a 20-year-old woman who has been using her current device, a Pathfinder, for five years. The Pathfinder is a mixed static/dynamic screen speech generating device with a 128-location (8 by 16 grid) static screen and an additional touch-screen window that supports a message output bar, word prediction and an icon row that holds nouns categorized by activity ("activity row"). The static screen is organized according to the Unity system and, like all Unity systems, supports spelling. GH accesses the device with her right thumb. She produces language on her device through a combination of icon sequences and spelling. Using her SGD, GH communicates with familiar and unfamiliar partners and gives presentations to groups. Additionally, she uses the SGD for media access, including e-mail, social networking, and writing for pleasure, as well as for community college coursework.

Table 5: *Subject Characteristics, Aided Communicators*

Subject	**Sex**	**Age**	**Communication Device**	**Software on device**	**Yrs used**	**Means of access**	**Educational level**
AB (#1)	F		Delta Talker	Unity	10 yrs	Headpointing (optical pointer)	High school
CD (#2)	M	22	Eco (144-location)	Unity, Word Power	2 yrs	Head pointing (reflective dot)	Some college coursework

EF (#3)	F	31	Delta Talker	Unity	15 yrs	Head pointing (optical pointer)	Some college coursework
GH (#4)	F	20	Pathfinder Plus	Unity	11yrs	Thumb	Student at comm. College

Materials.

Stimuli: picturable objects.

In recall of picturable objects by authentic aided communicators, the three stimulus sets from Study One (Sets One, Two and Three) were used. In Study Two, these sets were matched for average word frequency, but they were not matched for average length of SGD sequence, because each authentic aided communicator used slightly different sets of output sequences for each word. Please see Chapter Four for further analysis of output sequences used by authentic aided communicators.

Stimuli: high frequency words.

The goal of Study Two was to assess effects of SGD-based motor plans on short term recall by authentic aided communicators. Anecdotal reports of SGD use suggested that authentic aided communicators are likely to use SGD-specific sequences to produce very frequently used closed class words, whereas they may not typically use SGD-specific sequences for less frequently used words, such as object labels. Therefore, to increase the chance of aided communicators relying on SGD-based motor plans, authentic SGD users were asked to recall lists of words selected from a published compilation of 100 words most frequently used by proficient adult augmented communicators (Hill, 2001), in addition to recall of highly picturable objects. To assess recall of high frequency words, three new sets of words (Sets Four, Five and Six, see Table 6) were presented on a 14-inch computer monitor using Microsoft PowerPoint 2007. Sets Four and Five were matched for number of phonemes and word frequency (Brysbaert & New, 2009; Coltheart, 1981) using independent-sample t-tests (Jarrold, et al., 2000, see Table: Set characteristics). Set Six was limited to seven multi-syllabic words available in Hill, 2001. Though they are less frequently appearing than words in Sets Four and Five, all words in Set Six are among 100 used most frequently by aided communicators. In Set Four (short, phonologically dissimilar), items had one-syllable, phonologically dissimilar names (got, well, can, do, she, so, I, out). In Set Five (short, phonologically similar), items had one-syllable names that were phonologically similar, following descriptions of phonological similarity described in prior literature (it, is, in, this, if, with, will, which; following Foley & Pollatsek (1999), Jarrold, Baddeley & Hughes (2000), Baddeley, et al., (2002) and Hitch, et al., (1991). In Set Six (long), multi-syllabic items were used (because, people, about, device, better, different, really). All seven multi-syllabic words available in Hill (2001) were used in the recall task. High frequency words, which are predominantly closed class words and are not easily represented as pictures, were presented orthographically. Some implications of orthographic presentation are discussed in Chapter Five.

Table 6: *Word Sets, High Frequency Words*

Set	Word List
Set Four (short-dissimilar)	*Got, well, can, do, she, so, I, out*
Set Five (short-similar)	*It, is, in, this, if, with, will, which*

Set Six (long)	*Because, people, about, device, better, different, really*

Table 7: *Set Characteristics, High Frequency Words*

	Average Word Frequency*	# phonemes (MRC)
Set Four	4940	2.25
Set Five	5994	2.63
Set Six	1190	4.7

*SubtlexUS word frequency is # appearances per million words

Table 8: *Set Comparisons, High Frequency Words*

	Word Frequency	Number of phonemes
Set Four vs. Set Five	0.5^	0.32
Set Four vs. Set Six	<0.01	<0.01

^Listed are p-values based on independent-sample Student's t-test; p> 0.05 indicates no significant differences between sets

Design.

Experimental design was identical for recall of picturable objects and recall of high frequency words. Subjects were given six recall tasks: Tasks 1, 2 and 3, identical to those in the study of neurotypical subjects, as well as Task 4 (recall of short, phonologically dissimilar high frequency words), Task 5 (recall of short, phonologically similar high frequency words) and Task 6 (recall of long high frequency words). Word characteristic (similar vs. dissimilar and short vs. long) was manipulated as a within-subjects factor in list recall. Order of task presentation was balanced for word characteristic. In each recall task, subjects were given six lists. Each of the six lists in a task had six items (Hitch, et al., 1991). Items for each trial list were selected at random from the appropriate set (Hitch, et al., 1991; Hitch, et al., 1988) using a random number generator function in Microsoft Excel 2007. Items were never repeated within lists.

Procedure.

Experimental tasks.

Subjects were tested individually across several sessions. Each session lasted from an hour to two hours and subjects completed all tasks in three to seven hours. Word lists for each task were presented on a 14-inch computer monitor using PowerPoint 2007. High frequency items were presented orthographically, in black 96-point Times New Roman font in the center of a white screen. Each task was completed using SGD-based response.

In Tasks 1, 2 and 3, which involved recall of picturable objects, before beginning each recall task, subjects were asked to label each picture using their SGDs. On the rare occasions when a subject provided a label that was not the intended label, the subject was told "Today we will call this a ______." In the high frequency word condition (Tasks 4, 5 and 6), subjects were asked to use their SGD to 'read aloud' each word that was presented.

In both recall of picturable objects and recall of high frequency words, in each task, after all items were labeled, two practice lists of three items each were presented. Presentation rate was one item every second. After the two practice lists, six lists were presented for immediate recall. Subjects were encouraged to guess if they were unsure.

Interview.

Following completion of the tasks, aided communicators were asked follow-up interview questions about the tasks, including "How did you help yourself remember the lists?" (For complete list of questions, please see Appendix: Interview questions for aided communicators.)

Coding and data analysis.

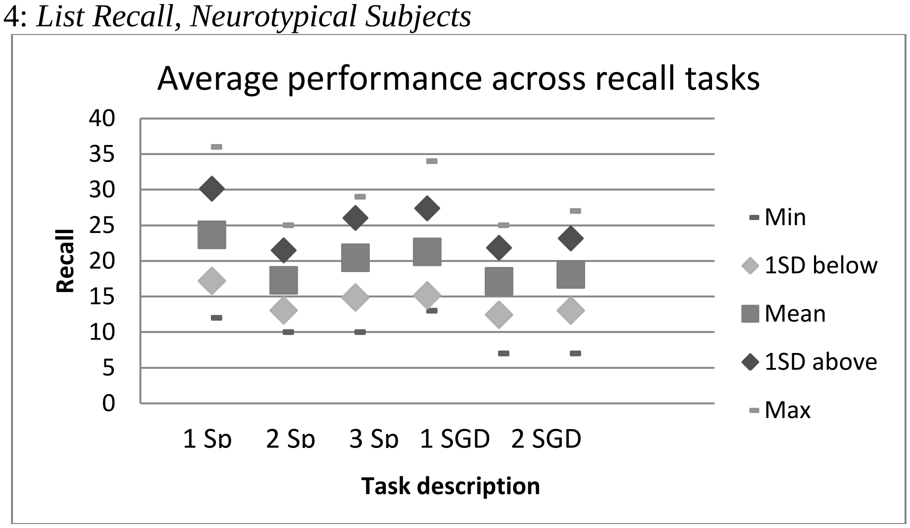
In scoring list recall tasks, following Larssen & Sandberg (2008), Hitch, et al., (1988), and Hitch, et al., (1991) and Foley & Pollatsek (1999), items in each list were scored as correct if they were recalled or immediately self-corrected in their correct ordered place in the sequence. Rates of recall of picturable objects were analyzed separately from rates of recall of high frequency words. In addition, for each stimulus word produced by each aided communicator, the subject's method of response on the SGD (icon sequence vs. spelling) and length of access sequence were described.

Chapter 4: Results

Study One: Neurotypical Subjects

The purpose of Study One was to compare short-term memory for picture lists in neurotypical adults under conditions of spoken and SGD-based response. Subjects were expected to show a significantly smaller phonological similarity effect in the SGD response condition than in the spoken response condition. Likewise, subjects were expected to show a significantly smaller word length effect in the SGD response condition than in the spoken response condition. Figure 1 demonstrates average task performance of neurotypical subjects. Performance on each individual task was normally distributed (please see Appendix A: normality distributions).

Figure 4: *List Recall, Neurotypical Subjects*



Phonological similarity effect

Table 9 shows the mean number of items recalled in the correct serial order for each condition in Tasks 1 and 2. These data were analyzed using a two-factor, repeated measures, ANOVA design, with factors being word characteristic (dissimilar vs. similar) and output modality (spoken vs. SGD). The analysis revealed a significant main effect of word characteristic [$F(1,21)=30.449$, $p<0.001$], due to poorer recall of phonologically similar words. There was no evidence of a significant main effect of output modality [$F(1,21)=1.730$, $p=0.202$]; that is, recall was not significantly different in the SGD condition than in the spoken condition. The word characteristic by output modality interaction was also not significant [$F(1,21)=2.439$, $p=0.133$]; that is, phonological similarity of words was equally damaging to spoken and SGD-based recall. These analyses demonstrate that phonological similarity of words has a detrimental effect on short-term recall across output modalities, suggesting that items are encoded phonologically for both spoken and SGD recall.

Table 9: *Phonological Similarity Effect, Neurotypical Subjects*

Spoken		***SGD***	
Task 1 (Dissimilar)	*Task 2 (Similar)*	*Task 1 (Dissimilar)*	*Task 2 (Similar)*
Mean 23.65	Mean 17.26	Mean 21.26	Mean 17.13
SD 6.47	SD 4.21	SD 6.11	SD 4.7

Note 1: The maximum number of correct responses for each task is 36.
Note 2: Data for each task were normally distributed (see Appendix D: Distribution of Subjects' Performance, Neurotypical Subjects)

Word length effect

Table 10 shows the mean number of items recalled in the correct serial order for Tasks 1 and 3. These data were analyzed using a two-factor, repeated measures, ANOVA design, with factors being word characteristic (short vs. long) and output modality (spoken vs. SGD). The analysis revealed a significant main effect of word characteristic [$F(1,21)=13.821$, $p=0.001$], due to poorer recall of long words. There was evidence of a significant main effect of output modality [$F(1,21)=6.691$, $p=0.017$], due to poorer recall of words in the SGD response condition. The word characteristic by output modality interaction was not significant [$F(1,21)=0.001$, $p=0.979$]; that is, increased word length was equally damaging to recall in the spoken and SGD response conditions. This analysis demonstrates that increased word length has a detrimental effect on short-term recall across output modalities, suggesting that items are rehearsed phonologically for both spoken and SGD recall. Changing output modality from spoken to SGD response also has a detrimental effect on recall.

Table 10: *Word Length Effect, Neurotypical Subjects*

Spoken		***SGD***	
Task 1 (Short)	*Task 3 (Long)*	*Task 1 (Short)*	*Task 3 (Long)*
Mean 23.65	Mean 20.43	Mean 21.26	Mean 18.09

SD 6.47	SD 5.58	SD 6.11	SD 5.06

Note 1: The maximum number of correct responses for each task is 36.
Note 2: Data for each task were normally distributed (see Appendix D: Distribution of Subjects' Performance, Neurotypical Subjects)

Both sets of results consistently demonstrate effects of word characteristics on short-term list recall. While no main effects of SGD use are demonstrated in comparisons of phonological similarity, a significant main effect of SGD use is demonstrated in comparisons of word length. Because SGD response requires additional new skills in comparison to spoken response, subjects are expected to be less successful with SGD response than spoken response. Analysis of SGD effects within individual tasks demonstrates significant difference between SGD and spoken response in Task 1 (recall of short, dissimilar words; paired sample t-test, one-tailed, p=0.043) and Task 3 (recall of long words; paired sample t-test, one-tailed, p= 0.022, both due to poorer performance in the SGD condition. There is no indication of significant difference in performance between SGD and spoken response in Task 2 (phonologically similar words; paired sample t-test, one-tailed, p=0.45). All comparisons are consistent in not demonstrating any interaction between word characteristics and output modality.

Study Two: Aided Communicators

The purpose of Study Two was to describe the short-term storage modality of adult aided communicators. Aided communicators were expected to demonstrate limited phonological similarity and word length effects. To imitate conditions presented to neurotypical subjects, aided communicators were asked to recall lists of picturable objects. In addition, to assess short-term recall of words most likely to have robust SGD-based motor plans, subjects in this study were asked to recall lists of words used most frequently by aided communicators (Hill, 2001), also sometimes called "core" words (The Bridge School, 2008). Core words, which are primarily closed-class words and difficult to picture, were presented to subjects in writing. Therefore, each effect was evaluated using both picturable objects ('fringe') and high-frequency ('core') words. Because of the small number of subjects, the Wilcoxon signed-rank test was used to analyze data. The Wilcoxon signed-rank test is used in place of a t-test with samples that cannot be assumed to be normally distributed, such as samples with small numbers of subjects. It is calculated by assigning a rank (first, second, third, etc.) to each value in a sample to determine whether groups of data points cluster in high ranks or low ranks. Following the ranking, a p-value is assigned using a pre-calculated p-value table to determine statistical significance of the distribution (McDonald, 2009).

Phonological similarity effect.

Table 11 shows the number of items recalled in the correct serial order for each condition. These data were analyzed using the Wilcoxon signed-rank test. Analysis revealed no phonological similarity effect in the recall of picturable objects (p>0.2). Although the lack of phonological similarity effect appears consistent with the study hypothesis, further analysis of the data indicates that, in this condition, at least two of the subjects appeared to respond no better than chance (Subjects 2 and 3). This suggests that study results were influenced by floor effects, discussed further in Chapter Five.

In recall of high-frequency words, the phonological similarity effect approached significance (0.1>p>0.05). Given the very small number of subjects, a result that approaches significance suggests that subjects are likely to be encoding high-frequency words phonologically.

Table 11: *Phonological Similarity Effect, Aided Communicators*

	Picturable Objects			**High Frequency Words**		
Subject #	Number of items recalled (out of 36)		*Difference*	Number of items recalled (out of 36)		*Difference*
	Dissimilar	Similar		Dissimilar	Similar	
1	12	8	*4*	16	11	*5*
2	6	8	*-2*	11	9	*2*
3	6	8	*-2*	18	11	*7*
4	17	20	*-3*	18	14	*4*

Word length effect.

Table 12 shows the number of items recalled in the correct serial order for each condition. These data were analyzed using the Wilcoxon signed-rank test. Analysis did not demonstrate a word length effect in recall of picturable objects ($p>0.2$) or high-frequency words ($p>0.2$). Further analysis of the data indicates that, in the recall of picturable objects, results were affected by the same low scores of Subjects 2 (short words) and 3 (short and long words). This, again, suggests that study results were influenced by floor effects.

Table 12: *Word Length Effect, Aided Communicators*

	Picturable nouns			**High frequency words**		
Subject #	Number of items recalled (out of 36)		*Difference*	Number of items recalled (out of 36)		*Difference*
	Short	Long		Short	Long	
1	12	8	*4*	16	8	*8*
2	6	10	*-4*	11	9	*2*
3	6	5	*1*	18	12	*6*
4	17	11	*6*	18	21	*-3*

To augment findings from the small data set, aided communicators were asked to report on tools and strategies that they used to remember words (please see Appendix C: Interview Questions for Aided Communicators). Subjects' responses suggest a combination of phonological, visuo-spatial and motor encoding and storage. Two subjects (2 and 4) reported that they hear the words to be recalled in their heads, one subject (Subject 3) primarily spelled responses and reported hearing them in her head. Subjects also reported use of other strategies, such as remembering drawings as they were presented on the screen (Subject 2) and overt rehearsal of the device-based access sequence (Subject 1).

Spelling vs. icon sequencing by aided communicators.

Anecdotal evidence has suggested that literate users of SGDs, and particularly users of Unity systems, which provide quick access to spelling, may attempt to spell lower frequency (‘fringe’) vocabulary rather than use icon sequences, even when icon sequences are available for the fringe vocabulary. Therefore, data was collected on method of encoding for all sets of picturable objects and for all high frequency word sets, across subjects. Table 13 presents the proportion of icon sequence use for each task conducted with aided communicators. For example, in “Picturable objects, Task 1,” Subject 1 used icon sequences for five words out of the eight-word set used in the recall task. The other three words in the set were consistently produced via spelling. Icon sequences were typically Unity-based sequences. For Subject 2, however, the category “icon sequence” includes sequences produced via WordPower software. CD’s version of WordPower represented whole words on single icons. Even though these words were presented orthographically, the use of whole words made WordPower closer to icon sequences than to spelling. Across subjects, spelling includes use of word prediction.

Table 13: *Proportion of Icon Sequences Used Per Task*

	Subj 1	**Subj 2**	**Subj 3**	**Subj 4**
Picturable objects:				
Task 1	5/8	4/8	0/8	8/8
Task 2	5/8	4/8	0/8	8/8
Task 3	7/8	8/8	0/8	7/8
High frequency words:				
Task 4	8/8	5/8 (all wp)	2/8	8/8
Task 5	8/8	7/8 (all wp)	5/8	8/8
Task 6	7/8	4/7	6/7	6/7

Note: wp-WordPower

Data on use of spelling vs. icon sequence were analyzed using a Latin Square Design. A Latin Square Design is useful in analyses where several confounding factors (in this case, word characteristic and subject number) need to be considered, and in groups with small numbers of subjects ("Latin Square Design," 2011). Tasks 1, 2 and 3 (that is, tasks using short words, similar words and long words) were combined into the category “picturable objects.” Tasks 4, 5 and 6 were combined into the category “high frequency words.” This created the independent variable of stimulus characteristic (picturable objects vs. high frequency words). Subjects were also treated as an independent variable and subjects’ rate of icon sequence use was the dependent variable.

Use of icon sequence was found to vary significantly by subject ($p<0.001$), with Subjects 1 and 4 using icon sequences for the majority of recall tasks. Subject 2 used icon sequences, including WordPower, for about half of all presented items, while Subject 3 used icon sequences for less than a quarter of all presented items. Use of icon sequence also varied significantly by stimulus characteristic (picturable objects vs. high frequency words, $p=0.038$), with subjects using significantly more icon sequences for high frequency items. This finding supports anecdotal reports that users of Unity systems take advantage of icon sequences more often when needing to produce high frequency words than when they are producing fringe vocabulary such as object labels.

Overall success rates, picturable objects vs. high frequency words.

For neurotypical speakers, short-term recall is more successful with higher frequency items (Gathercole, Frankish, et al., 1999). To assess whether authentic aided communicators were more successful with higher-frequency items, each subject's scores from Tasks 1, 2 and 3 were combined to form a "picturable objects" score and each subject's scores from Tasks 4, 5 and 6 were combined to form a "high frequency words" score. The total scores for picturable objects and high frequency words were compared using the Wilcoxon signed-rank test. The difference between recall of picturable objects and high frequency items did not reach a significance cut-off (p=0.1). Further analysis demonstrates, however, that the result of the Wilcoxon test was affected by the high scores of Subject 4, as well as the very small number of subjects. All subjects were more successful with high frequency recall than picturable object recall (see Table 14), and, given the small number of subjects, p=0.1 suggests a trend towards significant differences in performance between recall of high frequency words and picturable objects.

Table 14: *Recall Success of Picturable Objects vs. High Frequency Words*

Subject #	**Picturable objects – total recalled in Tasks 1, 2 and 3**	**High frequency words – total recalled in Tasks 4, 5 and 6**
1	28	35
2	24	29
3	19	41
4	48	53

Summary of Results

The results of Study One demonstrate continued reliance of neurotypical subjects on phonological encoding for SGD-driven list recall. The results of Study Two are more difficult to interpret, due to the small number of subjects and floor effects across several tasks. Overall, Study Two suggests a reliance on phonological encoding for high-use words, with inconclusive results for the lower frequency sets of picturable objects. The results are discussed in Chapter Five.

Chapter 5: Discussion

The overall aim of the current study was to examine the effects of output modality on short-term memory. This goal was achieved by describing list recall of neurotypical adults trained on use of SGDs, as well as by description of list recall conducted by a small group of authentic aided communicators. This chapter discusses performance by neurotypical subjects, then performance by aided communicators. It concludes with a general discussion.

Neurotypical Subjects

Phonological similarity.

The results of this part of the study replicate previous findings that phonological similarity of words has a detrimental effect on serial list recall (Lobley, Baddeley, & Gathercole, 2005). The main purpose of this part of Study One was to determine whether there is an interaction between word characteristic and output modality, so that phonological similarity of words may have less a detrimental effect with a non-speech output modality. The current study does *not* suggest any changes in the size of the phonological similarity effect when the output modality is changed from spoken to SGD-based output. This demonstrates that typical speakers continue to encode items phonologically even when the task involves non-phonological input and output modalities. .

Word length effect.

The results of this study replicate previous findings of increased word length having a detrimental effect on serial list recall. The main purpose of this part of Study One was to determine whether there is an interaction between word characteristic and output modality, so that word length may have a less detrimental effect with a non-speech output modality. The current study does *not* suggest any changes in the size of the word length effect when the output modality is changed from spoken to SGD-based output. This demonstrates that subjects continue to rehearse items phonologically even when the task involves non-phonological input and output modalities.

General discussion of neurotypical subjects' performance.

Broad implications of findings.

Results of list recall by neurotypical subjects do *not* suggest that SGD-based output makes short-term memory less sensitive to word length and phonological similarity. The results can be interpreted by assuming that subjects are using phonological encoding and subvocalization to maintain lists in both spoken and SGD conditions, unaffected by a change in output modality. These results speak against immediate effects of output modality on storage, but they leave room for multiple interpretations of the reasons for this lack of effects.

Lack of automaticity of SGD-based output .

It is possible that no SGD-based output plans were formed during training time. SGD-based production was a new skill set, introduced to speaking subjects with a single training of about twenty minutes (Reisberg, et al., 1984; Wilson & Fox, 2007). As described in Chapter Four, SGD-based response negatively affected list recall performance in two out of three conditions (short-dissimilar words and long words). This suggests that SGD-based response was likely causing additional cognitive load, possibly because it was not completely automated and subjects were forced to search for icon sequences. Over the course of SGD-based tasks, slightly less than half of all neurotypical subjects demonstrated one or two searching behaviors, and two subjects demonstrated over five searching behaviors, also suggesting incomplete automaticity.

Nevertheless, the vast majority of subjects were observed to have fluent mastery of the vast majority of icon sequences during recall; that is, they completed icon sequences independently, without pausing, and showed very limited searching behaviors. During SGD-based output, neurotypical subjects also demonstrated several response patterns that suggested at least some use of SGD-based motor plans for output. Several subjects made errors by hitting locations that bordered on target icons. This can be explained with the assumption that subjects had broad knowledge of target icon location, but either lack of detail on the motor plan or lack of fine motor control caused them to hit slightly off-target. In a similar pattern, some subjects produced icon sequences in a way that appeared to combine motor planning and visual search. For one or more icons in a sequence, subjects quickly moved their finger to a small (about 2x2 icons) area of the screen that included the correct icon, then hovered briefly over that small area, apparently using visual search to select the right icon within that small area. This can again be explained by assuming that subjects had broad knowledge of the SGD-based production plan, but required visual support at the end of some moves to hit the precise location. One subject directly reported strategically remembering SGD-based sequences, saying that “you remember a pathway, for example, three things you press that are always on the right-hand side.” Based on observation of SGD-based production, it is likely that general SGD-based output plans were formed for the vast majority items in the list recall. However, the output plans could have been imprecise, and a few items may have lacked complete automaticity, causing minor delays in SGD-based output.

Whatever SGD-based motor plans were formed, they appear to have been used primarily for output, pre-empted by phonological forms in storage and rehearsal. This could be an indication that production modality does not affect word storage and that word storage relies exclusively on phonological forms (Baddeley, 2003). It is equally likely, however, that the use of phonological encoding by neurotypical subjects was determined by the higher effectiveness of speech-based than SGD-based encoding in this particular task. If it is true that SGD-based encoding, although fluent, was not entirely automated, then it was not a good enough strategic choice for neurotypical subjects. The deficiency in SGD-based automaticity may have been exacerbated by the highly picturable nature of the stimulus set.

Tendency towards verbal labeling of stimulus sets.

To facilitate training, and in line with prior list recall literature (Hitch, et al., 1989), stimulus pictures were highly picturable objects. Prior studies have suggested, however, that adult neurotypical speakers have a strong tendency to provide covert verbal labels for nameable pictures and even to invent verbal labels for unfamiliar items or events (Wilson & Fox, 2007). The highly nameable nature of the stimuli in Study One is likely to have facilitated and, in fact, encouraged, verbal labeling of stimulus items. With adult subjects, SGD-based output may have more pronounced effects on storage modality when combined with stimulus sets for which verbal labels are not readily available. In addition to a strong tendency to label, adults have also had a lifetime of experience with memory-enhancing strategies, many of which rely on speech-based encoding. Some of these strategies are described below.

Verbal strategies in support of storage.

Most typical adults are familiar with some common strategies that are believed to support short-term verbal recall. One strategy that supports recall involves joining unrelated word lists into sentences, as in “the cat saw a hat on the ant” for the list items “cat, hat, ant”. The use of sentences presumably provides semantic support for recall and joining words into sentences was a strategy that multiple subjects reported trying during the recall tasks. For neurotypical subjects, this strategy must have necessitated accessing the phonological forms of list items, because subjects did not have any experience formulating complex language via SGD.

Another strategy reported by subjects was the use of the first letters of list items, so that they remembered “a, c, h” for “ant, cat, hat”. This strategy requires access to phonological or grapheme representations of list items. Used consistently in verbal-only recall, this strategy actually takes the focus off the full phonological forms that trigger similarity and length effects, and thus may reduce effects of phonological similarity and/or of word length. However, in the current study, the use of the first-letter strategy must have interfered with any device-based encoding in favor of phonological encoding.

Other strategies reported by subjects included the use of different pitch for each set of three items, so that, in the list “teeth, sun, kite, cake, leg, wood”, the set “teeth, sun, kite” was rehearsed (covertly!) in a high pitch and “cake, leg, wood” was in a low pitch. This strategy also required verbalization of target items. Though the pitch-difference strategy was unique to one subject, all storage strategies that subjects reported were verbal strategies, so that, in order to use these strategies, subjects needed to access the phonological forms of list items.

Voice output on SGD

In the SGD-based output recall condition, neither the stimuli nor the production plan necessarily required access to the phonological forms of words. However, all subjects heard the spoken labels of the stimuli at the conclusion of their SGD-based output. Thus, the phonological forms of all the stimuli had been accessed within seconds or minutes of each recall task, possibly facilitating access to the phonological forms of stimuli. There is some limited evidence that suggests that voice output in AAC may encourage attempts at verbalization in authentic AAC users (Millar, Light & Schlosser, 2006). The effects of the voice output component of SGDs on language encoding modality require further evaluation. One way to address voice output effects on encoding modality is to evaluate SGD-driven short-term recall with and without the speech generating component.

Modality effects and age.

As it stands, this study did not demonstrate any effects of output modality on storage in adults. These results are consistent with short-term memory research that suggests adults are highly inclined to phonological storage (Baddeley, 2003). Children, however, are less likely to name and phonologically rehearse visually presented stimuli (Hitch, et al, 1991), presumably because their phonological storage systems are less practiced and less efficient than those of adults. Current best practices in language intervention for children with SSI recommend introducing aided communication at young ages to facilitate language development (Cress & Marvin, 2003). SGD-based output may have stronger immediate effects on the storage modality used by younger children, who have not yet developed efficient phonological storage mechanisms. Childhood, up to five years of age, is also the age at which phonological short-term memory is presumably used most intensively in word learning (Gathercole & Baddeley, 1989), so earlier influences on phonological storage may have farther-reaching consequences in language acquisition. Use of SGD-based motor plans needs to be evaluated separately in children. If SGD-based motor plans are, in fact, used for language encoding by children with SSI, clinicians and educators of these children need to decide how SGD-based encoding of language can be used to support phonological encoding of language.

The development of an efficient SGD-based encoding mechanism early in childhood has more potential for both immediate and lifespan effects on modality of word storage than the development of this mechanism later in life, when more phonological experience has been had. However, early, ongoing, motorically consistent use of SGDs is actually quite rare, with children much more likely to receive their devices in elementary school or later and go through a range of different devices, as demonstrated by the authentic aided communicators, discussed next.

Aided Communicators:

Phonological similarity.

The main purpose of this part of Study Two was to determine whether long-term users of SGDs demonstrate phonological similarity effects in short-term recall. In the evaluation of phonological similarity effects with authentic SGD users, results of recall of picturable objects are inconclusive due to floor effects. With recall of high-frequency lists, which was much more successful overall, the phonological similarity effect approached significance. This suggests that aided communicators were encoding lists phonologically for recall of high-frequency words.

Word length.

The main purpose of this part of Study Two was to determine whether long-term users of SGDs demonstrate word length effects in short-term recall. With word length, as with phonological similarity, results of recall of picturable objects are inconclusive due to floor effects. Results of recall of high-frequency lists, which was much more successful overall, are inconclusive on the question of word length effects. Although the word length effect did not approach significance in recall of high-frequency words, three out of four subjects were more successful with recall of short words than recall of long words.

During recall of picturable objects, across tasks, two subjects consistently used the spelling capacity of their SGDs to spell several words in the set and one subject consistently spelled all words in the picturable object set, suggesting certain orthographic and likely phonological encoding. Below, some implications of results with high frequency and picturable object recall are discussed. Before discussing word characteristics, it is also useful to reconsider the linguistic status of the aided communicator participants.

General aided discussion.

Effects of subject characteristics.

Length of device use.

The current study contrasted "neurotypical speakers" with "authentic" aided communicators. A closer look at the aided communicators suggests that, although the aided communicators are genuinely fluent, long-term users of their devices, they are not early and native users of device-based encoding; that is, they began using devices at a much later age than speaking children begin to speak. All of the participants reported receiving devices in high school or later. Participant 4, GH, prior to her current device, had a device that was organized according to the Unity language system just like her current device. Of all the authentic SGD users, therefore, she has had the most continuous years of practice with a consistent set of motor plans. However, none of the participants, including GH, had devices like these before elementary school. This means that the participants were exposed to the phonological forms of words for many years before their first exposure to device-based production plans. Thus, the input-output dichotomy is unbalanced. The participants have not had equal exposure to spoken and device-based representations; rather, they are early recipients of spoken language, with device use and planning for device production coming in as a distinct secondary modality after years of hearing spoken language, and possibly after initial literacy instruction. This is reflected in subjects' use of their devices and their storage strategies.

When asked about strategies for short-term storage, all four subjects reported using some type of speech-based encoding for recall. CD reported hearing the list items in his head, EF used spelling for a large number of the items and GH reported making sentences in her head to support recall. AB was the only one to report strategically using device-based icon sequences for storage. She also reported using phonological encoding, however. For example, in one task, AB attempted to use the icon for "ship" instead of the target icon of "submarine" in one of the recall tasks. On this occasion, she reported that she remembered the phonological form "submarine" throughout the task, and only changed the output to "ship" when she couldn't immediately find the "submarine" icon on the screen.

A turning point in the use of phonological forms occurs between the ages of five and eight. Around this age, neurotypical children expand their use of phonological encoding from spoken stimuli to those presented both aurally and visually (Hitch et al, 1991). This appears to be the time when children develop enough phonological knowledge for phonological encoding to become the most effective method of storage, even for non-spoken input. In the experience of aided communicators described in this study, devices were introduced several years after this time. Even when implemented in later years, introduction of a new output modality still has potential to affect encoding. Brief use of a new modality affects encoding in concurrent tasks requiring use of that modality, as in the 'finger loop' task (Reisberg,1984, Wilson & Fox, 2007). Extended use of a new modality has been found to affect encoding even in tasks where that modality is not utilized. This was demonstrated by a study of fluent typists, described in Chapter Two, who, even with no keyboard in front of them, were influenced by locations of letters on the QWERTY keyboard when making familiarity judgments for letter combinations (Yang, et al., 2009). Thus, even late introduction of SGDs may lead to device-based encoding. Any long-term effects of output modality, however, are likely to be more pronounced the earlier the modality is introduced. As the price of SGDs falls and the familiarity of SGDs increases, we may be more likely to see earlier and more consistent use of SGDs by younger children, who will begin to produce device-based output at an age similar to when neurotypical children begin to talk. Thus, while current results do not demonstrate any significant effects of output modality on phonological storage in literate adults, earlier and more consistent implementation of device use may generate different results.

Automaticity and timing of different access methods.

Aided communicators in this study were required to be direct selectors, that is, to be able to access all icons on their screen, rather than using a single switch to scan through all screen locations. However, the four direct selectors differed in methods of direct access and in levels of physical impairment. Only one participant, GH, accessed the device with her hand, using her right thumb. Two participants used optical pointers attached to the right side of their glasses, and another used a reflective dot on his forehead to access the SGD. Essentially, three of the subjects used their heads for device access. The head is larger than fingers and is not typically used by neurotypical individuals for discreet fine motor tasks such as the selection of icons on a screen. It is not surprising, then, that participants AB, CD and EF, who used head-pointing, were much slower with their responses than participant GH, who used her thumb. It is possible that precise head movement requires more cognitive and physical control than precise finger movement.

In measuring response time, a consistent distinction could not be made between time required to recall a word and time required to actually produce that word, because the two processes had very similar outward representations, including pausing and hovering. However, response time was observed informally. While GH produced words as fast as device parameters allowed her, at less than one second per hit, participants CD and EF frequently required up to ten seconds to access each part of a sequence. These rate differences were maintained in spontaneous conversation, supporting the theory that it was access time, not recall time, that was affecting rates of production. Participant AB also showed frequent spans of uncontrolled athetoid movement that prevented any device access for 30 seconds or longer. Increased response time negatively affects recall (Baddeley & Hitch, 1994), which may explain in part why GH was so much more successful with recall across conditions.

Effects of word characteristics.

Phonological similarity and word length.

Although study results are inconclusive with regard to effects of phonological similarity and word length on recall of picturable objects, because of floor effects across recall tasks, results of high frequency word recall show a trend towards phonological encoding, with all four subjects performing better on phonologically dissimilar words than phonologically similar words, and three out of four subjects performing better on short words than long words, tentatively suggesting phonological encoding of list items. Further research is necessary to address encoding by users of SGDs, because of lack of conclusive results and considering the output differences between core and fringe word conditions, described below.

Picturable objects vs. high frequency words.

There has been a distinction made in the AAC literature between high frequency 'core' words and lower-frequency 'fringe' vocabulary such as item labels (Beukelman & Mirenda, 2005, pp. 29-30). Fringe and core tasks in this study differed on several parameters, including word frequency, input modality (written vs. pictured) and output modality (mostly device-specific vs. mostly spelled).

Though the lists differed along several dimensions, discussed above, in the following discussion they will be labeled 'high frequency' vs. 'picturable object' lists, according to the primary goals pursued in their initial selection. Subjects' performance in list recall demonstrated a trend towards better performance with high frequency lists than picturable object lists. This trend is not surprising and can be attributed to a variety of factors, both phonological and SGD-driven. Picturable objects were presented as pictures, while high frequency words, which are not easily picturable, were presented in writing. In addition to general difficulties with phonological storage, people with SSI are known to be particularly inefficient in recoding pictures into phonological forms (Card & Dodd, 2006). Though it is possible that re-coding orthography into phonological form was easier for these subjects than re-coding pictures into phonological form, it seems unlikely that naming common pictures would cause highly literate adults to get the extremely low results shown in the picture recall tasks, given that all participants successfully named all the pictures before beginning the recall task. Rather, other considerations may explain better core word performance. Higher phonotactic frequency of core words makes their phonological forms easier to recall (Gathercole, Frankish, et al., 1999). High frequency words have shorter device-based access sequences than object labels do. In addition, subjects take advantage of device-based sequences in production more often with high frequency words than with object labels, making the access sequences more robust and faster to produce via SGD.

Faster production time results in better recall for neurotypical speakers, and, given the time it took for several of the users to access each step of an SGD sequence, shorter sequence length must be a significant contributor to recall success.

In the recall of picturable objects and high frequency words, participants demonstrated more frequent use of icon sequences for high frequency vocabulary than for object labels, even though all object labels in study tasks could be accessed through icon sequences programmed in subjects' SGDs. This is consistent with prior anecdotal evidence suggesting frequent use of icon sequences for core, but not fringe, vocabulary (Bidstrup, Sharp, personal communication, 11/2010). Subjects gave two reasons for their use of spelling vs. icon sequence. They reported not knowing the sequence for a particular item label, even though it was available in their SGD, and/or reported and demonstrated knowing the sequence, but indicated that they preferred to spell. On several occasions, subjects also switched between spelling and icon sequence for the same item. Spelling of fringe vocabulary suggests that subjects must encode phonologically and/or orthographically when producing less frequent words. Whether the process of spelling via SGD also involves a motor plan, akin to the way that typing involves both orthography and keyboard-based motor plan, is not clear from this study. Further research is necessary to describe the number and type of word representations stored by SGD users, which is likely to include phonological, SGD-based and traditional keyboard-based representations. It is also necessary, in future study of SGD-based language, to make careful distinction between tasks that assess the use of high frequency 'core' vocabulary vs. open class 'fringe' vocabulary such as nouns. The small number of subjects makes these findings inconclusive, but the observations provide a first step towards empirical description of authentic device-based production, focusing on differences between core and fringe vocabulary.

Broadly, the recall results demonstrated by aided communicators support findings across literature on subjects with SSI (e.g.Foley & Pollatsek, 1999), which finds that people with no functional speech since birth do tend to encode phonologically for short-term storage and demonstrate a range of list recall skills. People with no functional speech typically perform worse than speaking subjects, but some people with SSI, such as GH, fall well within the range of typical performance.

General Discussion

Summary.

On balance, the results of both studies suggest that phonological short-term memory is resilient both to long-term changes in output modality, as with authentic long-term users of SGDs, and immediate changes in output modality, as with neurotypical subjects trained in SGD use over a single session. That is, subjects continue to demonstrate phonological similarity and word length effects and continue to report phonological encoding, even when output modality is altered. These results can be interpreted in two ways.

One interpretation suggests that the phonological loop, including phonological storage and rehearsal, is a dedicated mechanism distinct from and unaffected by output modality. Another interpretation suggests that phonological storage, rather than being generally unaffected by task demands, was the most obvious choice for storage in this study because it was supported by years of practice with phonological forms via both input and output, as well as because of the highly nameable nature of stimulus pictures and due to the high literacy levels of all subjects involved. The strategic choice explanation is more consistent with findings that children are not, in fact, storing all stimuli phonologically (Hitch, et al., 1991), as well as the finding that, when given stimuli less available to verbal labeling, adults do readily use other storage modalities (Wilson & Fox, 2007). While this study showed subjects using phonological encoding for short-term storage, further research is necessary to address the possibility and characteristics of concurrent activation of SGD-based production plans.

Limitations of the current study.

Testing effects of SGD use presents challenges related to the low incidence and varied profiles of populations requiring SGDs. The current study looked at a very small group of authentic SGD users, limiting the ability to analyze and generalize study findings. Within the small group, the severity of motor impairments of several subjects resulted in inconsistent performance on the recall tasks. Interpretation of results in Study Two was also confounded by different presentation modality of high frequency words vs. picturable objects.

Training of neurotypical subjects is one way to analyze SGD effects separately from primary effects of the speech impairment that has been used in other areas of AAC research (Binger & Light, 2008; Trudeau, Sutton, Dagenais, de Broeck, & Morford, 2007). In the current study, the extensive experience of neurotypical subjects with spoken production, verbal naming and verbal memory support strategies likely pre-empted a need for SGD-based encoding. In future studies, care must be taken with neurotypical subjects to account for their experience with spoken words and to discourage verbal naming of stimuli. This can be done by forcing articulatory suppression at item presentation and/or creating less easily labeled stimulus sets.

An additional difficulty lies in determining levels of automaticity of device use. While automaticity in device use has received some attention from device manufacturers, there is no established definition of automaticity in SGD-driven production. In the current study, neurotypical subjects may not have reached a level of automaticity that would make SGD-based encoding more efficient than speech-based encoding. Future research on SGD-based production may establish guidelines for automaticity, such as comparing rates of recall via spoken response to rates of recall via SGD-based response (Reisberg, et al., 1984). Assuming that speaking is automatic, no significant difference between SGD-based and spoken recall may indicate that automaticity has been reached with SGD-based response. Other means of rating automaticity will need to be determined for authentic users of SGDs.

Finally, authentic users of SGDs appear to present different patterns of device use for higher frequency (‘core’) vs. lower frequency (‘fringe’) words. This study began to address some of the factors that could account for differences in fringe vs. core recall and production. Further research will need to untangle device-based effects from those driven by the spoken language environment of the SGD users.

Future Research Directions.

The current study suggests that phonological encoding in literate adults remains active in short-term storage even when neither input nor output require the use of phonological forms. However, further exploration of SGD-based encoding is necessary to explore the limits of phonological loop resilience. Particularly, further research with neurotypical subjects should focus on SGD-based short-term recall of stimuli that are less susceptible to verbal naming. More training with SGD-based output may also influence encoding. Because phonological encoding does not exclude the possibility of other types of encoding, studies should look for signs of SGD-based encoding concurrent with phonological encoding, such as effects of length of device-based output sequence and effects of similarity in device-based motor plan.

With consistent use, motor plans, such as those used for typing, begin to affect non-production tasks (Yang, et al., 2009). To fully understand lifespan use of SGD-based motor plans, it is necessary to observe authentic SGD users for the characteristics of an SGD-based long-term store and describe the relationship of the SGD-based long-term store to phonological storage. Research conducted with users of ASL demonstrates the presence of a "sign loop" used for short-term recall, but does not discuss long-term storage of signs (Pa, et al., 2008). A description of a long-term store of SGD-based representations of language, as well as any relationships it has with short-term storage and production, will be highly relevant to models of short-term phonological storage and its relationship with language acquisition.

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Appendix A: Training Procedures for SGD Task

Step 1	Introduction text: "*I will show you some pictures and teach you how to find them on this device. We will practice several times until you get the words right. Please don't say words aloud while you are looking for them. However, if you need help, you may say "help". Let's practice. First, I will turn on the training screen. I will show you how to produce each item and you will practice it five times."*
Step 2	Change SGD to Minspeak/Unity training screen that only includes starter locations for selected stimuli. Text: "*I am now turning on a training screen to practice producing labels for the pictures you will see.*"
Step 3	Item introduction. Present picture on laptop screen Demonstrate production of label on SGD training screen with standard narrative for item. Text: *see Figure "Item narratives for SGD*" Subject produces each item five times on the SGD training screen. Help is provided by experimenter on request.
Step 4	Change SGD back to full screen. Text: "*Now let's turn the full screen back on to make sure you remember how to produce these items.*"
Step 5	Item review: Present each item (reverse order from first presentation) and request that the subject produce the item on the full screen. Provide help upon request. Instruct subject to repeat production one more time. Text: *"Now please find this item on the full screen.* [wait for production] *Now do it one more time."* If subject requires assistance to produce the item for the first time on the full screen, repeat part (a) after completing the list of eight. You may repeat part (a) twice. If subject requires assistance to produce an item on the third try, the subject is discontinued.
Comment:	By the time a subject is done training SGD-based production, they will have accessed each item anywhere from seven to 11 times

Appendix B: Item Narratives

Task 1:
TEETH: in your body, you have different parts, like _____.
SUN: different kinds of weather words include ____.
KITE: in containers, we keep toys like a ____.
CAKE: things we eat include deserts like ____.
LEG: in your body, you have different parts, like a ____.

WOOD: in tools and professions, we have tools like ____.
FOX: among living things, we have woods animals like a ____.
MASK: under holidays, we have Halloween, with ____.
Task 2:
CAT: among living things, we have pets like a ____.
HAT: in clothes and uniforms, we have clothes that we wear outdoors, like a ____.
BAG: among containers, we have a ____.
FAN: small appliances include a ____.
PAN: kitchen things include a ____.
HAND: in your body, you have different parts, like a ____.
GAS: in transport and colors you have car parts like ____.
ANT: among living things, we have insects like an ____.
Task 3:
BUTTERFLY: among living things, we have insects like a ____.
ELEPHANT: among living things, we have zoo animals like an ____.
HAMBURGER: things we eat include meats like ____.
RADIO: small appliances include a ____.
SUBMARINE: in transport and colors, we have transport for water, like a ____.
CAMERA: small appliances include a ____.
POTATO: things we eat include vegetables like a ____.
UMBRELLA: things we shouldn't forget include accessories like an ____.

Appendix C: Interview Questions for Aided Communicators

1. What do you do to help yourself remember words?
2. Do you hear these words in your head?
3. Do you picture the way you will get to these words on your SGD?
4. Which part was the easiest? Hardest?
5. Did you notice any differences between word lists? What differences?

Appendix D: Distributions of Subjects' Performance, Neurotypical Subjects

Subject performance on each task satisfied the normality assumption according to the One-Sample Kolmogorov-Smirnov Test. (Test results for each task in Table, Q-plots to demonstrate normality in Plots A-F)

Spoken response			SGD response		
Task 1 (short, dissimilar)	Task 2 (short, similar)	Task 3 (long)	Task 1 (short, dissimilar)	Task 2 (short, similar)	Task 3 (long)
p=.880	p=.843	p=.936	p=.852	p=.668	p=.986

Note: large p-values indicate normality of sample